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Transportation Research Record 1305

Contents

Foreword

The papers in this Record provide a cross section of current research and applications in transportation systems planning and administration. They cover the issues of taxation, finance, and pricing; transportation planning applications; transportation data and information systems; strategic management; transportation economics; transportation programming, planning, and evaluation; recruitment, retention, and training of the transportation professionals; and transportation and land development.

The papers about taxation, finance, and planning include a discussion of various taxation issues; a taxation model for road vehicles in Saudi Arabia, parking tax legislation that was promulgated in the State of Washington to assist local government to raise revenue and also to provide them with a local transportation demand management tool, and a sales tax program that was successfully implemented in San Diego after the regional plan identified potential revenue shortfalls. Other papers discuss a model for forecasting transportation program cash flow, public/private and intergovernmental partnerships, collecting overdue municipal vehicle license fees, price effects of road and other impacts fees on urban land, and multimodal financial planning from a regional perspective.

The papers on transportation planning include discussions on corridor traffic parking, temporal stability of trip generation rates, impacts of zonal reconfiguration on travel demand forecasts, estimating highway needs for the year 2005, and cordon line highway survey design and implementation.

The next group on transportation data and information systems includes papers on traffic volume statistics, one from a historical perspective. Another paper discusses the results of survey of traffic monitoring within a state and nationally that led to establishment of mandatory traffic data standards. The other papers look at the application of geographic information systems at the state and local level.

Strategic management is the focus of the next group of papers. Two papers are an assessment of alternatives and guidelines for automation of information management and processing for state departments of transportation. The third discusses linking strategic planning and budgeting for state departments of transportation.

Transportation economics includes papers on the following topics: methodology for estimating road damage costs resulting from a rail branch line abandonment; economic evaluation of toll plaza operations; a quantitative method for road investment policy analysis, roadway congestion in major urban areas; highway district and economic sector employment effects of transportation expenditures; impact of pavement performance consideration on economic evaluation of pavement strategies; and employment and income impact of expenditures for bypass, loop, and radical highway improvements.

The next papers are on transportation programming, planning, and evaluation. Two papers focus on telecommuting, one defining telecommuting, the second looking at the travel behavior impact of telecommuting following the San Francisco Earthquake. Two papers look at the planning and planning network design aspects of national highways system in the U.S. and Finland. One study discusses computerized methodology for highway deficiency and project development studies. The next paper in this section focuses on the transportation decision making process in Portland, Oregon. Two papers focus on innovative approaches on multimodal transportation and marketing of transportation from a state perspective (Minnesota). The last paper in this section summarizes the result of an effort to assess the present state of intelligent vehicle-highway systems technology and the prospects for its future development in the United States.

Recruitment and retention of transportation professionals is the focus of the next group of papers. Two papers specifically focus on attracting women and minorities to the transportation profession. One paper focuses on an innovative approach to continuing transportation education in Florida. Other papers discuss transportation planning and engineering for post-graduate studies in a small developing country, training needs for engineers, a university perspective, and the development of a balanced transportation research program at the University of Minnesota.

The final group of papers on transportation and land development includes four papers discussing jobs, housing balance and whether or not it is an effective solution for traffic congestion, and air pollution concerns; transportation roles in site selection for manufacturers relocation in North Carolina; traffic calming by balancing and integrating land uses, giving priority to environmentally preferable modes of travel and reducing vehicle density where there is high population density; and evaluation of transportation demand management programs at residential developments.

Financial Dynamics: A Model for Forecasting Transportation Program Cash Flow

W. M. HILLIARD

A process and computer model for forecasting transportation program cash flow are described. The differences between financial management on an accrual or encumbrance basis and full cash flow management are briefly discussed. The need for a comprehensive yet compact and flexible process for relating all aspects of an organization's financing is addressed. The financial overview framework used by the Florida Department of Transportation, called the Program Plan Model, is described. The logic used to define categories and subcategories for program planning and cash flow forecasting is explained. The cash flow model is described, and its inputs, outputs, and variables are explained. Variables in the model, which include flow rates or payout rates, participation ratios, and receivables, are described. The process for calibration of the model and its reconciliation to a short-term forecast and actuals from previous years is explained. Model outputs, including menu-driven charts as well as printed tables containing all inputs, variables, and results, are outlined. A summary of selected graphical output is included. Reports for tracking and monitoring are described, and use of the model for district and resource planning is briefly discussed.

Most state departments of transportation do not operate on a full cash flow basis. Typically, annual authority for contractual commitments and expenditures is appropriated by state legislatures on the basis of forecasts prepared by a central state authority. Case flow management, if practiced, is performed by the central state authority for a combination of all state programs. In states that have a trust fund for transportation, cash to cover outstanding obligations may be on deposit in a central state account. In most cases, the cash is used in other programs, as is done with the National Transportation Trust Fund. These deposits can total as much as 1 to 3 years of revenues. Even though these funds may earn interest, the time between collection of transportation taxes and their application to transportation needs is delayed, resulting in an opportunity cost to society. Full cash flow management, as practiced by the Florida Department of Transportation (FDOT), attempts to minimize the amount on deposit in transportation trust funds by making contractual commitments against future revenues, thus drawing down the cash on deposit awaiting payout.

Financial management in a full cash flow environment is substantially different from the more common accrual or encumbrance environment practiced by most government agencies (*1*). The critical time frame is shifted from the present, for which data are known and reliable (e.g., revenue on hand, existing cash balance, etc.), to a time possibly years in the future, for which only projected values of these parameters are available. Financial control must shift from a static situation to a dynamic, less predictable one. The financial management task is broadened from one that involves primarily accounting to one that must use the forecasts and judgment of economists, engineers, production managers, and others. Additional risks are unquestionably involved, but the rewards, which may be 1 or more years of a transportation product without an increase in taxes, outweigh these risks.

Balancing commitments so that future cash flows equal available revenues without overcommitting (which would result in cash shortages) or undercommitting (which would result in high cash balances) requires a process that accurately relates future work programs to future cash flows. Because few government agencies practice full cash flow management, little information is available on the techniques used. Most forecasting work has focused on individual project forecasting or the cash flow projection of isolated components of an overall transportation program. A process is needed that incorporates all financial activity of an organization in a condensed, comprehensive way, yet simplifies and aggregates the abundant financial data to give top management a reliable "big picture" view of transportation finance. Such a model is described along with the process used by FDOT to develop work programs of transportation projects that will result in minimum, but adequate, cash balances in the trust fund while ensuring that transportation taxes are put to work in the form of transportation facilities at the earliest possible time.

PROGRAM PLAN CASH FLOW MODEL

The Program Plan Cash Flow Model (*2*) is a personal computer (PC)–based spreadsheet model used by FDOT to analyze proposed multiyear program plans to determine their cash impact on the state transportation fund and other funds. Introduced by FDOT in 1985, the model was abandoned during a period of extensive accounting system and management change. Cash flow problems that began in 1988 resulted in a critical audit by the state auditor general early in 1989 (*3*). Two studies, one commissioned by FDOT and another by the Florida Transportation Commission, resulted in reports (*4,5*) that recommended actions to correct accounting and systems

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problems and reinforced the need to restore a process relating proposed work programs to future cash flows and the accounting systems.

The FDOT Program Plan Model, which evolved from the original model and the recommendations of the two studies, is simple in design. It consists of planned program data, formulas for cash-flowing these data, flow rates (variables), fund participation rates (variables), summary schedules, graphics, and printed output showing key elements of financial analysis. These components are arrayed in a spreadsheet format with menus to transfer from one part of the spreadsheet to another. By introducing new or changed program plan, budget, flow rate, or participation ratio data, the user can determine the impact of any proposed scenario on cash, commitments, federal participation, federal matching, or other factors. The results can be viewed on graphs and printed in a set of tables and schedules.

PROGRAM PLAN

The FDOT program plan is a listing of major activities in categories corresponding to major program areas that are compatible with the way operating management views plans and tracks resources. The categories are grouped into four major areas, as follows:

1. *Product*: A product is anything a citizen can ride on, feel, or use for transportation purposes (e.g., concrete, steel, asphalt, earth, and rights-of-way). In the case of grants to other agencies (such as grants for public transportation), the product is the amount of the grant.
2. *Product Support*: Product support activities are those directly related to and in support of the production of a product, for example, planning, design engineering, engineering inspection, and work in support of the acquisition of rights-of-way, as well as some work that indirectly supports the production or improvement of the product, such as research and materials testing.
3. *Operations and Maintenance*: Operations and maintenance activities are those relating to operating or maintaining existing systems (i.e., product). This category includes routine maintenance, traffic operations, toll operations, and weight law enforcement.
4. *Administration*: Administration includes those activities that support the total organization and do not fall logically into the other three categories. Included are top management, personnel, legal, the comptroller's office, purchasing, and similar functions in the district and central office, as well as housing (offices) for these functions.

A summary of a typical program plan is presented in Table 1. The operations in the "Other" category are already included in the first four categories; because of state budgeting practice, these functions are repeated to highlight them. The "Total Budget" line thus contains a double counting of these functions but is the total that agrees with state budget reports. The "Total Program" lines are the real-dollar totals used in cash flow analysis.

The subcategories may vary and should group activities into areas of interest or concern to operating managers. These categories do not appear in legislative budgets or accounting reports, nor do they reflect organizational arrangements. In Florida, government budgets and accounting reports are designed for legislators and auditors and do not present data in forms that are the most useful to operating management, at least in transportation. Data presented in formats for operating management must be easy to translate into the formats required by legislators, budgeters, and auditors.

Summary Reports

It is essential that a condensed, one-sheet representation of all actual and planned program and budget activities be designed and used in this process. There is no limit to the amount of detailed data, and supplementary reports, that can be included. An overview capability allows management to take the big-picture approach and fosters identification of financial activities and problems in order of relative importance to the bottom line. Many organizations experience difficulty or failure because management cannot see the "forest for the trees" with the reports that are made available to them.

The summary reports of an organization's plans must contain all proposed and actual financial data relating to all activities. The bottom line for such reports should be the total budget or program in the same terms as those used by other agencies to measure the activity of the agency. For FDOT, the bottom line for the program plan is the total FDOT budget.

The act of producing summary reports and overviews that cover all activity of the agency in a closed system helps in finding errors and omissions, promotes uniformity in terms and definitions, encourages organizational cooperation, and, if used consistently over time, enhances familiarity and understanding of the reports and, thus, the organization and its business.

Segregation by Work Category

Once a program plan is prepared, it is then arrayed by appropriate work and fund categories. The work categories depend on the areas of interest to management, areas of program emphasis by the legislature and others, and areas of budget and management control, as well as the variation in cash flow characteristics of each program. For example, resurfacing work normally does not require extensive engineering, earthwork, or other activities associated with heavy construction (such as the building of interchanges). The time required between the commitment or contract letting of a resurfacing project and its completion (and thus the rate of contract payout) is much faster than more complex work, and the cash flow pattern is substantially different. Resurfacing, therefore, is segregated in the program plan, and separate cash flow rates or flow models would be used for that program. The individual phases of specific projects (such as engineering, right-of-way, and construction) will be cash-flowed in separate program groups similar to the way large programs of projects are actually managed (as opposed to individual project management). The combination of phases for specific projects for project management or other purposes can be obtained from the short-term systems or from a project scheduling system independent of the aggregate cash forecasting system. The work categories will vary depending on these

TABLE 1 PROGRAM AND RESOURCE PLAN SUMMARY

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04-Jan-90 FLORIDA DEPARTMENT OF TRANSPORTATION OMB
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TENTATIVE WORK PROGRAM FISCAL YEARS 1990/91 TO 1998/99
FISCAL YEARS 1990/91 THROUGH 1998/99 (MILLIONS OF $)

PROGRAM AREAS	COMM. 88/89	CURRENT 89/90	90/91	91/92	92/93	93/94	94/95	5 YR TOTAL	95/96	96/97	97/98	98/99	4-YEAR SUB-TOT	10-YEAR TOTAL
I. PRODUCT	738.0	1136.7	1187.2	1371.2	896.1	839.1	928.2	5221.8	943.1	1032.2	1050.1	1073.1	4098.5	10457.0
A. Express. Const	345.4	229.0	195.2	548.2	195.2	175.1	181.3	1295.0	264.0	272.0	281.0	290.0	1107.0	2631.0
B. Arterial Hwys.	115.6	157.8	208.6	196.8	192.3	175.8	193.8	967.3	126.1	124.9	138.2	138.2	527.4	1652.5
C. Right Of Way	26.4	422.0	408.5	314.5	129.5	92.8	112.0	1057.3	151.1	148.5	151.7	155.7	607.0	2086.3
D. Aviation	34.5	44.8	43.5	44.8	45.2	46.1	47.9	227.5	50.7	52.3	53.9	55.6	212.5	484.8
E. Transit	24.7	22.8	40.0	33.8	23.8	25.1	25.7	148.4	38.0	38.0	38.0	38.0	152.0	323.2
F. Rail	50.6	45.2	40.6	39.5	54.5	56.1	57.6	248.3	45.1	45.0	6.7	5.0	101.8	395.3
G. Safety	13.9	10.7	19.6	11.0	12.5	10.8	14.0	67.9	17.0	17.0	17.0	17.0	68.0	146.6
H. Resurface/Rehab	34.7	55.0	154.7	115.4	130.8	169.6	226.3	796.8	164.1	244.8	259.4	259.4	927.7	1779.5
I. Bridge	92.2	149.4	76.5	67.2	112.3	87.7	69.6	413.3	87.0	89.7	104.2	114.2	395.1	957.8
II. PRODUCT SUPPORT	316.9	271.2	386.4	323.8	270.2	287.1	298.9	1566.4	300.6	311.8	323.0	337.1	1272.5	3110.1
A. Prel. Eng.	147.1	103.0	139.3	111.8	114.0	120.4	123.2	608.7	98.6	103.0	108.6	114.0	424.2	1135.9
B. Const Eng Insp.	74.0	72.5	63.8	91.3	58.8	67.7	73.2	354.8	78.6	81.1	82.7	86.7	329.1	756.4
C. R/W Support	41.1	46.7	130.0	64.8	39.2	37.9	35.1	307.0	51.5	52.4	53.0	55.4	212.3	566.0
D. Material & Res.	28.2	24.4	25.9	27.3	28.6	30.0	32.3	144.1	35.0	36.6	38.2	39.9	149.7	318.2
E. Planning	21.4	18.8	20.5	21.4	22.0	23.1	26.7	113.7	28.1	29.5	30.8	30.9	119.3	251.8
F. Pub. Trans Oper.	5.1	5.8	6.9	7.2	7.6	8.0	8.4	38.1	8.8	9.2	9.7	10.2	37.9	81.8
III. OPERAT.& MAINT.	263.4	241.5	273.0	288.6	303.0	318.7	334.6	1517.9	353.0	370.4	388.9	408.4	1520.7	3280.1
A. Routine Maint.	170.4	159.4	176.5	189.2	198.7	208.7	219.2	992.3	231.2	242.7	254.9	267.6	996.4	2148.1
B. Traffic Eng.	10.9	10.8	10.1	9.7	10.2	10.5	10.9	51.4	12.2	12.8	13.4	14.1	52.5	114.7
C. Toll Oper.	73.6	61.9	75.7	78.5	82.3	87.1	91.5	415.1	95.9	100.6	105.6	110.9	413.0	890.0
D.Motor Carrier Comp.	8.5	9.4	10.7	11.2	11.8	12.4	13.0	59.1	13.7	14.3	15.0	15.8	58.8	127.3
IV. ADMINISTRATION	51.4	58.7	65.8	69.3	72.3	75.4	84.4	367.2	89.5	93.6	95.2	99.5	377.8	803.7
A. Admin.	44.0	53.9	61.2	64.3	67.3	70.4	79.4	342.6	84.5	88.6	90.2	94.5	357.8	754.3
B. Fixed Capital	7.4	4.8	4.6	5.0	5.0	5.0	5.0	24.6	5.0	5.0	5.0	5.0	20.0	49.4
TOTAL PROGRAM	1369.7	1708.1	1912.4	2052.9	1541.6	1520.3	1646.1	8673.3	1686.2	1808.0	1857.2	1918.1	7269.5	17650.9
V. OTHER	94.1	107.1	108.0	127.5	131.2	135.0	139.1	640.8	143.9	148.4	153.0	157.9	603.2	1351.1
A. Dep.Data Ctr.	13.1	12.2	14.2	14.9	15.7	16.5	17.3	78.6	18.3	19.2	20.1	21.1	78.7	169.5
B. CME	52.2	45.9	50.8	57.6	60.5	63.5	66.8	299.2	70.6	74.2	77.9	81.8	304.5	649.6
C. Non-Oper. Trnfs.	28.8	55.0	55.0	55.0	55.0	55.0	55.0	275.0	55.0	55.0	55.0	55.0	220.0	550.0
D. Offset-Pay Pack	0.0	-6.0	-12.0	0.0	0.0	0.0	0.0	-12.0	0.0	0.0	0.0	0.0	0.0	-18.0
TOTAL BUDGET	1463.8	1815.2	2020.4	2180.4	1672.8	1655.3	1785.2	9314.1	1830.1	1956.4	2010.2	2076.0	7872.7	19002.0

factors. Sometimes trial-and-error methods are required to find the appropriate categories and flow rates that will result in an accurate cash flow projection. The program categories and subcategories used in the FDOT model are presented in Table 2.

Segregation by Fund Category

The defined categories must then be segregated by fund. In a leveraged financial system that has more than one paying fund, it is not enough to know the total payout associated with a particular program. The extent of participation by each contributing fund source must also be revealed. The fund categories currently used are presented in Table 2.

Once a summary report covering all activity of the organization is available, a cash flow of each of the items included will yield a cash flow report. It is presumed, of course, that no business is conducted and no money is paid on activities not included in the program plan.

CASH FLOW MODEL

Operational use of the model to prepare a financially feasible program plan involves the following steps:

TABLE 2 PROGRAM, FUND, AND CASH FLOW CATEGORIES

PROGRAM CATEGORIES AND SUBCATEGORIES:

PRODUCT:	
CNST	Construction
TOPS	Traffic Operations
PREV	Preservation (Resurfacing)
BRDG	Bridge
ROW	Right-of-Way
PTO	Public Transportation Operations
TRTF	Toll Facilities Revolving Trust Fund
2080	Special Local Gov't program
EDEV	State Economic Development Program
SUPPORT:	
PEI	Preliminary Engineering (In-house)
PEC	Preliminary Engineering (Consultant)
CEII	Construction Engineering and Inspection (In-house)
CEIC	Construction Engineering and Inspection (Consultant)
RWII	Right-of-Way Support (In-house)
RWO	Right-of-Way Support (Consultant)
M&R	Materials and Research
PLAN	Planning
PTOO	Public Transportation Operations Support
MAINTENANCE AND OPERATIONS:	
RMNT	Routine Maintenance
TE	Traffic Engineering
TOLO	Toll Operations
MCC	Motor Carrier Compliance
ADMINISTRATION:	
ADMN	Administration
FCO	Fixed Capital Outlay

FUNDS:

I,ACI	Interstate, Advanced Const Int
IR,ACIR	Interstate Rehab, AC Int Rehab
O.F.A.	Other Federal Aid
100% FED	100% Federal Financing
100% STATE	100% State Financing
TURNPIKE	Financed with Turnpike Bonds
TOLL,LOC,OTHER	Toll, Local, or other financing
BOND	Bond Financed (not Turnpike)
above with"/ROW"	Indicates funds for Right-of-way
CSX	CSX Railroad Corridor Purchase

CASH FLOW CATEGORIES:

Federal Aid Interstate Construction
Other Federal Aid Construction
Federal Aid Preservation and Traffic Operations
Federal Aid Bridge Construction
Federal Aid Rights-of-Way
Consultants
State Construction
State Preservation and Traffic Operations
State Bridge Construction
Other Construction
State Rights-of Way
Public Transportation Operations
Budget - Flow in Year of Commitment
Other - Special Cash Flow Situations

PROGRAM CATEGORIES AND SUBCATEGORIES:

PRODUCT:	
CNST	Construction
TOPS	Traffic Operations
PREV	Preservation (Resurfacing)
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CASH FLOW CATEGORIES:

Federal Aid Interstate Construction
Other Federal Aid Construction
Federal Aid Preservation and Traffic Operations
Federal Aid Bridge Construction
Federal Aid Rights-of-Way
Consultants
State Construction
State Preservation and Traffic Operations
State Bridge Construction
Other Construction
State Rights-of Way
Public Transportation Operations
Budget - Flow in Year of Commitment
Other - Special Cash Flow Situations

- Preparing a proposed program plan using separate spreadsheet software;
- Loading this program plan into the model, which is designed to accept the data through file combination functions;
- Observing resulting cash flow and other financial results; and
- Making adjustments to proposed program, fund, or other variables in an interactive process using summary graphics and charts for interpreting interim results until a satisfactory financial balance is achieved.

The Program Plan Model is a PC-based spreadsheet model that uses the program plan as a data base for amounts to be flowed. By using an aggregate approach not tied to specific projects, the Program Plan Model can be used in developing the program plan at a time when projects are not yet defined. This aggregate approach lacks the detail of a near-term, project-oriented model; however, a near-term model is developed using the Interactive Financial Planning System (IFPS) for projects that are under way. The results are reconciled to the aggregate model to ensure that planned programs are linked to accounting system data. Both models are balanced to produce the same result in the near term.

The long-term model is easy to use on a PC and is exportable to district offices or other units that want or need to be involved. Program plan proposals can be analyzed in minutes, thus ensuring that program decisions are based on good financial information.

MODEL VARIABLES

Flow Rates

Once the categories are established and balanced to the program plan, each commitment in the plan is cash-flowed using formulas that attempt to estimate the payout that will result from annual commitments of the category type. The payouts are represented in the formulas as a percentage of the total annual commitment that would pay out in the year of commitment and each subsequent year until the full amount is flowed. The following is a typical flow formula:

Year	*Payout* (%)
1	20
2	50
3	25
4	5
Total	100

Note that these formulas attempt to flow the total dollar volume of a class of projects that might be committed in a year. Neither the number nor the specifics of projects are known; this knowledge is not needed to predict total cash flow successfully. A program that contains thousands of projects can be cash-flowed in the aggregate using this simple function for each group of projects to yield an acceptable bottom line result.

Much of the work that has been done on transportation cash flow has focused on the development of flow models for individual projects (*6,7*). However, when dealing with programs involving thousands of individual projects with varying payout characteristics, the payout model for individual projects becomes irrelevant and only the start and stop times and total cost for each project are needed. This aggregate approach, in addition to being satisfactory from the standpoint of results, greatly reduces the data and processing time required to analyze specific scenarios. Also, factors other than the payout pattern of individual projects, such as participation ratios and receivables, may dominate the cash flow. Use of the model focuses attention on these factors. What may seem intuitively important at the beginning is often overshadowed by factors whose importance is not evident except through aggregate modeling.

Flow rates for past years can be derived from actual flow data in the process of developing and calibrating the model. Future rates can then be estimated on the basis of history as well as on planned policy actions that may affect the progress of programs. Budget or cash items are assumed to pay out in the year of commitment. A variables table in the model consists of a set of ratios, similar to those in the typical formula presented, for each of the cash flow categories presented in Table 2. A pictorial representation of the flow rates by year for one class of project—Interstate construction—is shown in Figure 1. Note that the rates vary slightly from year to year but that, overall, changes are gradual and can be related to specific payout history or projections of program commitment rates. In addition, separate rates for existing commitments for each category are included as variables. A method for tracking and adjusting rates on a continuing basis is a necessary part of the cash flow process.

Participation Ratios

Participation ratios are a set of factors for each year that estimate the extent to which federal funds will be used to finance a class of transportation projects. In the FDOT model, the classes used are (a) construction and (b) all other work, including planning, engineering, and right-of-way acquisition. These classes are used because of similar participation history

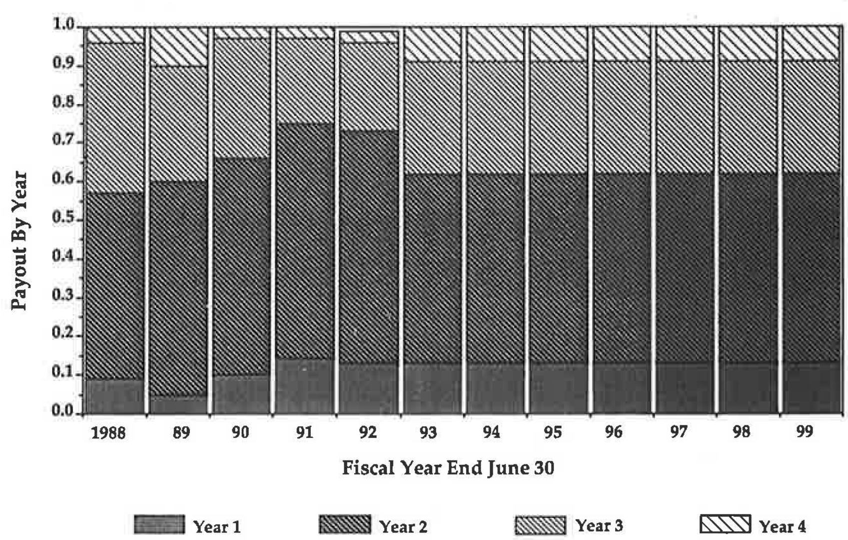

FIGURE 1 Flow rates (commitment payout) for Interstate construction.

and reporting practice. More recent versions of the model have refined the categories to isolate right-of-way and preliminary engineering.

Although the program plan is based on the year of commitment for product categories, participation rates refer to the ratios in effect at time of payment rather than commitment so that the latest available information concerning participation can be used and unplanned participation changes can be introduced into the analysis. The ratios are derived from studies of federal programming activity and current federal reimbursement experience and then input to the model. The monitoring, analysis, and management control of participation rates must be an integral part of the cash flow and financial planning process.

Federal Receivables

The model uses a federal aid receivables table that estimates, for each year, the amount of any federal participation that may be owed but for various reasons will not be collected. The extent of federal funds in the transportation budget requires that any fluctuation in the receivables balance be taken into account in the cash flow analysis. Any change in the balance, whether because of normal processing delay, a change in the level of those billings for which reimbursement is delayed or denied, or failure to submit reimbursement paperwork in a timely manner, must be estimated annually and introduced into the table. Further, any planned reductions to this balance must be accompanied by management action to cause the reduction to occur. Because the receivables balance can fluctuate by tens of millions of dollars in any year, this factor can easily overshadow many other elements of cash flow. Proper management of the receivables balance is an essential part of cash flow management.

MODEL CALIBRATION AND RECONCILIATION

The Program Plan Model was calibrated to actuals by requiring that the predicted payout in the various forecasting categories match the actual payout in those same categories for FY 1987–1988 and FY 1988–1989. The model began on June 30, 1987, with outstanding commitments in all categories. Flow rates for existing commitments were included as a variable. Actual commitments for the 2-year period were entered in the program plan, and new commitments were taken from the plan. Matching ratios for the 2 years were estimated. Existing and new commitment flow rates and participation ratios were then adjusted so that the projected cash flow by category was sufficiently close to actuals. The most recent version compared actual and projected cash flows to within 5 percent for any line item category that constituted 0.5 percent or more of total expenditures for the year.

In addition to calibrating the model for 2 years of actuals, the detailed, project-oriented, near-term model is compared with the long-term model for the 36-month period of the near-term forecast and calibrated to the same accuracy. The Program Plan Model can virtually duplicate actual cash flows and the cash flows projected by the more detailed near-term model. Program plans can then be developed using the long-term model and its gaming capabilities with assurance that a more refined analysis (the near-term model) would yield the same result.

MODEL OUTPUTS

Output from the model includes menu-selected graphics and printed schedules. Graphics provided in the basic model include the following:

- Cash flow charts;
- Commitments (total and by fund);
- Outstanding (unliquidated) commitments; and
- Federal aid receivables, payments, receipts, and matching revenues and expenditures.

Typical graphical output is shown in Figures 2 through 4. Figure 2 shows the overall cash balance of the State Transportation Trust Fund (STTF) by fiscal year compared with

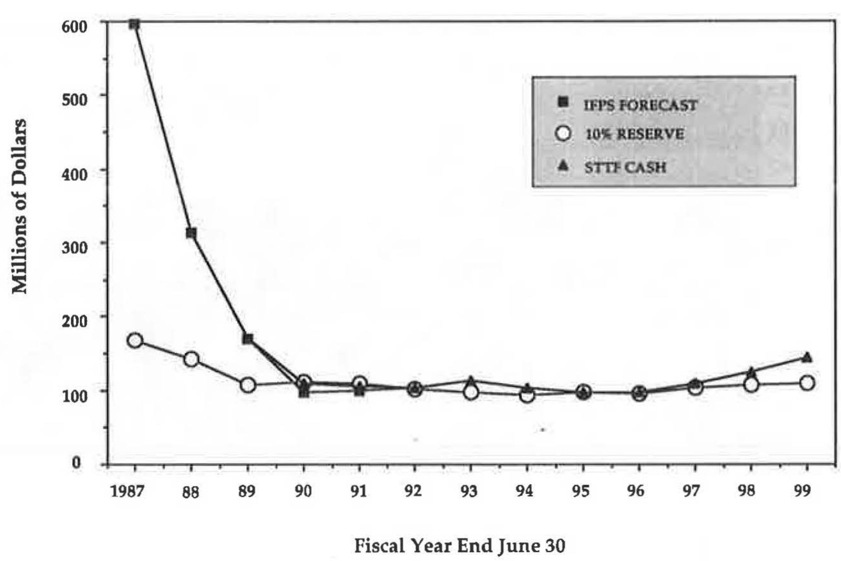

FIGURE 2 STTF cash flow.

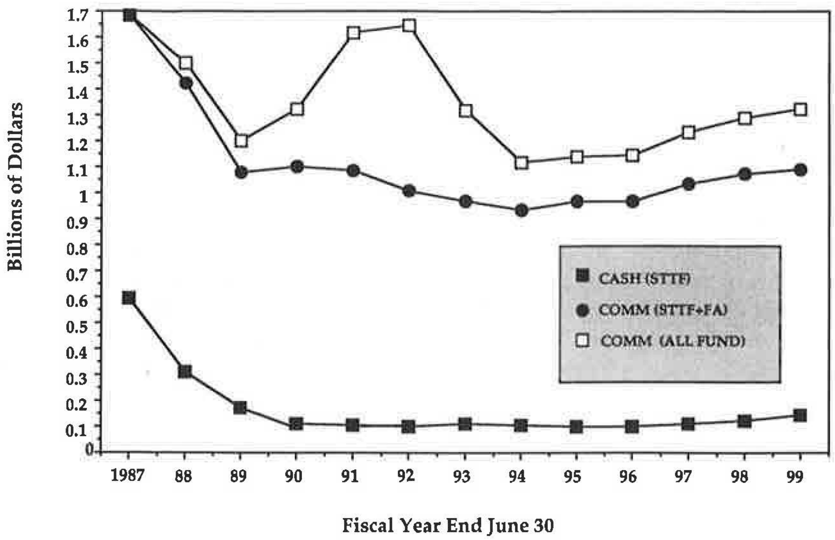

FIGURE 3 Outstanding (unpaid) commitments.

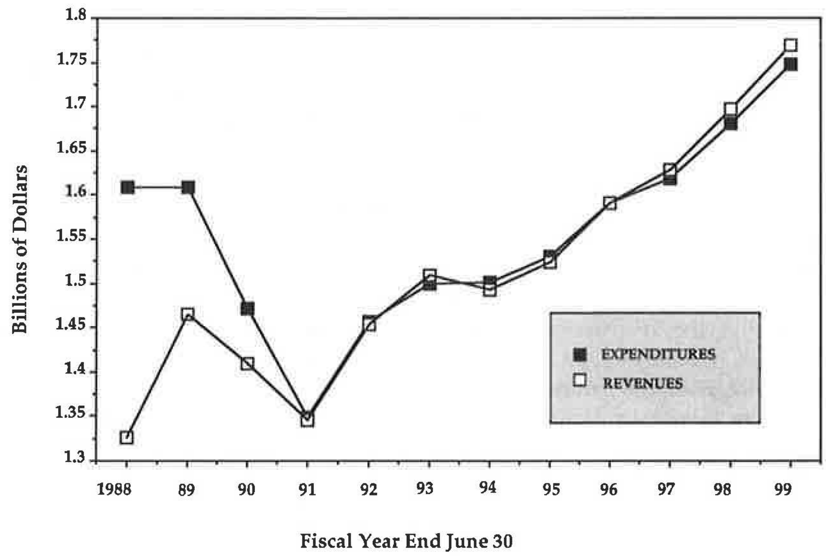

FIGURE 4 Revenues and expenditures.

the short-term forecast (IFPS) and a target cash balance set of 10 percent of outstanding commitments. The target balance is set to coincide with the end-of-year balance produced by the monthly short-term model. The graph in Figure 2 shows the result after imbalances have been corrected through interactive gaming. Figure 3 shows outstanding balances for various fund combinations, and Figure 4 shows a summary of overall revenues and expenditures.

The complete printed output of the model detailing the program input, cash flows, and summaries and balance checks, as well as other revenue and finance assumptions, consists of seven double-sized pages of computer output and provides a complete record of any particular scenario for analysis or recording. Included are the following:

- Program plan and cash flows,
- Variables,
- Commitment and cash flow summaries,
- STTF cash flow summary, and
- Reconciliation.

Other graphs and schedules for cross-checking totals and detailing federal aid, outstanding balances, and so forth are included in the printed output. Other tables and summaries may be developed as required.

MODEL DYNAMICS

The dynamics of interactive gaming to adjust programs, flow rates, matching ratios, and other variables to achieve a balancing to actuals or future available cash is not demonstrated by the final result charts included here. The interaction of these factors in a leveraged fund situation reveals characteristics about the relationship among commitments, funds, and cash flow that are not apparent by any other means. The insights gained through the use of the model have had a major effect on program development strategies, particularly in the mix and timing of alternative programs, the control of federal participation, and the selection and implementation of cash control strategies. As an example, participation rates were low before use of the model, resulting in a greater expenditure of state funds than was forecast and thereby contributing to state transportation fund cash problems. Adjustment to the new rates was painful, requiring the deferral of projects, but the change resulted in a more realistic program.

TRACKING AND MONITORING

The development of a program plan balanced to actuals and to the more detailed near-term forecast does not ensure the accuracy of the result; rather, it ensures that the result is in balance with all known histories and systems affecting the overall financial picture. Once the model is set up and running, the actual experience of commitments and cash flow must be monitored and compared with planned and predicted experience, and appropriate adjustments must be made both to planned commitments and to predicted cash flows. The report used to accomplish this function is called the Program Plan Progress Report. It details actual commitments and expenditures by month, program, and fund. A preliminary summary report for fiscal year 1989–90, without the detail by program and fund, is presented in Table 3. The report should be reviewed monthly or as often as new data are produced from the accounting system that verifies or corrects the forecast. Several cycles of forecasting, monitoring, and adjusting are required to forecast accurately. Even then, during periods of major change in any of the factors affecting finance, adjustments may be required in programs, flow rates, and matching ratios, and possibly in the set up and structure of the model itself.

OTHER USES OF THE MODEL

District Planning

As previously explained, the Program Plan Model is a spreadsheet (LOTUS) application that can be used on most PCs. It can thus be transmitted to districts or other organizational units to provide them with the ability to analyze the total FDOT program plan. If the program plan is segregated into district or other components, analysis and gaming of those components can be performed. Although cash flow and management of the STTF fund must include the total department and are therefore centralized, districts benefit greatly by having the capability to analyze and game with their own programs and to quickly determine the impact on their portion of the total cash. Given a theoretical cash target as the objective, many variations of the program can be tested to meet that objective. The primary benefit of the model to the districts, however, is in resource planning.

Resource Planning

Resource planning is the process of balancing manpower, money, time, or other resources to ensure that the availability of resources is not exceeded and that available resources are used effectively. Because the Program Plan Model incorporates the proposed program plan and budget, from which work programs will be built, and because the data are arrayed in program plan format compatible with the needs of resource planning, the model can be used to analyze resource relationships. The work would involve constructing charts, ratios, or other analysis aids from data in the model. Examples of analyses that have been performed include the following:

- Compare in-house preliminary engineering capability with that proposed in the program plan. Does the plan require additional people?
- Is there enough work for in-house forces?
- What portion of the engineering effort is planned to be performed by consultants? Is the total (in-house plus consultant) engineering effort balanced to the task as defined by the program plan?
- What will be the cost of engineering per dollar value of construction work designed? What is the in-house cost? What is the consultant cost?
- Perform the preceeding analyses for construction supervision.
- Are the amount and costs of rights-of-way in reasonable balance with the work program as proposed in the program plan?
- Are available federal aid and state funds used to maximum benefit for the districts?
- Are the rates of increase or decrease of costs for administration, operations, organizational budgets, program growth, and so forth consistent with past experience, or are the reasons for significant change understood and defensible?

These questions and problems are only samples of the many matters that must be resolved in developing a balanced, financially sound program. The Program Plan Model provides a flexible, compact data source from which to perform this work.

SUMMARY

The FDOT Program Plan Model provides a framework to incorporate all of the complex financial factors involved in transportation finance activity, such as program and fund changes, budget changes, flow rates, matching ratios, participation rates, federal receivables, and so forth, so that the relative contribution of any variable to the bottom line can be immediately evaluated, tested, and used in gaming activities. The model provides a means to quickly determine the financial impact of any budget or program decision on an interactive trial-and-error basis. Because it is balanced and reconciled to more detailed near-term processes, the resulting decisions will be consistent with accounting and programming systems. The model can be used not only to evaluate proposed or actual changes but also to optimize the programming of available resources, plan resources (e.g., manpower, con-

TABLE 3 PROGRAM PLAN PROGRESS REPORT

PROGRAM PLAN PROGRESS REPORT
(* = Variance > + or - 10%)

PLAN: ADOPT90F — PROGRAM YEAR 1989-90 — PROGRESS AS OF JUNE 30, 1990

	COMMITTMENTS PriorYr Actual	COMMITTMENTS CurrentYr Planned	COMMITTMENTS Planned	COMMITTMENTS Actual	COMMITTMENTS Var %	CASH FLOWS (ALL FUNDS) Planned	CASH FLOWS (ALL FUNDS) Actual	CASH FLOWS (ALL FUNDS) Var %	CASH FLOWS (STTF ONLY) Planned	CASH FLOWS (STTF ONLY) Actual	CASH FLOWS (STTF ONLY) Var %
I. PRODUCT	738.0	1136.7	1136.7	976.0	-14% *	834.6	726.0	-13% *	410.8	418.0	2%
A. Expessway Const.	345.4	229.0	229.0	240.0	5%	292.3	205.0	-30% *	100.0	99.0	-1%
B. Arterial Highways	115.6	157.8	157.8	152.0	-4%	159.2	170.0	7%	150.0	140.0	-7%
C. Right Of Way	26.4	422.0	422.0	300.0	-29% *	162.0	136.0	-16% *	63.0	75.0	19% *
D. Aviation	34.5	44.8	44.8	42.0	-6%	40.0	38.0	-5%	12.0	11.0	-8%
E. Transit	24.7	22.8	22.8	20.0	-12% *	18.0	17.0	-6%	5.0	6.0	20% *
F. Rail	50.6	45.2	45.2	30.0	-34% *	50.0	48.0	-4%	35.0	38.0	9%
G. Safety	13.9	10.7	10.7	10.0	-7%	10.5	5.0	-52% *	4.0	4.0	0%
H. Resurface/Rehab	34.7	55.0	55.0	52.0	-5%	18.5	19.0	3%	12.0	15.0	25% *
I. Bridge	92.2	149.4	149.4	130.0	-13% *	84.1	88.0	5%	29.8	30.0	1%
II. PRODUCT SUPPORT	316.9	271.2	271.2	275.0	1%	256.2	280.0	9%	172.0	174.0	1%
A. Preliminary Eng.	147.1	103.0	103.0	120.0	17% *	150.2	175.0	17% *	112.0	110.0	-2%
B. Const.Eng.Inspect.	74.0	72.5	72.5	72.0	-1%	40.0	50.0	25% *	25.0	28.0	12% *
C. R/W Support	41.1	46.7	46.7	38.0	-19% *	25.0	20.0	-20% *	12.0	12.0	0%
D. Material & Research	28.2	24.4	24.4	24.0	-2%	22.0	20.0	-9%	10.0	12.0	20% *
E. Planning	21.4	18.8	18.8	17.0	-10% *	15.0	12.0	-20% *	10.0	11.0	10% *
F. Public Transit Oper	5.1	5.8	5.8	4.0	-31% *	4.0	3.0	-25% *	3.0	1.0	-67% *
III.OPERAT.& MAINT.	263.4	241.5	241.5	239.0	-1%	231.0	223.5	-3%	220.0	219.0	0%
A. Routine Maintenance	170.4	159.4	159.4	160.0	0%	155.0	150.0	-3%	150.0	149.0	-1%
B. Traffic Engineering	10.9	10.8	10.8	8.0	-26% *	8.0	7.0	-13% *	4.0	5.0	25% *
C. Toll Operations	73.6	61.9	61.9	62.0	0%	60.0	58.0	-3%	58.0	58.0	0%
D. Motor Carrier Comp.	8.5	9.4	9.4	9.0	-4%	8.0	8.5	6%	8.0	7.0	-13% *
IV. ADMINISTRATION	51.4	58.7	58.7	55.0	-6%	55.5	52.0	-6%	51.0	52.0	2%
A. Administration	44.0	53.9	53.9	52.0	-4%	50.0	48.0	-4%	47.0	48.0	2%
B. Fixed Capital	7.4	4.8	4.8	3.0	-38% *	5.5	4.0	-27% *	4.0	4.0	0%
V. LOCAL GOV'T REIMBURSE	0.0	0.0	0.0	0.0		5.0	5.0	0%	5.0	5.0	0%
TOTAL PROGRAM	1369.7	1708.1	1708.1	1545.0	-10% *	1382.3	1286.5	-7%	858.8	868.0	1%
VI. OTHER	94.1	107.1	107.1	92.0	-14% *	100.0	99.0	-1%	100.0	99.0	-1%
A. Dept. Data Center	13.1	12.2	12.2	12.0	-2%	11.0	10.0	-9%	11.0	10.0	-9%
B. Mobile Equip.(CME)	52.2	45.9	45.9	46.0	0%	29.0	28.0	-3%	29.0	28.0	-3%
C. Non-Oper.Transfers	28.8	55.0	55.0	40.0	-27% *	50.0	55.0	10% *	50.0	55.0	10% *
D. Offset-Pay Package	0.0	-6.0	-6.0	-6.0	0%	6.0	4.0	-33% *	6.0	4.0	-33% *
TOTAL BUDGET	1463.8	1815.2	1815.2	1637.0	-10% *	1482.3	1385.5	-7%	958.8	967.0	1%

sultants, and money) to match work programs, maximize contracting power with available funds, analyze work programs from the standpoint of geographical and financial equity, optimize the use of federal aid, and conduct numerous other activities of top-level management.

In March of 1990, the model had already been in use for 1 year. Since that time, the following improvements have been made:

- Modification of the short-term model to report in program plan format for one-to-one reconciliations;
- Expansion of participation categories to separate engineering, right-of-way, and construction;
- Expansion of cash flow categories; and
- Other changes to refine the forecast and improve integration with the accounting systems.

While these minor changes were being made, the department developed 57 different program plan scenarios to accommodate the legislature and others seeking ways to improve transportation in Florida. An increase in taxes was the final result. Throughout this period, the model was the basis for evaluating the financial impact of all scenarios and is now being used to guide everyday financial decisions and to analyze the financial impacts of the current national economic situation.

Although additional refinements will undoubtedly continue, the model has proven essential in providing top management and the legislature with a means to evaluate future program plans and work programs and to identify and guide systems changes for improvement. The process has fully integrated the planning, work program, and accounting systems—a necessary requirement for operating effectively in a cash flow environment.

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Use of Public-Private and Intergovernmental Partnerships To Fund Transportation Improvements

MARK S. LEVENSON

In Minnesota public-private partnerships have been used to fund transportation improvements for highways, transit, and rail. The current upturn in the Minnesota economy and the state emphasis on attracting new and expanding development have generated increased growth. This growth has in turn placed more demands on existing highways and has increased the demand for new transportation facilities. Local jurisdictions are using private funds for the highway improvements needed to support economic expansion in their communities. Among the most successful techniques for soliciting public-private partnerships are negotiated agreements, often called joint power agreements, between the Minnesota Department of Transportation (Mn/DOT) and city and county governments. Another partnership technique is administered through Mn/DOT's Special Agreements program. Mn/DOT encourages local communities to improve their public works system by submittal of projects adjacent to needed trunk highway improvements. Local jurisdictions are responsible for contracts and construction, with help from Mn/DOT.

Backlogged needs and escalated costs continue to limit Minnesota's ability to finance and expedite the infrastructure improvements necessary to support new and expanded development. In response to this situation, many developers, local governments, and state public service providers in Minnesota are actively pursuing cooperative public-private partnerships to finance needed infrastructure improvements and new facilities.

Most Minnesota Department of Transportation (Mn/DOT) partnerships involve agreements between city and county governments. The local units are usually responsible for obtaining private-sector participation and funding assistance because local government is often closest to developers and business leaders.

Funding transportation improvements by private or partnership methods is growing in acceptance as a financing tool for transportation project development. In recent years, as needs have increased beyond revenue capacities, it has become necessary to examine alternative funding techniques.

The public sector is not able to assume the enormous financial burden by itself. Thus, many innovative methods have been tried to involve private enterprise in highway and other modal transportation improvements. As a result, public and private groups, local businesses, citizens groups, and city, county, and state governments are forming partnerships to make needed transportation improvements.

Minnesota Department of Transportation, Room 807, Transportation Building, 395 John Ireland Boulevard, St. Paul, Minn. 55155.

The business community has been an important factor in transportation decision making for many years. Industry leaders and business interests have often been the major impetus for transportation improvements. They have also played a leading role in developing strong coalitions to support legislative programs for transportation funding.

On a national level, highways, bridges, and rail and transit systems are deteriorating. More and more repair, reconstruction, and replacement are necessary to prevent further erosion of the infrastructure. It is estimated that highways and streets on the federal-aid highway system require more than $20 billion a year for improvements. Many state governments lack sufficient funds to make needed improvements. Thus, the future needs for transportation improvements require consideration of different approaches to funding.

In Minnesota, as in the nation, the use of public-private partnerships to finance transportation is becoming more commonplace. With a strong economy and a large transportation infrastructure (about 130,000 mi of roadways, 5,000 mi of railroad truck, and 83 million annual transit system passengers), alternative funding methods are essential to maintain and expand transportation facilities.

Economic growth is not being shared equally throughout the state. The Twin Cities metropolitan area is growing more rapidly than other regions. Fears that private participation in economically healthy areas could attract state dollars away from needs in the rest of Minnesota have tempered the development of explicit policy on public-private partnerships. Instead, interested private groups and local governments are being asked to participate in environmental and preliminary design activities rather than in the costs for actual construction. This situation is fostering participation and encouraging better local understanding of the relationship between transportation problems and land use decisions.

MODAL OVERVIEW

Highways

Private funding for highways has evolved from intermittent funding for minor site improvements to the use of private funds to help finance major highway improvements. Public and private funding agreements range from joint ventures and development agreements to tax increment financing.

Transit

Public transit usually operates on revenues from fares and public subsidies from federal, state, and local governments. In recent years, the federal government has reduced its contribution to funding partnerships, thus transferring more of the burden to state and local governments. This change has led to an exploration of the potential for increased involvement by the private sector as a means to reduce public subsidies.

The trend in transit is for government to contract with private firms to operate transit systems. Government is also encouraging the private sector to participate in new capital investments.

Rail

Since the 1960s, railroads have generally realized a small return on investment. They were unable or unwilling to invest needed capital in low-volume, low-profit branch lines. Low-interest loans or grants from the public sector combined with private investment from the railroads and rail users made the rehabilitation of some lines viable. Of the 5,000 mi of rail line remaining in Minnesota, 700 mi are a potential candidate for this type of public-private investment. Mn/DOT has established a rail service improvement program designed to provide state-funded loans for rail line rehabilitation to partnerships made up of shippers, governmental units, and railroad companies.

HIGHWAY IMPROVEMENT PROJECTS

Following are 17 examples of recent Mn/DOT highway improvement projects. Figure 1 shows the location of each project. (The circled numbers on the map correspond to the numbers in the text headings.)

1. Southwest Corridor—TH-212 from East of Cologne to I-494

TH-212 serves the area from Cologne to Eden Prairie, Minnesota. In a larger context, it is designated as the Yellowstone Trail and extends from Stillwater to Montana. The project is located in the southwest portion of the Twin Cities metropolitan area. The area gradually changes from rural at the western end to urban development at the eastern end and is experiencing rapid growth.

The improvement of existing TH-212 has been under consideration for almost 40 years. Lack of adequate or sufficient construction funds and consensus on the best location for the roadway has slowed the planning and design process. State, city, and county officials have identified the TH-212 southwest corridor as an important link for grain and other commodity movements between the southwest section of the state and the Twin Cities area.

The following are highlights of major activities in the southwest corridor:

- 1970—A study funded by the Minnesota Highway Department recommended a corridor for TH-212. It was supported by all affected units of government and many private organizations.
- 1974—A draft Environmental Impact Statement (EIS) was circulated for comment.
- 1979—Mn/DOT formed a citizens advisory committee. Public meetings were held with citizens' groups and agencies.
- 1980—A scoping report satisfied the preliminary federal environmental process, and work began on a new EIS.
- 1981—Mn/DOT stopped all work on new construction projects due to funding reductions. This action temporarily halted further progress on southwest corridor studies. (The TH-212 project has been recently reinstated.)
- 1986—A Mn/DOT scoping document and draft study outline were issued.
- 1987—The State of Minnesota, Mn/DOT, the Metropolitan Council, Carver County, Hennepin County, the city of Chanhassen, the city of Eden Prairie, and the city of Chaska entered into an agreement that would benefit all agencies and improve transportation in the southwest corridor.

This multiagency agreement, known as the Joint Powers Agreement, was worked out because Mn/DOT has consistently experienced a shortage in funding for either staffing or performance of environmental and design work. According to the agreement, a TH-212 task force will be formed and will include at least one staff member from each agency. In addition, the agreement calls for selection of a consulting firm to prepare an EIS and design study report. The total estimated cost of these activities is $320,000. Carver County has been selected as the project administrator and will retain the data collected with the study, together with summaries, maps, charts, and reports.

The cities of Chanhassen, Chaska, and Eden Prairie, as well as Carver and Hennepin counties, will contribute $30,000 each. The regional planning authority will contribute $50,000, and Mn/DOT's share will be $120,000. Total construction costs will be about $113 million. For BY 1993–1995, $56 million is programmed for half of the project.

The Joint Powers Agreement is a commitment by each participant to reduce highway congestion and provide safe transportation in the southwest metropolitan area. The participants are united in their belief that the TH-212 project is consistent with the long-term goals of their constituents. The creation of the agreement played a significant role in the timeliness of the project.

2. TH-5 from I-494 to TH-41

TH-5 in Eden Prairie and Chanhassen is an important link in the economic development of the southwest Twin Cities metropolitan area. Each day, more than 300 five-axle trucks use TH-5. Various segments of this roadway have been completed, parts are under construction, and parts are unscheduled.

A coalition of business leaders and developers located along the TH-5 route, adjacent cities, and Mn/DOT has agreed to share the costs of preliminary design activities.

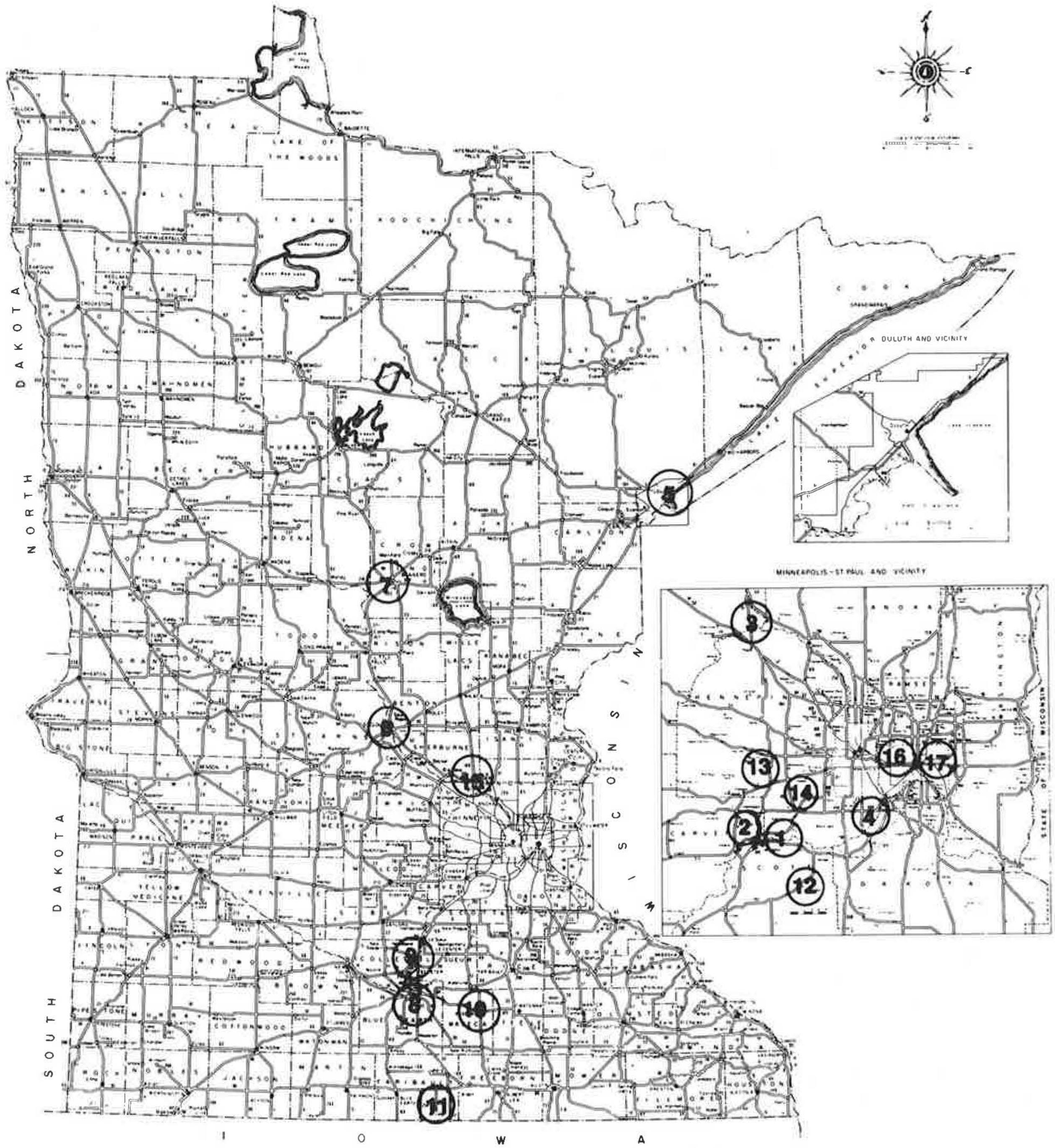

FIGURE 1 Minnesota highway improvement projects.

Two 1.5-mi segments of TH-5 in Hennepin and Carver counties are programmed with a total estimated cost of $6.1 million. The remaining 2.5 mi of major construction will cost about $4 million; this segment has not yet been programmed. It is anticipated that completion of the project will coincide with the 1991 U.S. Open golf tournament.

Eden Prairie is administering the private consulting contract. The following will be applied toward detail design costs:

- Eden Prairie—$50,000,
- Chanhassen—$50,000,
- Chaska—$20,000,
- Waconia—$10,000,
- Local business—$200,000, and
- Mn/DOT—$50,000.

In this instance, local business took an active role in cooperation with local and state officials to help defray the costs.

3. TH-101 from Rogers to Elk River

TH-101 was constructed on new right-of-way in the late 1960s. Enough right-of-way was acquired to construct a four-lane expressway. However, building more than two lanes was not justifiable at that time. There have been several requests for improvements to TH-101 since the early 1980s. These requests were generally initiated as a reaction to serious accidents or fatalities on the highway.

In 1987, a committee was formed comprising the cities of Rogers, Elk River, and Dayton, as well as Otsego and Hassan townships and Wright County. Meetings with Mn/DOT resulted in an agreement to monitor traffic on TH-101 and analyze the feasibility of signalizing intersections as an interim solution. In 1988, the committee decided to raise funds to investigate the possibility of hiring a consultant to do the environmental and preliminary design work, thus ensuring that the project will be programmed by Mn/DOT if construction funds become available.

The committee is currently negotiating a contract with an engineering consultant firm for design of a second roadway between Rogers and Elk River. Mn/DOT has added this project to FY 1994–1995 major construction work program. The total estimated project cost is $10.3 million. Elk River is acting as the contracting agency and will pay the consultant. Mn/DOT is the lead agency for the environmental and preliminary engineering design work. Mn/DOT is providing a project manager to supervise the consultant's work along with support services to minimize the committee's cost.

As of January 1, 1989, the committee had raised about $70,000 in donations and pledges, primarily from the private sector, for environmental and preliminary engineering. Other private-sector fundraising efforts include the sale of parchment certificates for inches of TH-101, a golf tournament, and various efforts by local special-interest groups. This project is a good example of cooperation between local governments, local businesses, and Mn/DOT.

4. I-494 from Minnesota River to I-394

Interstate 494 is in the southwest portion of the Twin Cities and circles the Twin Cities metropolitan area. Substantial development has occurred in the I-494 corridor since it was opened to traffic in 1960. This growth has produced an increasing volume of automobile and track traffic and a recurring need for Interstate maintenance, preservation, and interchange modifications. Congestion and capacity problems on I-494 have brought selected cities, counties, regional government authorities, and private developers together to help finance environmental documentation and preliminary design on the roadway from the Minnesota River to I-394.

In 1987 an I-494 corridor study provided a planning framework for further work in the corridor. The study recommended that alternative sources of financing be considered for I-494 improvements. A consultant was hired for environmental and preliminary design work. The total cost is estimated at $1.3 million, with Mn/DOT contributing half and the other groups contributing the remaining half. Eleven miles of this capacity improvement project (between TH-212 and the Minnesota River) will cost about $270 million. This work has been suggested for 1997 construction.

A Joint Powers Agreement was implemented to effect land use policy to help sustain the corridor and keep financing moving. The five adjacent cities of Richfield, Bloomington, Edina, Eden Prairie, and Minnetonka, along with the Metropolitan Airports Commission (MAC) and Hennepin County, will help finance the environmental and design work. A group of businesses, called Improve I-494, is raising the private-sector share. It is anticipated that the environmental work will take at least 3 years to complete.

Bloomington is managing the private sector's share of the environmental and predesign funding. The I-494 Corridor Commission, comprising the five adjacent cities and tied together by the Joint Powers Agreement, will coordinate planning efforts. The cost allocations for the environmental and design work were based on socioeconomic forecasts on I-494.

The various groups contributed the following amounts:

- Richfield—5 percent,
- Bloomington—5 percent,
- Edina—5 percent,
- Eden Prairie—5 percent,
- Minnetonka—5 percent,
- Hennepin County—7.5 percent,
- MAC—7.5 percent,
- Private sector—10 percent, and
- Mn/DOT—50 percent.

In addition, the Regional Transit Board is donating $10,000, and a nonprofit organization called Funding Transportation Management is donating an unspecified amount. The recommended roadway improvements to the I-494 corridor are costly. The addition of private-sector funds will assist the traditional funding mechanisms for a project of this magnitude.

5. Duluth, Minnesota

The city of Duluth is located in northeastern Minnesota on Lake Superior. With a population of nearly 93,000, Duluth is a major regional and economic center. Mn/DOT, the city of Duluth, and a local electrical utility company participated in a joint development project in downtown Duluth. The public-private partnership was responsible for a parking lot and plaza development at the intersection of Lake Avenue and Superior Street.

Mn/DOT built a new Lake Avenue bridge structure and an interchange with I-35, and the utility company built a parking lot adjacent to and beneath a portion of the bridge on Mn/DOT and city of Duluth right-of-way. Public plazas were provided on top of the deck structures. Duluth gave the utility company title to the land and reserved an easement for the public plaza. In return, the utility company reimbursed the city for construction costs and will maintain the public plaza area and the parking facilities.

6. St. Cloud, Minnesota

With a population of about 43,000, St. Cloud is a major regional center located approximately 70 mi north of the Twin Cities metropolitan area. The city of St. Cloud and Mn/DOT are considering a partnership to help finance the TH-15 project through the city.

The new alignment of TH-15 through St. Cloud has been a staged project. A $10 million river crossing and a $1.5 million improvement for the CSAH-29/TH-15 intersection are programmed in FY 1994.

The St. Cloud Area Planning Organization (APO) has developed a $1.3 million proposal to help finance the TH-15 projects. The proposal calls for earmarking $500,000 in federal-aid urban allocations for FY 1990–1991 to help in completion of TH-15. The St. Cloud Housing and Redevelopment Authority (HRA) will provide $500,000 worth of services by marketing and selling the excess right-of-way along TH-15. The added benefit of HRA involvement will be to pursue development compatible with the project. In addition, the APO believes that surrounding local communities will be willing to contribute about $300,000 in local funds.

7. Brainerd, Minnesota

Brainerd is a regional center located approximately 130 mi north of the Twin Cities. Because it is located near major lakes and recreational areas, Brainerd receives large volumes of pass-through tourist traffic during the summer months.

Development of a partnership agreement has cleared the way for corridor studies of a Brainerd bypass on TH-371. An agreement has been reached between Mn/DOT, the cities of Brainerd and Baxter, and Crow Wing County. The bypass would allow the large volumes of summer automobiles, recreational vehicles, and automobile and boat trailers to bypass downtown retail areas.

Mn/DOT will begin selecting alternative bypass corridors and subjecting them to the EIS process (which will lead to selection of the corridor in about 20 months). Local governments will assume responsibility for protecting the corridor from encroachment once it is established. In addition, a major land owner will donate a portion of the right-of-way to the project. It is hoped that other land owners will be persuaded to do the same.

At present, Mn/DOT will proceed through the corridor and EIS selection process only, because the project is not yet programmed for construction. Right-of-way donation and further local investment will be factors in favor of the project if it becomes authorized for construction.

8. Mankato, Minnesota

The city of Mankato is located approximately 128 mi southwest of the Twin Cities. A Mankato bypass project along TH-22 was initiated by Mn/DOT, Blue Earth County, and the city of Mankato because of economic development implications. Blue Earth County and the city of Mankato each gave $1 million toward the project, and Mn/DOT contributed the remainder of the cost, which totaled $3.2 million. This reconstruction project was let in July 1988 and opened in October 1989.

In another Mankato project, the construction of right- and left-turn lanes on TH-14 near the east edge of town was jointly funded by Mn/DOT and Mankato. An agreement between Mn/DOT and Mankato was reached whereby each unit contributed half of the total cost of the project ($27,500 each). A private lumber company located at the intersection paid for a portion of the project.

9. St. Peter, Minnesota

The city of St. Peter is located in south central Minnesota about 11 mi north of Mankato. The city expressed interest in realigning TH-22 in the downtown area. Mn/DOT is sharing intersection costs through its Special Agreements Program. This $4-million-per-year program is funneled through state aid engineers who act as liaisons with municipalities and counties. Mn/DOT assumes a share of the financial responsibility, but the local government agencies are responsible for contracts and construction. For the St. Peter project, the city's cost is $832,000, and Mn/DOT will contribute about $400,000.

10. Waseca, Minnesota

Waseca is a regional center in southern Minnesota about 75 mi from the Twin Cities. A potential bypass of Waseca by TH-14 is in the proposal stage. A bypass study may be undertaken for which the city of Waseca, Waseca County, and Mn/DOT will contribute $20,000 each. This project is currently in the planning stages.

11. Bricelyn, Minnesota

Bricelyn is a small community with a population of 487 located about 5 mi from the Iowa border in Faribault County. Mn/DOT and Faribault County negotiated a cost-sharing project to upgrade TH-253 so it could carry 80,000-lb gross vehicle loads all year. The county paid one-third of the upgrading costs. In addition, the county assumed responsibility for another 6-mi section of two-lane road previously under state jurisdiction.

12. TH-101/Shakopee Bypass Area

Completion of the Shakopee bypass to four lanes between Shakopee and Savage (TH-169 to TH-13) is estimated at $35 million. Construction began in FY 1990.

The city of Shakopee hired a consultant to prepare a portion of the final design plans. At present, Shakopee has raised $1 million using tax increment financing, in which the city sells bonds and repays them with property taxes generated from the development.

In addition, a new bridge over the Minnesota River and a bypass of downtown Shakopee is estimated to cost $7.6 million. The city of Shakopee has contributed $1.9 million toward the project using tax increment financing. The Shakopee money will be used to fund preliminary and final design.

13. I-494/CR-6 in Plymouth

The city of Plymouth, a northern suburb in the Twin Cities metropolitan area, plans to develop land in the I-494/CR-6 intersection area. Current plans call for additional access to local businesses. The city has requested construction of a new interchange on CR-6 at I-494 and hired a consultant to perform design work.

Mn/DOT and Plymouth will share the cost of the project. The city will do most of the intersection work and will pay $5 million to widen the bridge. Mn/DOT will reconstruct about 2 mi of Interstate and add a third lane. Reconstructing the main line, adding the auxiliary lanes, and constructing the CSAH-6 ramp is estimated at $7 million.

14. Eden Prairie

Eden Prairie is a fast-growing suburb in the southern portion of the Twin Cities metropolitan area. A new $350,000 pedestrian bridge that would span an improved TH-5 at CR-4 was recently approved by the city. The city will pay for the entire construction cost of the bridge. Mn/DOT will pay for design and engineering costs.

15. Elk River

Elk River is a rapidly growing city approximately 25 mi north of the city of Minneapolis. Land owners in Elk River entered into a partnership with Mn/DOT and contributed all right-of-way required for improvements to the intersection of TH-101 and CSAH-42. A cooperative agreement has also been established whereby the affected county and township will contribute $25,000 each toward total construction costs. The project is in Mn/DOT's Special Agreements program and began in FY 1990.

16. St. Paul, Minnesota (I-94)

An agreement between Mn/DOT and the city of St. Paul provides that the city contribute about $600,000 toward an extension of an I-94 bridge over an abandoned Burlington Northern Railroad right-of-way to accommodate a proposed pedestrian-bicycle trail.

Mn/DOT's reconstruction plan includes an opening under the bridge that could accommodate a future trail. The St. Paul Parks and Recreation staff proposed an additional 76-ft span to provide for a wider opening. Mn/DOT began design of the bridge extension and advised the St. Paul city council that they would incorporate the extra spans in the design at a later date. St. Paul agreed to reimburse the state.

17. St. Paul, Minnesota (Capitol Complex)

The Minnesota Historical Society has agreed to contribute $1 million for a cover over the 6th Street ramps from I-94 into the St. Paul central business district.

A study selected the site for the Minnesota History Center on the location of the former Miller Hospital. In choosing the site, the need for a deck over the I-94 connector ramp was deemed critical. A series of meetings between Mn/DOT, the Minnesota Historical Society, and the Capitol Area Architectural and Planning Board resulted in an agreement to construct the History Center deck.

PUBLIC-PRIVATE AND INTERGOVERNMENTAL PARTNERSHIPS FOR TRANSIT

The Mn/DOT Office of Transit provides the expertise needed to maintain the state's role in the delivery of transit service in partnership with the federal government and local communities. The transit activity is involved with intergovernmental partnerships in its development of policies and programs that assist local transit systems.

A significant part of transit's role in public-private and intergovernmental partnerships is providing technical and financial assistance to local transit systems. In addition, evaluating and improving local transit systems is a fundamental part of transit's role within Mn/DOT. The goal of the Office of Transit is to use state and federal investment in public transportation effectively.

A new federally funded position was established in the Office of Transit to identify new opportunities for private-sector involvement in the delivery of transit service to Greater Minnesota. Approximately 30 percent of the small urban and rural transit systems in the area are now contracted to the private sector.

The following public-private and intergovernmental partnerships have recently been formed in the city of Duluth.

Duluth Transit Authority

The Duluth Transit Authority (DTA) is a publicly funded transit program managed by a private company. DTA employees are considered to be employed by this private company for workers' compensation purposes. Some major maintenance work, such as engine overhauls, is also contracted out to private companies.

Trolley Service

DTA provides a rubber-tired trolley service that operates in the downtown Duluth and waterfront areas from May to October. Local businesses subsidize approximately 75 percent of the trolley's operating costs to keep fares at a minimum. The trolley makes 16 runs a day with stops near major hotels, restaurants, and tourist attractions.

Streetscape

DTA's downtown Duluth Streetscape project included the construction of two Superior Street transit centers in conjunction with private developments. DTA leases space for the West Transit Center from the Holiday Inn. The East Transit Center is owned by DTA, which leases a portion of the commercial and retail space to private companies. Maintenance and cleaning of the centers are provided by the private developers. DTA has also received a portion of local share funding for a variety of capital improvement projects (such as transit centers and transit shelters) from the Duluth Downtown Benefit Assessment program (tax increment district).

STRIDE

STRIDE is a specialized transportation program for those mobility handicapped individuals who are unable to use the regular DTA system. DTA contracts the dial-a-ride services provided by STRIDE to a private company in Duluth. DTA owns the vehicles used in the program and is responsible for major vehicle maintenance, scheduling, and dispatching; the contractor pays for all other expenses. The private contractor is chosen by a competitive bid process.

PUBLIC-PRIVATE AND INTERGOVERNMENTAL PARTNERSHIPS FOR RAIL

The purpose of the rail activity within Mn/DOT is to provide effective rail service in the state. This objective is accomplished by planning, regulating, and providing improvements for rail systems in Minnesota.

One method of meeting rail needs in Minnesota is through the Minnesota Rail Service Improvement Program. In this program, rail projects are selected and eligible lines are screened for possible rehabilitation. The program offers opportunities for public-private and intergovernmental cooperation.

Southern Minnesota

A $6.3 million rail service improvement project was implemented in southern Minnesota. Assisted by funds from shippers in seven southern Minnesota counties, the railroad and Mn/DOT began upgrading 165 mi of main-line track between Owatonna and the South Dakota state line and between Waseca and Hartland.

The line serves 50 shippers in Minnesota. Extensive rehabilitation is needed to safely handle unit trains of 100-ton hopper cars. The 2-year project includes installing 130,000 new crossties, adding 116,000 tons of rock ballast to strengthen rail roadbeds, and relaying 5 mi of track.

Mn/DOT is providing $4.5 million, the railroads are providing $1.3 million, and the remaining $0.7 million will be raised by local shippers. In addition, seven southern counties have agreed to provide $30,000 each in interest-free loans to assist the shippers. These funds will be repaid by a surcharge on rail freight.

Freight Access Improvement Projects

Two successful freight access improvement projects were negotiated with local governmental units and private businesses to finance county road improvements. Recent rail abandonments had placed the entire shipping burden on public highways, which lacked sufficient pavement strength to carry heavy trucks. These freight access improvement projects were designed to finance county road improvements and were initiated to test the feasibility of using public-private partnerships for local road strengthening projects.

Gary, Minnesota

The city of Gary, with a population of 241, is located in Norman County about 25 mi from the North Dakota border. Gary, the county, and its businesses funded about $5,000 for the surfacing of CSAH-19 from TH-32 into Gary to provide access for trucks carrying 80,000-lb gross vehicle weight. The total project cost was $52,000. A federal grant administered by the state paid for half ($26,000) and Norman County paid the remainder ($21,000).

Two Harbors, Minnesota

Two Harbors is located along the shore of Lake Superior in northern Minnesota. Local business participation in Two Harbors provided about 15 percent of the total costs to upgrade CSAH-2 and CR-200 into Walter H. Norlen Industrial Park and the Louisiana Pacific Corporation siding plant. Louisiana Pacific contributed about $8,500, and several other businesses provided $800 each.

CONCLUSIONS

Public-private and intergovernmental funding partnerships will continue to grow. As long as transportation needs are greater than current funding, there will be a need for alternative financing of the transportation infrastructure.

U.S. highways are deteriorating, and traffic is increasing faster than needed improvements. Transit and rail systems require increased private involvement to continue to improve their levels of service. Because Mn/DOT cannot keep pace with the overwhelming costs of needed new construction and continue to provide an adequate level of highway preservation and maintenance, an alternative revenue source is necessary. To fill this void, local governments and private businesses have offered the use of private funds to help with transportation improvements. This action will benefit local communities by encouraging economic expansion.

The private sector is encouraged to take the initiative in proposing funding for various transportation projects. Mn/DOT can thus participate in public-private partnerships for funding preliminary engineering, design, right-of-way, and highway construction.

Greater private participation in transportation is being explored in both the public and private sectors of the economy. Because there are few systematic and organized ways to facilitate public-private partnerships, further experience is needed to define the nature of such partnerships. Their value lies in the increased transportation benefits to the participating communities. The turnaround time from project inception to completion is faster when the predesign and environmental work is financed by sources other than Mn/DOT. More projects can be completed in a timely manner with economic benefits for everyone, including increased safety and less congestion.

Projects stimulated through the use of private funds are recognized as important by community officials. This in turn makes Mn/DOT responsive to the public. The primary objective of Mn/DOT is to provide transportation systems, services, and facilities that will allow safe, efficient movement of people and goods throughout the state. A well-integrated transportation system is a key element in achieving statewide social, economic, and energy-related goals. The use of more public-private partnerships will help Minnesota realize these goals.

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Taxation Model for Road Vehicles in Saudi Arabia

KHALID ABDULGHANI, MADAN GOPAL ARORA, FAHD BALGHUNAIM, FOUAD BAYOMY, AND DONALD PEARSON-KIRK

A taxation model for road vehicles in the Kingdom of Saudi Arabia has been developed on the hypothesis that vehicles should pay their fair share for roadway maintenance. A number of load- and traffic-counting stations were selected on the main highway network in the Eastern Province of the kingdom. Representative ranges of truck loads and dimensions, traffic volumes, and pavement deterioration were monitored at these stations. Data related to kilometers traveled per day were also collected on the basis of driver interviews. At all survey stations, a large number of trucks were found to exceed the load and dimensional limits of the Ministry of Communication. The pavement condition survey indicated a prevalence of load-associated damage. Assuming pavement maintenance costs for major and routine maintenance operations, a model to assess vehicle taxation in terms of an annual tax as well as a load violation charge is presented with illustrative examples. As a result of this study, 11 weight control stations have been installed on major truck routes in the kingdom. Early results of the weight control program are encouraging.

The transport sector of the Kingdom of Saudi Arabia is one of the most vital sectors of the Saudi economy; economic development of the kingdom relies heavily on its extensive road network. The kingdom today has about 100 000 km of roads, of which about 30 000 km is of high-specification asphalted roads. These roads were designed according to the AASHTO procedure for a specified number of 8.2-t (18-kip) equivalent axle load (EAL) applications anticipated during the design life of 20 years (*1*).

It is well known to highway engineers that pavement damage increases exponentially with axle loads. For example, AASHO road tests have shown that pavement damage is approximately proportional to the fourth power of the axle load (*2*). Thus, if an axle load is increased to twice the EAL, one application of the increased axle load will cause the same amount of damage to the pavement as 16 applications of the EAL. Applying this logic to lighter loads of passenger cars, it can be seen that a fully loaded truck may cause approximately 10,000 times more damage than a passenger car.

For economic reasons, there is a growing tendency toward increasing truck sizes and weights, and thereby toward increased axle loadings. Increased truck weights accelerate pavement damage and shorten the maintenance-free life of the pavement. Problems resulting from overweight trucks are being experienced worldwide. In the kingdom the problem is worse because much higher axle loads than the Ministry of Communication (MOC) legal limits are operating on the highway network (*3*). A number of major highways, expressways, and bridges in the kingdom are showing signs of structural distress much earlier than their design lives (*4–6*). Hence, if the large capital investment made in the highway network is to be protected, there is an immediate need to regulate axle loads and the gross weight of trucks.

One approach to alleviate the problem of overloading and meet the increasing budgetary needs for road maintenance is to introduce taxation for road vehicles commensurate with the damage they cause to the road pavements (*7,8*). The existing taxation policy in the kingdom needs refinement because it is not based on pavement wear. Placing higher taxes on trucks with higher axle loads would not only generate revenue for increasing maintenance needs but would also discourage use of trucks that do the most damage to the roads. A rational taxation model was formulated in which vehicles are charged equitably in accordance with the cost of roadway maintenance attributable to their operations. Field data related to operating traffic volumes, vehicle dimensions and loads, vehicle kilometers traveled, and pavement damage and maintenance, which constitute an important data base for the model development, were collected for certain primary highways in the Eastern Province of the kingdom.

MODEL DEVELOPMENT

The model is developed in two parts. Part I deals with the estimation of vehicle annual taxation covering the annual maintenance expenditure on the road system. This tax will be determined separately for each vehicle class on the basis of average values of vehicle attributes within the class. Part II deals with the estimation of additional taxation for overloaded vehicles that are violating the legal load limits. This tax will be determined separately for each individual vehicle and will be based on the degree of overloading by the vehicle and the average roadway use by the corresponding vehicle class.

For estimation of vehicle annual taxation, a distinction has to be made between the annual maintenance cost for routine maintenance and the equivalent annual major maintenance cost. Routine maintenance cost accounts for regular or normal maintenance such as roadway cleaning and repairs of minor pavement distresses, which are generally nonload associated. Routine repairs most commonly include crack sealing and

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patching. Major maintenance cost accounts for periodic pavement rehabilitation (i.e., overlays) due to load-associated pavement distresses. Because the routine maintenance cost is nonload associated, it is logical to distribute it among road vehicles in accordance with their base areas representing roadway occupancy area. The major maintenance cost, being load associated, is distributed among vehicles in proportion to the damage caused by their loads. Hence, the vehicle annual tax (VAT) is divided into two portions: annual major maintenance tax (AMMT) and an annual routine maintenance tax (ARMT).

Vehicle Annual Tax

Annual Major Maintenance Tax

Assuming that a road section requires an overlay after each n years and its estimated cost per lane-kilometer is CMM, the average annual major maintenance cost (AMMC) can be determined by the following:

$$\text{AMMC} = \text{CMM} \times C_{\text{rf}} \tag{1}$$

where

C_{rf} = capital recovery factor = $\dfrac{i\,(1+i)^n}{(1+i)^n - 1}$ and
i = interest rate per year.

The damage induced on a road section in 1 year is proportional to the amount of EAL applied on the road section during this period. Accordingly, the share of each EAL to the major maintenance cost in a year's time can be determined by the following:

$$\text{UMMC} = \frac{\text{AMMC}}{\text{total EAL passed on 1 lane-km/yr}} \tag{2}$$

where UMMC is the unit major maintenance cost per lane-kilometer per unit EAL.

Estimating the average annual kilometers (AKT) traveled by a vehicle, the AMMT accruing to the vehicle can be estimated by the following:

$$\text{AMMT} = \text{UMMC} \times \text{RDF} \times \text{AKT} \tag{3}$$

where the relative damage factor (RDF) of a vehicle on the basis of the EAL concept is given by the following equation:

$$\text{RDF} = \sum_{i=1}^{n} \text{EAL}_i \tag{4}$$

where

n = number of vehicle axles and
EAL_i = equivalent axle load of Axle i.

EAL_i is determined by the following equation:

$$\text{EAL}_i = \left(\frac{L_i}{L_s}\right)^4 \tag{5}$$

where

L_i = actual load of Axle i and
L_s = corresponding standard axle load.

L_s is assumed as 5.4 t for a single axle with single tires, 8.2 t for a single axle with dual tires, 13.6 t for a double axle with dual tires, and 18.5 t for a triple axle with dual tires (*2,6*). The RDF of any vehicle will be a function of the vehicle's axle load and is expected to vary in each operation. Legal RDF (RDF_0) is used in Equation 3, assuming that the vehicle is operating at MOC legal load limits. Legal axle loads (L_{i0}) and the corresponding RDFs for different vehicle classes on the basis of MOC legal load limits are presented in Table 1.

Annual Routine Maintenance Tax

It is assumed that routine maintenance needs are independent of the damage caused by vehicle loading. Other than the annual kilometers traveled by a vehicle, the ARMT of the vehicle should depend on the size of the vehicle, which represents its degree of occupying the road. For instance, assuming the kilometers traveled remain the same, a truck having a base area three times that of a passenger car should pay three times the car's share of the annual routine maintenance cost. Hence, to estimate ARMT, base areas of all vehicles are transformed into equivalent passenger car (EPC) units, defined by the following:

$$\text{EPC} = \frac{\text{base area of a vehicle}}{\text{base area of a passenger car}} \tag{6}$$

The share of each EPC unit to the routine maintenance cost per year per lane-kilometer is as follows:

$$\text{URMC} = \frac{\text{ARMC}}{\sum_{k=1}^{s} (N_k \times \text{EPC}_k)} \tag{7}$$

where

URMC = unit routine maintenance cost per lane-kilometer per unit EPC,
ARMC = average annual routine maintenance cost per lane-kilometer,
N_k = average annual volume of vehicles of Class k, and
s = total number of vehicle classes.

Therefore, the ARMT for a vehicle can be estimated by the following:

$$\text{ARMT} = \text{URMC} \times \text{EPC} \times \text{AKT} \tag{8}$$

Finally, the VAT covering both the routine and major maintenance is determined by combining Equations 3 and 8 as follows:

$$\begin{aligned}\text{VAT} &= \text{AMMT} + \text{ARMT}\\ &= (\text{UMMC} \times \text{RDF}_0 + \text{URMC} \times \text{EPC})\,\text{AKT}\end{aligned} \tag{9}$$

TABLE 1 RELATIVE DAMAGE FACTOR (RDF) FOR DIFFERENT TRUCK TYPES ON THE BASIS OF MOC LEGAL LOAD LIMITS

Truck Description	Truck Designation	Legal Axle Load in Tons and Corresponding EAL for Axle (i)	Legal Gross Load in Tons and Legal RDF (RDF_0)
Rigid Body	RB2	6 - 13	19
with 2 Axles		(1.52) (6.32)	(7.84)
Rigid Body	RB3	6 - 10 . 10	26
with 3 Axles		(1.52) (4.68)	(6.20)
Semi-Trailer with 3 Axles	S2.1	6 - 13 - 13	32
(2 in front)		(1.52) (6.32) (6.32)	(14.16)
Semi-Trailer with 4 Axles	S2.2	6 - 13 - 10 . 10	39
(2 in front)		(1.52) (6.32) (4.68)	(12.52)
Semi-Trailer with 4 Axles	S3.1	6 - 10 . 10 - 13	39
(3 in front)		(1.52) (4.68) (6.32)	(12.52)
Semi-Trailer with 5 Axles	S3.2	6 - 10 . 10 - 10 . 10	46/40[a]
(3 in front)		(1.52) (4.68) (4.68)	(10.88)/(6.40)
Semi-Trailer with 5 Axles	S2.3	6 - 13 - 7 . 7 . 7	40
(2 in front)		(1.52) (6.32) (1.66)	(9.50)
Semi-Trailer with 6 Axles	S3.3	6 - 10 . 10 - 7 . 7 . 7	47/40[a]
(3 in front)		(1.52) (4.68) (1.66)	(7.86)/(4.68)

[a] 40T is legal gross load limit.

The AKT values were estimated from driver interviews. The RDF and EPC values were determined from the vehicle weight and dimension surveys. Field data collection and data analyses are presented in the following section.

Load Violation Tax

Load violation can represent either gross load violation or axle load violation, or both. Axle load violation can be triggered without a gross load violation, if the payload is not well distributed over all the axles. Gross load violation, without an axle load violation, can be triggered only for S3.2 and S3.3 truck types; for these truck types the MOC gross load legal limits, as presented in Table 1, are lower than the corresponding sums of the axle load limits. If both violations exist, the vehicle is charged for only one of the two, whichever calls for greater taxation.

Gross Load Violation Tax

The gross load violation tax (GLVT) must be in proportion to the excess of RDF applied by the overloaded vehicle above the legal limit. If a vehicle has an extra gross load of L_g above the legal limit of L_{g0}, the new relative damage factor RDF_n corresponds to load $(L_g + L_{g0})$ and is related as follows:

$$\left(\frac{RDF_n}{RDF_0}\right) = \left(\frac{L_g + L_{g0}}{L_{g0}}\right)^4 \qquad (10)$$

Accordingly, the increase in RDF units is as follows:

$$\Delta RDF = RDF_n - RDF_0 \qquad (11)$$

The amount of extra maintenance cost for each kilometer of travel to be covered by the excess in RDF units should be equal to $\Delta RDF \times UMMC_n$.

The $UMMC_n$ value is the new unit major maintenance cost per kilometer for the illegal loading conditions.

Hence, the GLVT can be estimated by the following:

$$\begin{aligned} GLVT &= \Delta RDF \times UMMC_n \times \text{trip length} \\ &= (RDF_n - RDF_0) \times UMMC \times \left(\frac{RDF_n}{RDF_0}\right) \\ &\quad \times \text{trip length} \end{aligned} \qquad (12)$$

The violation charge should be a function of the trip length each time the vehicle violates the legal load limits. Because estimation of actual trip length for each case is difficult, average distance traveled daily by each vehicle class is used, determined from driver interviews. The AKT used in Equation 9 was related to the average trip length (ATL) as follows:

$$AKT = 300 \times ATL \quad (13)$$

where 300 represents the number of working days per year.
Thus, the GLVT is as follows:

$$GLVT = RDF_0\left(\frac{RDF_n}{RDF_0} - 1\right)UMMC\left(\frac{RDF_n}{RDF_0}\right)ATL \quad (14)$$

The ratio of RDF_n to RDF_0 can be estimated by the fourth power of the ratio of the new illegal load to the legal load, as indicated in Equation 10. Accordingly,

$$GLVT = RDF_0\left[\left(\frac{L_g + L_{g0}}{L_{g0}}\right)^4 - 1\right] \times UMMC\left(\frac{L_g + L_{g0}}{L_{g0}}\right)^4 ATL \quad (15)$$

Axle Load Violation Tax

When the violation is due to axle load and not gross load, the same equation may apply using the EAL value for axles and not for the overall vehicle. Thus, for this case, the axle load violation tax (ALVT) is given by the following:

$$ALVT = EAL_{i0}\left[\left(\frac{L_i}{L_{i0}}\right)^4 - 1\right] \times UMMC\left(\frac{L_i}{L_{i0}}\right)^4 ATL \quad (16)$$

where EAL_{i0} is the legal equivalent axle load of Axle *i*.

FIELD DATA COLLECTION

Out of 16 major highways and expressways in the Eastern Province, 5 were selected for data collection in consultation with the Dammam Directorate of the MOC. The selected highways cover the range of construction materials, groundwater conditions, pavement age, cross sections, and distress manifestations typically encountered in the region. One load- and traffic-counting survey station was located on each selected highway for each direction of travel, at a place where the expected truck traffic was heaviest. Because the trucks had to be taken from the moving traffic stream and stopped for load measurements, careful planning of safety measures and the presence of traffic police were required to authorize truck stopping. Generally, a queue of trucks developed. While the trucks were waiting to be weighed, the truck drivers were interviewed to collect the trip length data and other crew members measured the trucks' dimensions.

Volume Data

Volume data were collected using manual counters. Classified volume data were recorded on specifically designed sheets. Two groups of data collectors were employed at each counting station, separately for daytime and nighttime counting. The observed average composition of truck traffic compared with that on freeways in Australia and in the United States is presented in Table 2 (*9,10*). The composition in Saudi Arabia is similar to that in the United States and Australia, except that more RB3s and less RB2s are observed in the kingdom. The table shows that the S3.3 is the most widely used truck in Australia, as opposed to the S3.2 in the United States and the kingdom. The S3.3 has better load distribution than the S3.2 due to its larger number of axles.

Load Measurement

Axle load measurements were made with the Trevor Deakin Portable Weighbridge designed by the U.K. Transport and Road Research Laboratory (TRRL). It comprises two lightweight weighpads with a separate electronic logaload readout unit having a digital printer. The vehicle is driven forward slowly; when the wheels are centered over the weighpads, the vehicle is stopped and the logaload displays the load applied. The vehicle is then driven until its next set of wheels is advanced to the weighpads and again weighed. The printout lists the load on each axle, gross weight, number of axles, ticket serial number, and date. A typical designed data sheet is presented in Table 3. Tire pressures were measured as supplementary information for the pavement design study. Analysis of axle loads revealed that overloading was most frequently encountered on triple axles—72 percent of them exceeded the legal limit. The other axle groups exceeding the legal limits were 55 percent of tandem axles, 43 percent of SS axles (single axle with single wheels) and 26 percent of SD axles (single axle with dual wheels).

Gross weights of loaded vehicles were analyzed in a similar manner as the axle loads. Gross overloading was encountered most frequently in the RB3 type (77 percent), followed by the S3.2 and S3.3 types (68 percent for each type). Further, 28 percent of the RB2 type and 25 percent of the S2.2 type were found to be exceeding their gross weight legal limits. The frequent overloading observed in the RB3 type may be attributed to the type of commodity (such as sand and ag-

TABLE 2 PERCENTAGE VOLUME COMPOSITION OF TRUCK TRAFFIC ON RURAL FREEWAYS AND EXPRESSWAYS

Truck Type	Percentage Volume Composition in		
	Saudi Arabia	Australia	U.S.A.
RB2	16	23	34
RB3	27	10	4
RB4	NA	4	1
	43	37	39
S2.1	NA	1	4
S2.2	11	6	8
S3.2	40	24	49
S3.3	6	32	NA
	57	63	61

NA = Not applicable

TABLE 3 TYPICAL AXLE LOAD DATA

SURVEY STATION: LC2 DATE: 24-09-85
HIGHWAY: FROM JUBAIL TO SAFWA TIME: 07:00 HRS.

Reg. No.	Truck Type	AXLE LOAD (TONS) AX1	AX2	AX3	AX4	AX5	AX6	Gross Wt. (Tons)	Tire Prs. (Kg/sqcm)	Comments
7057	S3.2	5.88	5.15	4.86	4.91	6.31		27.11		Container
7060	RB2	5.01	13.43					18.44	8.45	Container
7057	S3.2	6.04	7.60	8.04	8.51	8.38		38.57	9.16	Steel
7048	RB3	4.82	4.94	4.46				14.22		Empty
7136	RB3	5.66	12.90	13.28				31.84	7.04	Blocks
7106	S3.2	4.66	11.59	12.51	11.09	12.10		51.95		Equipment
7164	LT	1.85	3.69					5.54		Pipes
7136	RB3	6.58	10.91	11.76				29.25	6.34	Blocks
7077	S3.2	5.73	5.40	4.78	9.73	9.64		35.28		Tanker
7064	S3.2	6.25	8.00	7.03	8.13	8.12		37.53	7.04	Steel
7124	RB2	5.96	12.70					18.66		Tanker
7033	RB2	2.90	7.34					10.24	6.34	Container
7057	S3.2	6.18	7.82	7.12	7.98	8.34		37.44	7.04	Steel
7084	RB3	5.78	8.84	10.13				24.75		Tanker
7060	S3.2	4.88	10.38	10.20	12.76	12.27		50.49		Steel
7090	S3.2	6.40	12.54	11.94	18.11	20.85		69.84	10.57	Steel
7131	S3.2	6.30	12.00	12.55	17.81	17.40		66.06	8.45	Steel
7048	S3.2	6.30	15.10	14.67	17.91	18.83		72.81		Steel
7175	S3.2	6.20	13.43	12.61	16.47	18.16		66.87	9.86	Steel
7189	RB3	6.30	14.94	14.70				35.94		Aggregate
7041	RB2	5.15	9.57					14.72		Gas
7038	S3.2	7.12	12.42	11.74	14.68	13.90		59.86	8.45	Blocks
7184	S3.3	7.90	11.81	12.10	22.40	13.67	20.12	88.00		Aggregate
7067	S3.2	6.67	3.60	3.25	3.21	3.52		20.25		Pipes
7065	RB3	6.80	15.80	16.11				38.71	8.45	Aggregate

gregates) usually carried by it. Overloading in the S3.2 and S3.3 types may be due to the increased dimensions of these trucks and their increased empty weights. Mean empty weights of these two types were found to be 52.4 and 70.1 percent, respectively, of the corresponding loaded legal weight limits. The higher empty weights result in less payload limit if the legal weight limits are complied with, thereby making the operation of these truck types uneconomical to the operator. This situation leads to the overloading tendencies.

Dimensional Data

Measurements of dimensions of a number of passenger cars showed an average length of 3.4 m and an average width of 2.0 m, giving a base area of 6.8 m^2. This area was used for computing the EPCs of other vehicle classes. The 95th percentile values computed from the collected dimensional data are presented in Table 4, together with the current MOC dimensional limit and the dimensions of the corresponding AASHTO vehicles. For rigid trucks, the 95th percentile values for length and width exceed the corresponding MOC and AASHTO limits. For semitrailer trucks, the 95th percentile values of each element (i.e. length, width, and height) exceed the corresponding limits specified by MOC and AASHTO. Insufficient control of vehicle dimensions not only results in certain highway geometric design standards being inappropriate, but also contributes to the overloading problem. The combination of oversized and overloaded vehicles, operating at high speeds and poor levels of vehicle maintenance, contributes to increasing road accidents.

TABLE 4 COMPARISON OF DIMENSIONAL LIMITS

Vehicle Type	Dimension	Value (m) 95-Percentile	MOC Limit	AASHTO
Rigid Body Truck	Length	12.80	12.00[a]	9.10
	Width	2.75	2.50	2.60
	Height	3.88	4.00	4.10
Semi-Trailer	Length	20.00	18.00	17.00
	Width	3.10	2.50	2.60
	Height	4.70	4.00	4.10

[a] Length limit is 11.0 m for RB2

Average Trip Length Data

As mentioned earlier, the truck drivers were interviewed while they were waiting in queue for load and dimension measurements. The main purpose of the driver interviews was to collect information about average kilometers traveled per day. Supplementary data on types of commodity, routing (origin-destination), percent time the vehicle was operating at full load, and driving license and registration renewal were also sought. A separate interview sheet was completed for each truck. Because no passenger cars were stopped at the weighing stations, a separate interview survey was planned for them at selected gas stations—one on each selected highway. Only basic information related to the average distance traveled per day was collected from the car drivers.

Pavement Condition

The pavement rating (PAVER) technique developed by the U.S. Army, Corps of Engineers, was used to quantify pavement distress (*11*). In this technique, pavement condition evaluation is based on a numerical rating of 100, called the pavement condition index (PCI). The PCI is a measure of the overall surface condition of a pavement combining all types of observed distress manifestations. The types of distresses encountered were bleeding, longitudinal cracking, weathering and raveling, patching, and rutting, with severity levels ranging from low to high. The PCIs and pavement condition ratings are presented in Table 5 by section. According to the PAVER technique, a decision may be made to rehabilitate a primary highway when its PCI falls to 60 (*11*). If this limit is applied to the selected highways, the sections in need of major maintenance are identified as shown in the table.

ILLUSTRATIVE EXAMPLES

Vehicle Annual Taxation

Taxation assessment requires estimation of AMMC and ARMC. On the basis of interviews with local contractors performing maintenance contracts for MOC, average values of AMMC and ARMC were assumed as SR 4,183, and SR 1,940 per lane-kilometer per year. The value of AMMC assumes a 5-cm overlay costing SR 32,300 per lane-kilometer, distributed over a period of 10 years at a compound interest rate of 5 percent.

UMMC and URMC values were computed for each selected highway using the corresponding volume data and the mean values of the other data for the five highways. The computer values of UMMC and URMC for each study location are presented in Table 6. Typical computations for VAT for Abu Hadriyah-Dammam Expressway are presented in Table 7. Because VAT within a province should not be a function of road location, overall average values of UMMC and URMC for all study locations were used to compute the annual taxes. The taxes for various vehicle classes are presented in Table 8.

TABLE 6 UNIT MAINTENANCE COSTS FOR SELECTED HIGHWAYS

Highway	UMMC (SR x 10^{-2})	URMC (SR x 10^{-2})
Dammam-Ras Tanura	0.32063	0.080323
Ras Tanura-Dammam	0.34295	0.07524
Safwa - Jubail	0.43438	0.12644
Jubail - Safwa	0.41171	0.11341
Dammam - Abu Hadriyah	0.36008	0.18127
Abu Hadriyah - Dammam	0.30972	0.15966
Dammam - Riyadh	0.49979	0.25997
Riyadh - Dammam	0.41559	0.21895
Dhahran - Abqaiq	0.18102	0.084027
Abqaiq - Dhahran	0.17168	0.074568
Average	0.34476	0.13738

Load Violation Tax

On the basis of the average value of UMMC, additional taxes for gross load violation and axle load violation can be calculated for each vehicle class and axle type using Equations 15 and 16, respectively. As mentioned previously, if both violations exist, taxation for only the greater of the two will apply. For example, consider a semitrailer S2.2 carrying gross overloading of 10 t. The GLVT can be estimated as follows: $L_g = 10$ t, $L_{g0} = 39$ t, $RDF_0 = 12.52$ (Table 1), UMMC = SR 0.34476×10^{-2} (Table 6), and ATL = AKT/300 = 525 km (Table 7). Substituting these values in Equation 15, GLVT = SR 84.

TABLE 5 PAVEMENT CONDITION INDEX OF SELECTED HIGHWAY SECTIONS

Highway	Section	Direction	PCI	Rating	Major Maintenance Need
Dammam-Ras Tanura	A	Northbound	85.6	Excellent	No
Dammam-Ras Tanura	B	Northbound	93.1	Excellent	No
Ras Tanura-Dammam	A	Southbound	82.7	V. Good	No
Ras Tanura-Dammam	B	Southbound	79.0	V. Good	No
Safwa-Jubail		Northbound	89.2	Excellent	No
Jubail-Safwa		Southbound	91.4	Excellent	No
Dammam-Abu Hadriyah	A	Northbound	89.4	Excellent	No
Dammam-Abu Hadriyah	B	Northbound	35.1	Poor	Yes
Abu Hadriyah-Dammam	A	Southbound	90.9	Excellent	No
Abu Hadriyah-Dammam	B	Southbound	26.0	Poor	Yes
Dammam-Riyadh		Westbound	82.5	V. Good	No
Riyadh-Dammam		Eastbound	95.1	Excellent	No
Dhahran-Abqaiq	A	Westbound	24.5	V. Poor	Yes
Dhahran-Abqaiq	B	Westbound	35.0	Poor	Yes
Abqaiq-Dhahran	A	Eastbound	43.5	Fair	Yes
Abqaiq-Dhahran	B	Eastbound	39.3	Poor	Yes

TABLE 7 ESTIMATION OF VEHICLE ANNUAL TAX CORRESPONDING TO ABU HADRIYAH-DAMMAM EXPRESSWAY

Vehicle Class	RDF_o	EPC	Annual Vol./Lane	AKT (km)	ΣEAL_i/Yr.	ΣEPC_i/Yr.	AMMT(SR)	ARMT(SR)	VAT (SR)
(1)	(2)	(3)	(4)	(5)	(6) = (2)x(4)	(7) = (3)x(4)	(8)	(9)	(10) = (8)+(9)
PC	0.00	1.0	135768	25338	0	135768	0	40	40
LT[a]	0.6263	2.5	14652	79570	9177	36630	155	317	472
BUS	3.0483	4.0	340	96725	1036	1360	913	617	1530
RB2	7.8400	3.0	14516	93440	113805	43548	2269	447	2716
RB3	6.2000	3.6	29487	100010	182819	106153	1921	574	2495
S2.2	12.5200	5.3	24740	157602	309745	131122	6113	1333	7446
S2.3	9.5000	5.3	326	157602	3097	1728	4638	1333	5971
S3.2	6.4000	6.4	105204	157602	673306	673306	3125	1610	4735
S3.3	4.6800	7.0	12212	157602	57152	85484	2285	1761	4046

[a]Light Truck

URMC = 1940/ΣCol(7) Col. (8) = UMMC. (2) . (5)

UMMC = 4183/ΣCol(6) Col. (9) = URMC . (3) . (5)

TABLE 8 TAXES BY VEHICLE CLASS

Vehicle Class	PC	LT	Bus	RB2	RB3	S2.2	S2.3	S3.2	S3.3
AMMT (SR)	0	172	1016	2525	2138	6804	5163	3478	2543
ARMT (SR)	34	273	531	384	494	1146	1146	1385	1514
VAT (SR)	34	445	1547	2909	2632	7950	6309	4863	4057

Assuming that the 10-t overloading occurs on the tandem axle group, the ALVT can be estimated as follows: L_i = 30 t, L_{i0} = 20 t, and EAL $_{i0}$ = 4.68 (Table 1). Substituting these values in Equation 16, ALVT = SR 174.0. Because the ALVT is greater than the GLVT, the load violation tax in this case is SR 174.

The suggested taxation structure is tentative because of the limited data collected (*12*). As more data are collected over a longer period of time and over other major highways, the input values will be revised to predict more realistic trends in pavement maintenance and related vehicular data.

WEIGHT CONTROL PROGRAM ENFORCEMENT AND EVALUATION

As a result of this study, 11 weight control stations and a number of automatic counting stations have been installed by MOC on major truck routes in the kingdom. The Saudi experiences with weight control programs were reported by Mufti and Al-Rashid (*13*) and are briefly summarized here. In the initial stages of enforcement, extensive efforts were made to establish contacts with major trucking agencies, seeking their cooperation for compliance with the legal load limits. Numerous difficulties were encountered in the initial stages of program enforcement. These difficulties most commonly related to the collection of penalties and to avoidance of the weighing stations by drivers. When the penalties were high, they were difficult to collect. Police assistance was invariably required either to hold the trucks and release the drivers to allow them to obtain the money, or to reduce the penalties.

Instances of weighing station avoidance were also frequent even though the station sites were carefully selected to avoid such incidents. Hence, traffic spot checks were routinely made on nearby routes, and trucks clearly avoiding the weighing stations were redirected. Due to the extent of complaints received and a fear of economic consequences on the trucking industry, a 1-year grace period was given to the truckers to allow them to comply with the legal load limits.

The effectiveness of the weight control program was evaluated on the basis of changes in the degree of overloading and percentages of overloaded trucks. Typical gross load data from the Taif weighing station during the later months of the grace period and the early months of the full weight control program were analyzed. The degree of overloading before enforcement frequently exceeded 200 percent. Five months after full enforcement, it was reduced to below 20 percent. Figure 1 shows the monthly percentage of overloaded trucks

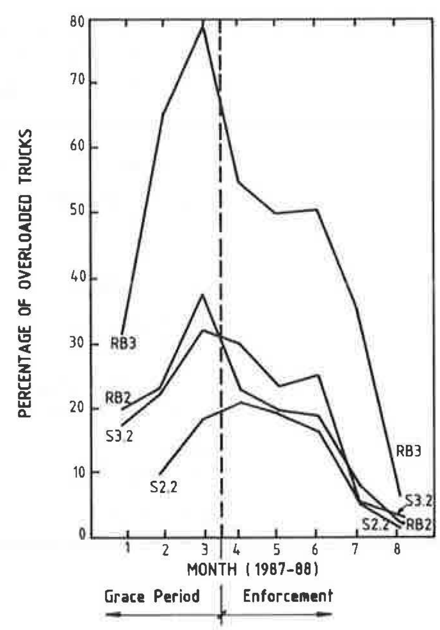

FIGURE 1 Percentage of overloaded trucks before and after enforcement.

of a given type relative to the total number of trucks of the same type passing the station during the same month. The percentages of overloaded trucks peaked at the end of the grace period and ranged from about 20 to 80 percent. These percentages declined sharply to as little as 2 to 6 percent by the end of the 5th month of the enforcement period.

SUMMARY AND CONCLUSIONS

A method of road vehicle taxation has been formulated in the Kingdom of Saudi Arabia on the basis of an economic rationale that roadway maintenance costs be equitably allocated among the vehicle classes in proportion to the damage they cause to the roads. Both major and routine maintenance costs have been considered for recovery through taxation. The input data needed for the model were generated through extensive field surveys and related to traffic volume, vehicle loads and dimensions, average daily kilometers, and pavement distress condition. The surveys were conducted at selected highways in the Eastern Province of the kingdom. Axle load and dimensional surveys revealed gross violation of the corresponding MOC limits. The proposed taxation model, which calls for higher taxes for trucks with heavier axle weights, would not only generate revenue for roadway maintenance but would also discourage use of trucks that do the most damage to the roads. As a result of this study, 11 weighing stations and a number of traffic-counting stations have been installed on major truck routes in the kingdom. Early results of the weight control program are quite encouraging. The proposed taxation structure will be revised, if necessary, as more data collected at the stations become available.

ACKNOWLEDGMENTS

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Collecting Overdue Municipal Vehicle License Fees: A Case Study

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One solution to the fiscal pressures on local governments is a more intensive effort to collect delinquent revenues. Nationally, this alternative has been underused. A case study of Elgin, Illinois, is presented to examine the potential of this approach for the sale of overdue municipal vehicle licenses. To this end, Elgin currently uses police roadblocks and two sequential collection letters; however, the noncompliance rate is over 10 percent. This noncompliance results in a loss of $200,000 to $400,000 in revenue. At current levels, roadblocks return $6 in revenue for every $1 of cost; expansion is indicated if police time can be spared. The two collection letters return $6 and $2, respectively, for every $1 of cost. It does not appear that a third mailing would be warranted. Three experiments are suggested to establish costs and revenues: sending collection letters by certified mail, making state registration records prima facie evidence that a sticker is required and using Small Claims Court, and using civilian employees to search parking lots for scofflaws.

Fiscal concerns facing local governments, fueled by political resistance to increased taxes, state-imposed tax and spending limits, reductions in aid from higher levels of government, and slow growth rates, have placed officials in a bind. Cutting back on services is unpopular; reducing waste and inefficiency is difficult. In response, many localities have turned to benefit-based taxes and user charges (*1*). The need to establish mechanisms to collect the resulting bills is incumbent.

Often overlooked for increasing revenue is a more intensive effort to collect delinquent accounts. Debt collection has tended to be a low priority in many municipalities (*2*). The lack of a prompt and aggressive system for collecting outstanding accounts results in the loss of significant amounts of potential revenue. A survey of California cities revealed that the vast majority did not have an adopted debt collection policy or formal debt collection goals (*3*). Private-sector debt collection tools and techniques are not universally used in the public sector (*2*).

The issue of the collection of accounts is explored through a case study of motor vehicle license fees in Elgin, Illinois. The city, with a population over 60,000, is located about 40 mi northwest of Chicago. The city's licensing of vehicles dates back to horse-and-buggy days. All motorized vehicles, including motorcycles, trucks, and buses, registered to an Elgin city address are required to purchase the license. In 1988 over $1 million was collected, based primarily on a $25 fee on automobiles. Senior citizens and motorcycles receive lower rates; trucks pay higher amounts. After an annual February 15 deadline, an escalating late fee is imposed.

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ENFORCEMENT

Enforcing the purchase of a vehicle license is more difficult than enforcing water bills or real estate taxes, for which service can be denied or liens placed on property for nonpayment. It is necessary to determine who is noncompliant and to choose a method of extracting payment. Elgin currently uses two approaches.

Immediately after the annual deadline, police officers set up roadblocks at key intersections in residential subdivisions during the morning rush hour. Vehicles without an Elgin sticker are stopped; if the driver's state license shows an Elgin address, a citation is issued. A bond of cash, a driver's license, or a bond card is taken to assure appearance in court. Before the citation can be cleared, proof of sticker must be shown and court costs of $28 must be paid.

A second method involves mailing collection letters to vehicle owners suspected of being noncompliant. These are derived from vehicle registration records acquired from the state, which are matched against the names of those who have already purchased stickers. Addresses not within the corporate limits of Elgin, post office boxes that could belong to persons or businesses outside the jurisdiction, and persons known to be deceased are eliminated manually. The remaining names are mailed a computer-generated notice. Later in the year, the procedure is repeated, exempting those who corrected erroneous information (e.g., the vehicle was sold or is not used) and mail returned from the first mailing (i.e., the vehicle owners no longer reside in Elgin).

A number of questions about enforcement efforts could be explored. Are the police roadblocks cost effective? Do the roadblocks show diminishing returns? Are the collection letters cost effective? Should a third collection letter be sent out? Are there other effective methods for compliance?

CURRENT LEVELS OF COMPLIANCE

The number of motor vehicles in Elgin is constantly changing due to purchases and sales of vehicles and population movements. An upper limit can be obtaining by calculating the number of stickers sold before the first followup letter and adding the number of letters mailed. State information on registration lags the current situation but provides the basis of the mailing. This measure suggests 52,000 vehicles. This number would have to be decreased by the number of returned letters and the phone calls correcting the state records (both of which are compiled and total 6,000) and increased by the number of vehicles added in the community (which is not known). A lower limit of 46,000 vehicles is possible.

On the basis of the total number of stickers sold in 1988 (41,700), the noncompliance rate is in the range of 10 to 20 percent; between 4,500 and 10,300 vehicles did not have the required stickers. Decreasing the rate by 5 percent would yield over $100,000. The goal of the city manager is to achieve a 95 percent compliance rate.

COSTS AND REVENUES OF ROADBLOCKS

In 1988 the Elgin Police Department used 14 roadblocks to enforce compliance between February 16 and April 15. This frequency is a typical yearly number. The activities take place between the hours of 7 and 9 a.m., which is a relatively quiet time for the police. The evening rush hour is not used because manpower is necessary for more pressing enforcement activities during that period. Roadblock decisions are based on personnel availability; days when scheduling makes the number of available officers higher than normal are candidates.

The choice of location is based on a number of considerations: (*a*) areas with suspected high rates of noncompliance according to computer printouts from the Finance Department, (*b*) areas generating reasonable volumes of local residential traffic, and (*c*) complaints from residents regarding noncompliance in the neighborhood. Through streets are not used due to the resulting traffic disruption and the higher number of non-Elgin residents that would be present. Although officers do not count the properly licensed vehicles that pass by, it is likely that they see a higher percentage of noncompliants than indicated by the overall city rate because of the way locations are selected.

Determining revenue attributable to this method is difficult because sales of stickers resulting from citations are not noted as such. However, because a citation requires bond to be posted, it can be assumed that each will result in $48.50 in revenue (the average cost of a late-purchased sticker plus $10 of the court cost, which is rebated to the city).

This amount is apt to understate the revenue that actually results from this method. Elgin police report that some vehicles see the barricade and turn around before reaching it. Although such motorists may be trying to avoid a traffic delay, others may realize that the police are checking for stickers and wish to avoid a citation. The latter group may be motivated to then purchase the license.

A list of the number of citations issued at each roadblock is presented in Table 1. On the basis of the 159 citations issued, revenues approximated $7,700.

Costs were based on labor expended and a portion of vehicle costs. The deputy chief of police for operations estimated that blockades lasted 1 hr, with two or three officers and two or three squad cars. Thus, 35 hr of both officer and car time was used. The city attorney estimated that, in the 95 percent of cases that are not contested, under 5 min for both the assistant corporation counsel (the attorney responsible for vehicle-related court appearances) and the court liaison officer is required; if contested, 10 min would be required. In addition, 3 hr of a finance clerk's time is necessary.

Applying the average of the 1988 salary ranges (including benefits) to the hours spent produced the total labor costs presented in Table 2. Hourly costs for a squad car were based on yearly budgeted amounts for vehicle purchase, fuel, and maintenance. Cars are used around the clock over a 2-year period, producing an hourly rate of $1.62 per squad. It could be argued that vehicle expenditures can be considered as overhead or fixed costs for the purposes of roadblocks and should therefore be excluded. However, their inclusion will not have a significant effect on the results.

TABLE 1 CITATIONS ISSUED FROM POLICE ROADBLOCKS IN 1988

Date	Citations
February 16	20
February 17	21
February 22	22
February 23	9
March 2	19
March 7	10
March 16	5
March 17	9
March 29	4
March 30	3
March 31	3
April 7	7
April 14	10
April 15	17
Total	159

At the intensity prevailing in 1988, the roadblocks returned almost $6 for every $1 of cost. Thus, this method appears cost effective. Whether expansion would be appropriate depends on the extent to which returns will diminish. The average costs associated with a roadblock are approximately $92. If three or more citations result, revenues will exceed costs. Given the history cited in Table 1, it would appear advantageous for Elgin to expand its roadblocks. This action would be qualified by whatever activities would have to be curtailed to obtain the additional time.

COSTS AND REVENUES OF COLLECTION LETTERS

The first collection letter was mailed in mid-June to over 14,928 owners of suspected noncompliant vehicles. In the subsequent 14 business days, 1,076 stickers were sold. Of these, 866 were attributed to the mailing on the basis of Finance Department calculations of the difference in average daily sales during the 10 business days before the mailing. A second letter was mailed in mid-September to over 10,440 owners; 287 stickers were sold in the subsequent 11 business days, of which 201 were attributed to the letter. Revenues were determined by multiplying the identified sticker sales by the average cost of a late-purchased license during the respective period ($48.50 and $56). Revenues of $42,000 were

TABLE 2 COSTS OF POLICE ROADBLOCKS

Item	Hourly Cost[a]	Total Hours	Total Cost
Police	$20.93	35	$733
Squad Car	1.62[b]	35	57
Court Officer	14.90	14	209
Finance Clerk	6.52	3	20
Ass't Corporation Counsel	19.58	14	274
Total			$1,293

[a] Based on salary range midpoints for personnel plus average benefits.

[b] Based on yearly budgeted amounts for purchase price, fuel, and maintenance, assuming two year life and full time use.

produced from the first letter and $11,000 from the second. These figures understate the revenue from the letters because some sticker sales resulting from the letters occurred after the 2-week followup period.

Roadblocks were not set up during the followup periods for the collection notices. Only sticker citations issued to motorists who were stopped for another offense were included in the followup period; this situation occurred more or less uniformly throughout the year. Thus, the revenue streams from each method are fairly distinct.

The costs of the collection letters were estimated by the Finance Department. For the first letter, the state computer tape of vehicle licenses was provided free of charge by a nearby municipality; otherwise it would have cost $500. The cost of the tape for the second mailing was incurred. Also included were the cost of computer time, letters, envelopes, postage, and personnel time. These amounts are presented in Table 3.

According to the data, the first letter resulted in a return of almost $6 for each $1 of expense. (If the computer tape had to be purchased, the return would be slightly lower.) The second letter returned about $2 for each $1 of expense. Another way of examining the effectiveness of the letters is to compute the percentage of stickers sold as a percentage of

TABLE 3 COSTS OF COLLECTION LETTERS

Item	First Letter	Second Letter
Computer Tape	*	$500
Computer Time[a]	$400	400
Letters and Envelopes[b]	452	317
Postage[c]	2,551	1,809
Personnel[d]	3,854	2,348
Total	$7,257	$5,374

Note: 14,928 copies of the first letter were sent to 12,148 addresses. 10,400 copies of the second letter were sent to 8,557 addresses.

[a] Calculated at $40/hour

[b] Calculated at $.01784 per letter and $.0153 per envelope

[c] Presorted first class at $.21 each

[d] Primarily customer service time (permanent employees) and temporary staff; average cost about $10.50 per hour.

* The first tape was provided free by another municipality

letters mailed, which was 5.80 percent for the first notice and 1.93 percent for the second.

The revenues that could be generated by a third letter would depend on the response. After the second mailing, the subsequent sales, the returned mail, and the phone calls correcting information, about 8,200 vehicles remained noncompliant. If the sales response rate continued to decline at the same rate as between the first and second letters (67 percent), a third notice could result in a sales rate of 0.64 percent, or about 50 licenses. This amount would create revenue of about \$3,000. Expenses of labor, materials, postage, and computer time would total approximately \$3,500. Hence, a third letter would not be justified.

A related question is whether the cost of another state computer tape is justified for the second letter. The second identified 188 vehicle owners who were not in Elgin according to the first tape. Because these individuals were receiving letters for the first time, the 5.80 percent response rate was assumed, suggesting sales of 11 licenses, or about \$500 to \$600 of revenue. With the additional costs of personnel, stationery, envelopes, and postage added into the cost of the tape, expenses totaled \$580 for this group. Thus, the cost of the tape for the second mailing was not warranted. If the state were to provide the tape for free, or if it could be obtained from another municipality, it would be worthwhile.

A similar concern is the method used to mail the notices. Currently, they are sent by first-class mail. Another possibility would be to send the letters by certified mail, which currently cost \$0.85 and requires a signature for delivery. For an additional \$0.90, a signed receipt is returned to the sender upon delivery. There are several benefits to this method that might outweigh the costs. For example, the letter receives special attention by the recipient. In addition, the notice cannot be accepted by a new resident after the intended recipient has moved. This procedure would allow more accurate updating of the list of suspected noncompliant owners, particularly if a more aggressive letter and court threat (described in the following section) were used. A test of this option is recommended to establish costs and revenues.

OTHER OPTIONS

One alternative would be to strengthen the collection letters by making the state registration records prima facie evidence that a sticker is required. Persons who did not respond to the letter would then be scheduled for a hearing in Small Claims Court. If a judgment were placed against the violator, the city could facilitate payment by placing a lien on property, garnishing wages, or using a Denver Boot. This strategy has been used successfully in Oakland, California (*4*), and Newark, New Jersey (*5*).

This alternative would require additional time by city staff and the court. After two collection notices in 1988, over 8,000 vehicles were suspected of being noncompliant. A stronger letter with a court threat would likely reduce this number. For example, the proposed letter is similar to one currently sent to parking-ticket scofflaws. It appears that over 50 percent of these cases settle with the city before reaching court. If the same results occurred with vehicle stickers, 4,000 vehicles would remain noncompliant. Further analysis of costs, along with the availability and cooperation of the court, would be necessary to determine if this option is cost effective. A small-scale experiment to determine the feasibility of this option is recommended.

A second alternative would be to search for noncompliant vehicles in parking lots within the city. The search could be conducted by police (as is done in one nearby municipality) or by other personnel. A printout of suspected vehicles or a hand-held computer terminal could be used for checking purposes. A nonscientific experiment suggested that this option may have merit. Vehicles in a parking lot next to City Hall were compared with a list of noncompliant vehicles. In 30 min, 180 vehicles were compared. Three suspected noncompliants were discovered, which compares favorably with the success rate of current police roadblocks. The search could be conducted by one person, without using sworn officers or squad cars. This employee could also carry a list of parking- and traffic-ticket scofflaws. However, because bond is not taken, collection rates would be lower than for the roadblocks.

MEASURING EFFECTIVENESS

An interesting question is, How many licenses would be sold after the deadline without enforcement actions? This number appears to be significant and could lower the number of noncompliants that any enforcement measure could reach. For example, in the 2 weeks before the first collection letter was mailed, license sales averaged 15 per business day. Some of these would be attributable to new residents or vehicles. In the 2 weeks before the second letter was mailed, daily sales averaged 8.

To address this question, Table 4 presents monthly vehicle license sales in 1988 and the timing of enforcement activities. Data obtained for 1989 had similar patterns. More intensive

TABLE 4 SALES OF VEHICLE STICKERS AND COLLECTION ACTIONS BY MONTH IN 1988

Period	Sales	Collection Actions
Pre-deadline	32,596[a]	
Feb. 16-29	1,430[a]	Police Roadblocks
March	1,540	Police Roadblocks
April	902	Police Roadblocks (to 4/15)
May	709	
June	1,521	Collection Letter
July	777	
August	539	
September	764	Collection Letter
October	579	
November	329	
December	15	New Stickers on Sale
Total	41,701	

[a] Estimated

analysis of the period from February 16 to March 31 indicates that between 70 and 80 percent of sales are to noncompliants; the remainder are to new residents or new vehicles. Sales are greatest on Fridays. Those months in which specific enforcement activities were undertaken show a surge in sales. Other months show lower sales levels.

Unfortunately, the underlying nonenforcement sales rate cannot be determined because of the possible carryover effects of previous enforcement efforts. Although the bulk of police roadblock activity had ended more than 2 months before the first letter was mailed, the halo effect may have extended well beyond that period. Similarly, a halo from the first letter may have extended over the 3-month period before the second letter was sent.

As previously discussed, the attribution of revenue to roadblocks was based on citations issued and, for collection letters, on increments to the previous sales rate. These amounts are not diminished by whatever stream of delinquent sales were independent of enforcement efforts. Nevertheless, it would be useful if a way to link delinquent responders to the reason they purchased their license could be constructed. This would provide a more accurate measure of program revenues.

CONCLUSIONS AND RECOMMENDATIONS

In a time of fiscal pressure, tax increases and service cutbacks may not be desirable or politically feasible. More intensive collection efforts of existing municipal bills could be an answer. The current methods used by Elgin to secure overdue vehicle license fees—roadblocks and letters—are both cost effective. It appears that more roadblocks would be warranted, if additional officer time is available. Although both collection letters are profitable, a third mailing would not be. Individual aspects of or proposed modifications in programs can be analyzed by costs and revenues. For example, if municipalities can share state registration computer tapes, it would be worthwhile to apply an updated tape to each mailing. If not, only the cost of the first tape for the first letter would be justified.

Three other possibilities are suggested and could be tested for feasibility. First, the method of mailing collection letters should be analyzed. Second, use of the courts in conjunction with the letters should be considered. Finally, the use of civilian employees to search parking lots for scofflaws appears promising.

Appropriate collection efforts will depend on the tax or charge involved, the legal and political options available, and an analysis of the costs and benefits. It is urged that municipalities make the efforts to apply this framework to their individual situations.

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Parking Tax in Washington State

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The Washington State Legislature recently passed legislation that increased funding for transportation purposes. The new law allowed for several local option taxes, including a commercial parking tax. The objectives of this measure were not only to help local jurisdictions raise revenues, but also to provide them with a transportation demand management tool. The Washington State Transportation Center will conduct an evaluation of the new law. The research approach is outlined, including a description of the new legislation, the potential impacts of its implementation, and a process that will be used to evaluate the effectiveness of various alternatives. Because no jurisdiction in Washington has adopted a parking tax based on the legislation, it is premature to conduct an evaluation of its transportation demand management effects. The new law has characteristics that make it different from those enacted in other localities. First, the law is flexible enough to give local jurisdictions freedom to decide on the type of tax to impose and how to impose it. Second, the new law allows local jurisdictions to apply the tax to all parking, even if it is supplied with a lease of nonresidential space and if no fee is charged for the use of the parking spaces. A third distinctive element of the tax is flexibility in charging the tax for different types of use. A fourth unique aspect of the law is that the revenue collected must be used for transportation purposes. Two important sets of legal issues concerning implementation of the parking tax are discussed. The first set is concerned with whether the tax is construed as a property tax or an excise tax. In Washington constitutional questions must be addressed if it is considered a property tax. The second set of issues concerns the definition of a reasonable distinction in charging differential rates.

Parking policy is a crucial element in transportation demand management. Because parking is essential at some point for virtually all automobile trips, the price of parking has a strong influence on whether people choose to make their trips by automobile. Parking is usually the most sensitive variable in modal split models. The availability and cost of parking are crucial factors in decisions of investment and residential or job location. Because of the importance of parking, any policy affecting its price is a sensitive political issue.

A parking tax is one way to influence the cost of parking. The tax can be both a revenue-generating tool and a transportation demand management device. Virtually all studies of parking price concur that transportation choices are highly dependent on the cost level, but the best way to impose a parking tax that will have the desired effect on mode choice and frequency of travel is not clear. A parking tax can certainly raise revenues, but unless it is transferred directly to the parkers and they perceive the additional cost, it is unlikely to be a useful tool in transportation demand management.

The Washington State Legislature recently passed legislation that increased funding for transportation purposes. The new law included several local option taxes. One of the alternatives provided the legal framework for a commercial parking tax. The objectives of this measure were not only to help local jurisdictions raise revenues, but also to provide them with a transportation demand management tool to alleviate increasingly heavy traffic conditions.

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In the following sections, the elements that distinguish this legislation from other existing parking taxes are examined, and research on the implementation of the legislation currently under way at the Washington State Transportation Center (TRAC), a consortium of the University of Washington, Washington State University, and the Washington State Department of Transportation, is detailed. However, because no jurisdiction in Washington has adopted a parking tax based on the legislation, it is premature to conduct an evaluation of its transportation demand management effects.

In Washington State, as elsewhere, free parking is the norm for most commuters. For instance, in King County about 80 percent of those who drive to work receive free parking (*1*). However, so-called "free" parking is free only to the parkers. Somebody pays the direct costs of the land where the cars park and its improvements. Someone also pays for the costly expense of parking lot maintenance.

In addition, free parking results in indirect costs. Its existence encourages the use of single-occupancy vehicles (SOVs), which contributes to fuel consumption and air pollution (*2*) and leads to increasing traffic congestion and greater investments in the transportation infrastructure. Shoup (*2*) summarizes the impact of free parking by stating that "free parking benefits only those who drive to work, and does even that unequally because it disproportionately rewards solo drivers."

The legislators who supported the parking tax in Washington State emphasized the transportation demand management possibilities more than the revenue-generating prospects. Those who backed the new law based their support on the impact of a parking tax on trip reduction and the promotion of mass transit and other ridesharing options. This emphasis was continued by the Washington Environmental 2010 Action Agenda, an environmental initiative unveiled by the state governor 4 months after the parking legislation passed. The initiative recommended higher parking-meter fees and new local parking taxes in an effort to wean commuters from their cars. It also encouraged the use of other financial incentives to promote carpooling and use of mass transit. The main reason for the initiative was to avoid an increase in Washington's production of carbon dioxide and other greenhouse gases (*3*).

NEW LEGISLATION IN WASHINGTON STATE

On March 14, 1990, Governor Booth Gardner of Washington State signed into law Senate Bill 6358, which approved a $1.1

billion transportation package. To finance several highway and other transportation projects, the new law included, among other elements, increases in the state fuel tax, the motor-vehicle excise tax, and the gross-weight fees paid by truckers. Section 208 of the bill, entitled "Local Option Commercial Parking Tax," authorized cities and counties of the state to impose two types of taxes on commercial parking.

The first form of the tax can be imposed on persons engaged in a commercial parking business. The tax rate can be based either on gross proceeds or on the number of stalls available for parking use. The second form of commercial parking tax applies directly to the user and is imposed on the act or privilege of parking a motor vehicle in a facility operated by a commercial parking business. This second form is available as an alternative to, rather than in addition to, the first tax.

In levying the tax, the city or county may provide that

- The tax be paid by the operator or owner of the motor vehicle;
- The tax applies to all parking for which a fee is paid, whether paid or leased, including parking supplied with a lease of nonresidential space;
- The tax is collected by the operator of the facility and remitted to the city or county;
- The tax is a fee per vehicle or is measured by the parking charge;
- The tax rate varies with the zoning or location of the facility, duration of the parking, time of entry or exit, type or use of the vehicle, or other reasonable factors, but the rates charged must be uniform for the same class or type of commercial parking business; and
- Tax-exempt carpools, vanpools with handicapped decals, or government vehicles are exempt from the tax.

The legislation included the following definitions:

> "Commercial parking business" . . . means the ownership, lease, operation, or management of a commercial parking lot in which fees are charged. "Commercial parking lot" means a covered or uncovered area with stalls for the purpose of parking motor vehicles.

The law also specified that a city may impose either tax within its incorporated boundaries and that a county may impose either tax only within its unincorporated area. Each local government may develop, by ordinance or resolution, rules for administering the tax, including provisions for reporting by commercial parking businesses, collection, and enforcement and provisions for payments of either tax to be made on a monthly, quarterly, or annual basis.

The revenues generated by the parking tax must be used for transportation purposes. The legislation defined transportation purposes as "including but not limited to the . . . operation and preservation of roads, streets, and other transportation improvements; new construction, reconstruction, and expansion of city streets, county roads, and state highways and other transportation improvements; development and implementation of public transportation and high-capacity transit improvements and programs; and planning, design, and acquisition of right of way and sites for such transportation purposes."

DISTINCTIVE CHARACTERISTICS OF THE LAW

The Washington State parking tax law has characteristics that make it different from similar legislation enacted in other localities. First, the law is flexible enough to give cities and counties the freedom to decide on the type of tax to impose and how to impose it. For instance, cities and counties can decide whether to charge the persons engaged in a commercial parking business or charge for the act or privilege of parking a motor vehicle. Also, the tax may be levied as a fee per vehicle or be proportional to the parking charge. The rate may vary with the zoning or location of the facility. The flexibility given local jurisdictions in how and where to impose the tax improves its transportation demand management potential.

Second, the new law allows cities and counties to apply the tax to all parking, even if it is supplied with a lease of nonresidential space and if no fee is charged to individuals for the use of the parking spaces. This option provides jurisdictions with a unique and powerful transportation demand management tool because it will enable them to charge a tax for the privilege of parking even when employers provide free parking to their employees.

A third distinctive element of the tax is flexibility in charging the tax for different types of use. Because cities and counties may provide that the tax rate vary with the duration of the parking, the time of entry and exit, and the type of use of the vehicle, the tax can be used to discourage SOVs and to reduce congestion. Local jurisdictions are able to confine charges to long-term parking and thus confine the impact to those who commute alone to work. This ability is complemented by the provision of the law that allows cities and counties to exempt carpools and vanpools from the tax, thus providing local jurisdictions with a unique transportation demand management tool. In addition, limiting the charges only to commuting uses lessens the resistance to such a tax from the business community.

A fourth unique aspect of the law is that the revenue collected cannot be deposited in the general fund, as it is in other jurisdictions. The law specifies that the revenue can be used only for transportation purposes.

Table 1 presents a comparative description of parking taxes already in existence or that have been considered in U.S. cities. In all cases, except Montgomery County, Maryland, the taxes have been basically a surcharge on fees collected for parking. This method of taxing has not allowed jurisdictions to have an impact on free parking. In addition, taxes have been collected regardless of duration, time of day, or vehicle use. This practice has limited the jurisdictions' ability to take advantage of the transportation demand management potential of a parking tax.

LEGAL ISSUES

Two important sets of legal issues need to be considered in implementing a parking tax under the new legislation. One is somewhat unique to the state of Washington. According to the Washington State Constitution, property taxes must be applied uniformly to all property, regardless of use. Thus, whether the parking tax is construed as a property tax or an

TABLE 1 PARKING TAXES ADMINISTERED IN OTHER PARTS OF THE COUNTRY

City/ County/ State	Status	Type/Rate	Collection	Exemption	Required Records	Auditing	Penalties, Fines
Baltimore	Ord. 318/ 89 Council Bill 551	City tax $.40/day or less, $2.75/week, $11.00/month.	By the operator together with the charges for parking. Remitted monthly to the Department of Finance	Residential Parking (meters not mentioned)	Of all motor vehicles parked on hourly, daily, weekly, monthly or other basis + amount of tax collected from all transactions.	By Director of Finance or other city representatives or employees.	Tax due + interest (1%/month) + penalty (10% of tax due).
Chicago	Municipal Code	$.90/vehicle/ day $4.50/vehicle/ week $18/vehicle/ month	By the operator together with the parking charge. Remitted to the Dept. of Revenue on a quarterly basis.	Residential parking	Of all vehicles parked. Copies of receipts.	By Dept. of Revenue.	$50 - $300 first offense. $50 - $500 second & subsequent offenses. For more than three offenses, incarceration is possible.
Los Angeles	Projected Approved	City tax 10% of the parking fee	By the operator together with the parking fee. Remitted to the City Clerk on a quarterly basis.	Parking meters. Residential parking (if there is any charge)	All records necessary to determine the amount of the tax.	By City Clerk.	Tax due + interest (%) + penalty (%).
Montgomery Co.	Vetoed	Excise tax $60/parking space/year	Tax return to be filed by operator. Tax due and payable on a yearly basis (February).	Parking meters. Park & Ride lots. Lots not commercial parking, business. Small lots owned by businesses that pay parking tax. Lots operated by municipal, state, and/or federal government. Reduction if TDM measures implemented.	Registration forms (with Director of Finance). No other requirement.	No procedure provided.	Tax due + interest (1%/month) + penalty (5%/month or fraction up to 25% of tax).
New York	Ord. 846 New York City (+ State since 6/1/90)	Sales tax 18 1/4% (State) + 6% (City) of parking charge	By the vendor together with the charge. Remitted to Tax Commission	Residential parking. Parking meters.	Of all occupancies & all amounts and taxes paid.	By Tax Commission or duly authorized agent or employee.	Tax due + interest (1%/month) + penalty (5% of amount due)
Pittsburgh	Ord. 52-19	City tax 25% of consideration/ transaction	By the operator. Remitted to the Treasurer on a monthly basis.	Residential Parking (Meters not mentioned).	Of completion of all parking transactions reflecting total amount of fee + total amount of tax.	By Treasurer or his designated agents.	Tax due + penalty (5%/month or fraction up to 50% of the tax).
San Francisco	Mun. Code Part III/ Art. 9, Ord. 286/70	City and county tax 20% of the rent	By the operator together with the rent. Remitted to the Tax Collector on a quarterly basis.	Parking meters. Residences or hotels. Armed forces. Cars owned by banks or insurance companies. Government Consular cars under certain circumstances.	As required by the Tax Collector.	Of records and equipment by the Tax Collector or any person authorized by him.	Tax due + interest (1%/month or fraction) + penalty (10% of the amount due). [+ penalty for fraud or interest to evade (25% of the amount due)]
Washington, D.C.	D.C. Code Chapter 20 M. R. Title 9, Sec. 400	Sales tax 12% of gross receipts from the charge	By the vendor together with the charge for parking. Remitted to the Collector on a yearly basis.	Residential parking (meters not mentioned). Parking sales to public institutions under certain circumstances.	Of all transactions, even tax-free sales.	By the Mayor or his duly authorized representatives.	Tax due + interest (1 1/2%/month or fraction) + penalty (5% for each month due up to 25%) [+ penalty for fraud: 75% of tax due + 50% of interest due + 20% if understatement].

excise tax is important. If it is an excise tax, the law remains secure. However, if it is a property tax, the parking tax would not withstand constitutional scrutiny because it taxes one type of property (i.e., that used for parking) differently from other types of property. The second set of issues concerns the definition of a reasonable distinction in charging differential rates.

Property Versus Excise Tax

Even though some case law suggests otherwise, the strongest evidence is that the newly enacted commercial parking tax can be construed as an excise tax, if it is properly designed. The legislature clearly intended that the tax be an excise tax; the law includes language imposing a tax on the transaction of leasing commercial parking or using property for that purpose or for the privilege of operating a commercial parking business, rather than on property used for parking. However, legislative intent is not legally sufficient to guarantee that the tax will be construed as an excise tax.

A tax is an excise tax if it is imposed on the use or transfer of property rather than on the property itself. Disregard for the legal implications in the definition of, or administration of, the tax may lead to legal difficulties. For instance, if the tax rate is determined by the value of the property, it may be construed as a property tax. Because legal challenges to the tax are inevitable, it is important that care be exercised in defining the parking tax.

In the case of a tax imposed on the owner or operator, there is some concern that such a tax could be construed as a property tax. Some case law maintains that a tax on rents from real estate is a tax on the real estate itself. However, more recent cases cast doubt on this assertion. First, a parking tax imposes an excise on the use of property as opposed to a tax on the property itself. Second, a parking tax can be distinguished from a tax on rental income. Rental of property implies the exclusive right of continuous possession. Parking is more in the nature of a license to use real estate, which is subject to a business and occupation tax. The legality of that kind of tax has been tested in court.

In the case of the tax imposed on consumers, a user fee imposed on the consumer either as a flat per-car tax or on the basis of some percentage of the parking fee is different in character from a tax measured by the owner's revenues and imposed on the owner. The consumer's interest is far enough removed from the real property to be considered a rental income case. Also, a tax on the consumer is more clearly a use or privilege tax than a property tax (J. Reich, letter to R. Posthuma, Municipality of Metropolitan Seattle, June 19, 1990).

Reasonable Classifications in Structuring the Parking Tax

If a parking tax were to be used for transportation demand management purposes, it would be most efficient if a higher rate were charged in places where the most congestion occurred. Legally, geography could be used as a basis for classification, as long as the classification furthered either a regulatory purpose or a revenue-producing result. The market rate for parking might be used as a basis for charging differently in different areas, because the market rate would likely be correlated with congestion. However, the distinction of the parking tax from a property tax might be compromised. Other means, such as direct measures of congestion, would be preferable.

The classification could be based on duration of parking in order to target commuter parking. After all, long-term parking is used primarily by those who travel in the peak commuting hours. Therefore, charging by duration would be related to the regulatory basis of the law.

If the parking tax rate could be based on the degree to which parking were subsidized, the tax would provide a multiplier effect in transportation demand management because it would discourage the provision of free or subsidized parking. However, such a distinction might violate the uniformity provision required by the equal protection clause. Such a classification would also be difficult to administer. Despite these impediments to classifying parking tax rates according to degree of subsidization, such avenues will be thoroughly explored because of the high potential for effective transportation demand management through such a tool.

PARKING TAX EVALUATION

The Washington State Transportation Center is conducting several research projects related to transportation demand management. One of the goals of the research program is to evaluate a variety of parking policies that have potential for managing transportation demand. In the research described in the following paragraphs, the emphasis is on implementation of the commuter parking tax that is now available to local jurisdictions as a result of the new law.

To accomplish the goals of this research, several objectives have to be achieved, including the following:

- Provision of a detailed interpretation of the new legislation;
- Development of a set of alternative parking policies;
- Analysis of the administrative efficiency of each alternative;
- Estimation of potential revenue yield from each alternative involving a parking tax;
- Assessment of the attitudes of commuters, employers, and parking lot owners to each alternative; and
- Estimation of the potential vehicle trip reduction achievable through each alternative.

The research project has been organized into the following tasks.

Development of Background Information

The first step in the process will be to compile information on the effectiveness of existing parking policies. This step will be achieved through the collection and review of recent literature and communication with representatives of jurisdictions in which commercial parking taxes already exist. The research team will also contact jurisdictions that have included parking policies as part of transportation ordinances.

Detailed Interpretation of Parking Tax Legislation

Several questions concerning the intent and the legal interpretation of the legislation need to be answered. The implications of the different types of tax that can be imposed, the interpretation of several definitions provided by the law, and the responsibilities of owners and lessees when the parking space is leased need to be clarified. A law firm specializing in public finance will be included on the research team.

Alternatives Generation

The legislation gives great latitude to local jurisdictions in the way they may implement the parking tax. In addition to the options outlined previously, the project will also investigate the possibility of graduating the tax according to the degree to which parking is subsidized, the density or traffic congestion, or the availability of high-occupancy vehicle (HOV) options.

Administrative issues are also important. The parking tax may be collected through existing taxing or fee-collecting structures, or a new structure may be established. Enforcement of the parking tax may be based on extensive auditing and monitoring or on self-report, backed up by stiff fines for underreporting.

The revenues may be used for any transportation purpose. Thus, it is important to consider alternative uses as part of the alternative-generating process.

A large number of parking tax alternatives can be generated from these options. A project review team composed of representatives from local jurisdictions, transit agencies, chambers of commerce, and commercial parking businesses will review and endorse the list of options to be considered.

Criteria Development

Evaluation criteria will include revenue generation, mode shift and trip reduction, minimization of tax avoidance, minimization of spillover effects, maximization of public acceptability, and applicability to all types of jurisdictions. The project review team will approve the list of criteria used in the evaluation.

Parking Tax Administrative Analysis

The potential methods for collecting a parking tax will be evaluated through in-depth interviews with tax collection personnel from Washington State, King County, and the city of Seattle, and with experts of public finance and the legal aspects of tax collection. The results of the interviews will be used as a basis for the evaluation of several administrative alternatives for the collection of a parking tax.

Parking Inventory

A parking inventory will be required to estimate the potential yield from the parking alternatives and to evaluate the potential for mode shifts and trip reduction. The number of parking places will be estimated and classified according to such categories as commuter versus other type of parking, parking cost, extent of subsidization, geographical location, leased versus nonleased space, and ownership.

Parking will be estimated using three approaches:

1. Use of existing transportation data such as work and school trips by transportation analysis zones, average parking price, and parking inventories that have already been conducted;
2. Use of existing parking revenue records of parking places for which a fee or a sales tax is collected (state revenue records will provide information on location, ownership, and parking price for some types of parking places); and
3. Survey sampling of randomly selected geographic areas and the creation of complete inventories within those areas with the collaboration of the local jurisdictions.

Using these three estimates of the number of parking spaces and their characteristics will be determined for most urbanized areas in the Puget Sound region.

Modal Shift and Trip Reduction Analysis

Any policy that reduces parking availability or raises parking cost will reduce the demand for parking. This reduced demand may translate into shifts from SOVs to other models or to fewer person-trips. The modal shift response is the most likely for commuter trips. For this research, modal shift will be estimated from models currently under development at the Washington State Transportation Center. These models account for psychological and other noneconomic factors, as well as the traditional time and cost factors. They are also based on extensive analysis of data collected in the Puget Sound region over the past 2 years.

Analysis of Revenue Yield

An analysis will be conducted using estimates of parking spaces to project yield for each of the parking tax alternatives. In addition, the analysis will take into account the estimated changes in travel behavior. Yield will be estimated for a wide range of taxing levels.

Public Opinion Assessment

Public opinion will be assessed by contacting commuters, employers, building operators, and parking lot owners. The acceptability of parking policy alternatives will be analyzed, and information will be gathered to predict reactions to various parking policies. Public opinion assessment will be performed through a combination of focus groups and surveys. Focus groups will be the primary method used to obtain information from employers and parking lot owners. In addition, some focus groups of commuters will be formed to develop issues for further study in surveys.

Surveys will be conducted using a random selection of Puget Sound region commuters. The surveys will probably be conducted by telephone. However, other methods of administration may be considered, depending on the complexity of the instrument and budget availability. The results of the focus groups and surveys will be analyzed to evaluate the parking policy alternatives.

Evaluation of Parking Policy Alternatives

The project review panel will conduct the final evaluation of the parking policy alternatives at the end of the project. Information will be provided to the panel as it becomes available. The list of alternatives to be analyzed and the criteria for analysis will be reviewed by the panel in an early meeting. The panel will also meet during the project to review the legal interpretation of the parking tax legislation and the analysis of administrative options.

Formal and informal meetings will be held, aided by audiovisuals, to present the outcome of the research to policy makers, representatives of local jurisdictions, and other groups interested in the issue. These individuals will be able to use the additional information when making decisions that relate the parking tax to other new transportation revenue sources. The project will also yield a better understanding of the potential for using a parking tax as a demand management tool and as a way to influence parking policy.

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Price Effects of Road and Other Impact Fees on Urban Land

ARTHUR C. NELSON, JANE H. LILLYDAHL, JAMES E. FRANK, AND JAMES C. NICHOLAS

Urban land prices rise rather than fall in response to imposition of development impact fees due to one of two reasons. First, impact fees imply a contract for development that is worth more as a package than no fees and uncertain development. Impact fees are actually the final stage of a policy process that anticipates development pressures through a land use and facility planning scheme. In return for paying fees, developers are assured of adequate facilities. Impact fees thus enable the urban land market to internalize otherwise unpriced development externalities such as greater certainty in approval, extension of needed facilities, and reduced political opposition because developers are paying their own way. Second, if impact fee policy is part and parcel of an overall growth restriction effort, development production will fall in the near term because of higher construction costs represented by the fees. In the near term, developers either find ways to reduce development costs, perhaps through greater land use intensity or lower quality, or they take fewer profits. To avoid lower profits in the longer term, developers leave the market only to return when the post-fee profit margins equal pre-fee levels. Those levels are attained when prices rise just enough to offset the fees. Land owners in the urban land market respond to higher development prices by raising land prices if the land-to-development price ratios remain substantially unchanged. The central hypothesis—that urban land prices will rise in response to imposition of development impact fees—was applied to evaluations of the urban land markets in Loveland, Colorado, and Sarasota County, Florida. Evidence was found that supports the hypothesis, but the reasons are not yet clear. Although additional study is needed, the findings break new ground in an understanding of how urban land markets respond to development impact fees.

In recent years, local governments have created alternative revenue sources to finance facilities needed to accommodate new development. Among those inventions are development impact fees, defined as charges imposed by local governments on new development to generate new revenue for infrastructure necessitated by such new development.

The overall policy objective of development impact fees is to shift the burden of financing new infrastructure from the overall community to the owners of land, developers, or consumers of new development. Although the burden may be shifted away from the community, there are competing claims as to which groups in the development process will actually bear the cost of those fees in the form of higher prices, lower profits, or other outcomes. It is generally conceded that, in urban land markets in which the demand for new development is relatively inelastic (for example, when home buyers are relatively unaffected by increases in housing price because of few substitutes), it is the consumers of new development who pay the impact fees (*1,2*). Under this situation, impact fees are said to be shifted forward to consumers.

If the local urban market is relatively competitive, however, conventional wisdom and tax incidence theory suggest that urban land prices must fall by an amount sufficient to offset the additional costs of construction represented by the fees. Otherwise, new development will not be able to compete with available substitutes (*3–10*).

There is some speculation that urban land markets are not as competitive as one might think. Developable land is often in limited supply; for any given type of development the number of land owners is limited and they may know one another. The land owners may hold a reservation price below which they will not sell even if land sales slow down because of impact fees (*11*). Developers will thus be stuck with the need to raise prices or reduce profits. In the near term, they may have to reduce their profits. They will rid themselves of inventory and then wait until demand rises to a point at which post-fee profits return to pre-fee levels. In the end, it will be the consumer who pays the fees through higher prices (*6*). However, the practical effect of land owners holding out until they receive their reservation price is that the present value of their price in the future may in effect be equal to the price they could have received earlier. Higher land prices may thus be a function of time and not necessarily the change in the demand structure of the local urban land market.

Although the literature suggests that in relatively competitive urban land markets the imposition of development impact fees will result in either lower urban land prices or constant prices after accounting for demand and inflationary effects, the opposite is hypothesized, that is, that impact fees will result in higher urban land prices for two reasons.

First, development impact fees are a contract for development rights that are worth more as a package than no fees and uncertain development. This concept can be viewed in several ways. The fee may represent all the facilities and services promised to be delivered by local government in exchange for its payment. The fees thus reflect the value of facilities and services promised or contracted. The fee may also reflect more certainty in land use decisions because impact fee policy is required by law to be based on sound land use and facility planning. Impact fees also comport with demands of locally vocal slow- or antigrowth interests that new

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development pay its own way. Expressed another way, the presence of an impact fee policy may result in the urban land market internalizing these or perhaps other otherwise unpriced development externalities.

The second explanation involves the possibility that fees not only result in higher house prices but higher land values as well. This possibility has been theorized in terms of the optimal timing of development in a competitive housing market. For example, expanding on theories by Shoup (*12*), it might be argued that the optimal time for housing development occurs when the ratio of house construction cost to the market price of the housing, including land, equals the ratio of the interest rate on capital less the rate at which rents increase over time to the interest rate on capital, as follows:

$$P(K)/P(T) = (i - r)/i \tag{1}$$

where

P = price of capital,
K = amount of capital needed to build the house on a single lot,
$P(T)$ = value of the house with land when built at time T,
i = interest rate on capital, and
r = rate at which rents or house values are increasing.

The developer should wait until the interest saved by postponing development one period, $iP(K)$, equals the rent foregone, $(i - r)[P(T)]$. The price of the finished house is determined by the demand for housing, which in turn is assumed to increase continuously, causing values to rise at a constant rate (r).

Using this foundation, the effect of impact fees on the timing of development can be considered. Impact fees (IF) are added to the cost of house construction. The time of development may change to T^* with the resulting price of housing $[P(T^*)]$. $P(T^*)$ can be directly compared with the price of housing without the fee $[P(T)]$, which is analogous to Shoup's (*12*) analysis of the effect of taxes on the optimal time of development. In particular, when

$$[P(K) + \mathrm{IF}]/P(T^*) = (i - r)/i \tag{2}$$

then

$$P(T^*) = [iP(K) + i\mathrm{IF}]/(i - r) \quad \text{or}$$

$$P(T^*) = P(T) + [i\mathrm{IF}/(i - r)] \tag{3}$$

where

$$i/(i - r) > 1$$

The impact fee will therefore delay the time of home construction until the house price rises to $P(T^*)$, which is analogous to Wicksell's (*13*) optimal time of timber harvesting. In effect, the impact fee will delay construction until prices rise by an amount that offsets the interest charge on the impact fee. When applied to a growing urban area, the increase in housing prices will result in higher land prices. The effect of the impact fee is therefore to delay home construction to the point at which the fee is offset by higher house construction and land purchase price. It is possible that the impact fee policy is used in part as a growth-restricting device. As such, the practical outcome will be the same: land prices will rise when housing production is delayed to a later time when greater prices can be realized.

Unfortunately, there is virtually no empirical research concerning the price effects of impact fees in the urban land market. The principal aim here is to help overcome this void.

LOVELAND AND SARASOTA IMPACT FEE PROGRAMS

The city of Loveland, Colorado, and Sarasota County, Florida, provide reasonably good case studies for evaluating the price effects of development impact fees.

Loveland has a nationally recognized development impact fee program that has been in place since 1983. The city does not impose artificial limits on the supply of buildable urban land. Rather, supply is expanded as warranted by demand provided there are revenues available to extend necessary facilities. Those revenues are provided in part by development impact fees. Furthermore, considering the sluggish economy and housing market for the Front Range cities of Colorado since the early 1980s, there is little concern for the effects of unusual demands placed on existing supplies of buildable land.

Impact fees on new single-family houses in Loveland during the time of this evaluation (1981 through 1986) totaled $1,537 ($736 for parks, $98 for fire facilities, $24 for police facilities, $121 for libraries, $58 for museums, $271 for general government facilities, and $229 for streets). Loveland's cost recovery system won the American Planning Association's innovative planning program award for 1986. Many communities across the nation have recently copied and implemented Loveland's approach.

Sarasota County also has a nationally recognized development impact fee program, which was instituted in 1983. The county imposes limits on the supply of buildable urban land west of US-41, which demarcates the area of high-value homes found along the Gulf of Mexico. East of that highway, however, supply is expanded as warranted by demand (*14*).

In 1983 the county commissioners adopted an impact fee ordinance that divided the county into three subareas: (a) north municipal service taxing units (MSTUs), (b) south MSTUs, and (c) areas east of the MSTUs. Within the MSTUs, new development would be assessed differential levels of impact fees; the other areas were exempt from the impact fees during the study period. In both the north and south MSTUs, impact fees are assessed separately for parks and roads. In the north MSTU, the park impact fee is $80 per equivalent dwelling unit (EDU), which is defined as the average dwelling unit. The road impact fee is $826 per equivalent trip generation unit (ETGU), defined as 10 trips per day from an average single-family home. For the average dwelling unit, the total north MSTU impact fee is $906. In the south MSTU, the park impact fee is $124 per EDU and $575 per ETGU for roads, or a total of $699 per average dwelling unit.

EMPIRICAL RESULTS

Through support from the Urban Land Institute and with the cooperation of the Georgia Institute of Technology, Florida

State University, University of Florida, and University of Colorado, price effects of development impact fees on urban land in Loveland and Sarasota County were evaluated. In this section the model and methodology are reviewed. In the next section the findings are summarized.

The following model was used to test the central hypothesis that impact fees result in higher land prices in a relatively competitive urban land market:

$$P_i = b_0 + b_i\text{FEE}_i + \text{E}b_j\text{C}_{ij} + u_i \qquad (4)$$

where

- P_i = market price per acre or foot of transacted Parcel i;
- FEE_i = estimated fee that would be paid by a developer of Parcel i assuming that development would take place simultaneously with the land purchase;
- EB_jC_{ij} = a vector of j variables characterizing each Parcel i, including those variables reviewed in the following section; and
- u_i = stochastic disturbance.

It is thus hypothesized that $d\text{FEE}/dP > 0$.

Loveland

The land sales data for Loveland come from records collected by the Larimer County assessor's office. Sales records are updated continuously and coded by land class (residential, industrial, commercial, etc.), land use (vacant, built, etc.), and whether the transaction was arms length. Those files are typically used to calculate ratios or indexes for the purpose of adjusting property tax rolls by market trends. Specifically, the land data used for estimating the model consist of arms-length sales of vacant, buildable land within the city of Loveland, at least 1 acre in size, zoned for residential development, and transacted between July 1, 1981, and June 30, 1987. Buildable land includes those parcels that had full urban services (i.e., water, sewer, and roads) available to within 300 ft of the property at the time of sale.

Data on 33 arms-length transactions were collected for the study period and constituted the universe of qualifying transactions. The final independent variable selection was thus limited by degrees-of-freedom restrictions. The sample size is not unreasonable, although more cases would have been preferred.

The dependent variable was specified as the price per acre of land at the time of sale. The independent variables included (a) parcel size in acres to account for plattage value effects, (b) desirable view opportunities from the site (according to a windshield survey of all tracts), (c) a dummy variable for low-density neighborhoods, (d) the distance to the nearest freeway interchange (a proxy for centrality effects—Loveland has no single central core for retail and commercial activity, but it is within commuting range of shopping and employment centers in and around Fort Collins and Denver), (e) a continuous time variable representing the month and year of transaction, and (f) the amount of the impact fee per average-sized lot that would have been paid upon development if development occurred at the time of sale.

Table 1 summarizes the empirical results for the Loveland case study. In general, the regression results are consistent with traditional demand studies of land prices. Approximately 71 percent of the variation in price per acre is explained by the model. In addition, number of acres, view, and density are all statistically significant variables and have the expected signs. The demand variable, population, has the expected positive sign but is statistically insignificant. The negative, but insignificant, coefficient on the time variable suggests that, holding other factors constant, the price of land fell over this sample period. Given that there was a regional protracted slowdown in the construction industry during the study period, this finding is not surprising.

The independent variable of primary interest is the impact fee variable. Although impact fees have a statistically insignificant, positive effect on the price of land, the results are consistent with expectations. They are also consistent with findings offered by Singell and Lillydahl (*15*); that is, the entire impact fee was shifted forward onto home buyers in Loveland. Singell and Lillydahl found that prices not only of new homes but also of existing homes were affected significantly by the fee. In addition, they concluded that the quantity of housing, lot size, and other housing characteristics may also be affected by the fees.

Sarasota County

The data for Sarasota County come from land sales records collected by county tax assessment offices as reported to the Florida Department of Revenue, supplemented by data collected in the field. According to officials of the Department of Revenue, Sarasota County's recorded data are of high quality. Sales records are kept by fiscal year and coded by land class (residential, industrial, commercial, etc.), land use (vacant, built, etc.), instrument used in sale (cash, contract, trust deed, etc.), and relationship of seller to buyer (relative, closely held corporation, arms length, etc.). The files are typically used to calculate an index for the purpose of automatically adjusting property tax rolls by market trends. Cases

TABLE 1 REGRESSION RESULTS FOR LOVELAND, COLORADO

Independent Variables	B Coefficient	Beta	T-Value
Impact Fee	12.3	.31	.81
Acres per Parcel	-2983.1	-.56	-4.60
Good View	28,183.0	.46	3.30
Density	-28,367.0	-.46	-3.30
Distance	201.6	.04	.30
Population	10,743.0	.74	1.00
Time	-537.0	-.45	-.60

R^2 = 0.71

Adjusted R^2 = 0.63

n = 33

identified for the study were arms-length transactions of vacant, buildable land sold between July 1, 1981, and June 30, 1987, zoned for single-family residential development, located outside city limits, capable of being subdivided into four or more residential home sites, and that had full urban services available to within 300 ft at the time of sale according to city engineering and planning records and officials.

The total data set included more than 80,000 records of sales during the study period. After screening cases for only arms-length transactions of buildable parcels, a subset of approximately 850 cases was created that also met the general definition of buildable land. These cases were reduced to about 275 after removing large acreage subdivision lots that cannot be further divided. The pool was reduced further to 155 and then to 68 after eliminating parcels that could not be subdivided into four or more lots (the proxy for candidate parcel sales to builders). Thus, out of more than 80,000 total records, only 68 cases met the criteria of arms-length transactions of vacant, buildable land sufficiently attractive to developers.

However, 24 of those cases were zoned for agricultural densities—one unit per 5 acres minimum lot size. Those cases were eliminated because county plans indicated that zone changes to a range of urban densities were likely in the agricultural areas where these parcels were found. Another 4 cases were outliers, believed to be caused by honest errors either in assessor records or in the interpretation of them. The final universe of qualifying transactions was 40.

Sixteen independent variables or their log values were used in the final regression equations. The dependent variable was sales price per potential home site of a transacted parcel (LGPUNIT). This definition was selected because it was known that developers buy urban land not because of size but because of the potential number of developable home sites. (Unlike Loveland, where zoning restricted all parcels to similar density, zoning density throughout Sarasota County is variable.)

The independent variables included area of potential home sites in acres (LGUNITSZ); property tax rate (LGTAX); census tract income in 1980 (LGINCOME); number of residential units in a half section (LGDENS); distance to downtown Sarasota, Venice, the nearest Interstate exchange, the nearest regional shopping center, and the beach in 1,000-ft units (LGDSARA, LGDVEN, LGDXCH, LGDSHOP, and LGDBEACH, respectively); presence of a road in front of the parcel (ROAD); presence of sewer within 300 ft (SEWER); the month in which the parcel was transacted during the period, from 1 for July 1981 to 84 for June 1987 (LGTIME); change in county population in the year previous to sale as an indicator of demand (LGPOPCH); location inside an incorporated city (CITY); the impact fee per potential home site (LGUNITFE); and location inside the north or south MSTU (NMSTU and SMSTU, respectively).

There is little evidence of multicollinearity as there are no collinearities involving important variables above 0.70. Similarly, the plot of estimated values compared with residual values indicated no systematic bias in the residuals, suggesting that heteroscedasticity is not a problem.

Table 2 presents the regression results for the Sarasota County case study. Table 3 presents the same regression except substituting location in north and south MSTU for the

TABLE 2 REGRESSION RESULTS FOR SARASOTA COUNTY, FLORIDA

Independent Variables	B Coefficient	Beta	T-Value
Constant	0.716	0.000	0.081
LGUNITSZ	1.112	0.800	8.424
LGTAX	0.587	0.066	0.684
LGINCOME	1.203	0.151	1.278
LGDENS	-0.047	-0.129	-0.833
LGDSARA	-0.581	-0.409	-2.515
LGDVEN	0.038	0.037	0.145
LGDXCH	-0.227	-0.150	-0.970
LGDSHOP	-0.094	-0.039	-0.553
LGDBEACH	-0.483	-0.399	-1.572
ROAD	-0.093	-0.036	-0.507
SEWER	0.354	0.171	1.808
LGTIME	-0.111	-0.095	-1.106
LGPOPCH	-0.002	-0.001	-0.011
CITY	-0.270	-0.117	-1.009
LGUNITFEE	0.023	0.215	2.196

R^2 = 0.934

Adjusted R^2 = 0.892

n = 40

TABLE 3 REGRESSION RESULTS FOR SARASOTA COUNTY, FLORIDA: SUBSTITUTING LOCATION IN NMSTU AND SMSTU FOR IMPACT FEE

Independent Variables	B Coefficient	Beta	T-Value
Constant	-0.815	0.000	-0.087
LGUNITSZ	1.103	0.794	8.118
LGTAX	0.560	0.063	0.639
LGINCOME	1.318	0.165	1.327
LGDENS	-0.035	-0.097	-0.555
LGDSARA	-0.541	-0.381	-2.147
LGDVEN	-0.004	-0.004	-0.014
LGDXCH	-0.222	-0.147	-0.932
LGDSHOP	0.175	-0.042	-0.594
LGDBEACH	-0.462	-0.382	-1.461
ROAD	-0.071	-0.028	-0.368
SEWER	0.350	0.169	1.752
LGTIME	-0.113	-0.096	-1.102
LGPOPCH	0.004	0.001	0.016
CITY	-0.193	-0.083	-0.594
NMSTU	0.587	0.206	2.060
SMSTU	0.432	0.206	2.060

R^2 = 0.934

Adjusted R^2 = 0.888

n = 40

impact fee. Table 4 presents the results for only those 29 cases in which impact fees would be assessed when developed, that is, on parcels sold since 1983. (The impact fee was effected in October 1983. However, the imminence of impact fees and their approximate magnitude were well known throughout 1983. It was thus assumed that buyers of buildable land knew about the impact fee throughout the entirety of 1983 and purchased land accordingly. The unreported results for cases only occurring after 1983 were consistent with the reported findings.) Table 5 presents the same regression on the 29 cases except substituting location in NMSTU and SMSTU for the impact fee. Results are consistent with each other. The evidence is reasonably compelling of the positive price effect of impact fees on urban land values.

In Table 2, four variables are significant at the 0.10 level of the two-tailed t-test. They are unit size, distance from Sarasota, presence of sewer lines within ¼ mi, and the impact fee. Distance to beach is significant for a one-tailed test. All explanatory variables possess expected signs and reasonable magnitudes of coefficients.

The impact fee coefficient suggests that a 1 percent increase (or decrease) in the fee is associated with a 0.023 percent increase (or decrease) in value per home site. Because the mean home-site value is $14,396 and the mean impact fee per home site is $410, a 1 percent change in the fee of $4.10 is statistically associated with a $3.31 change in value per home site. This finding would imply that 81 percent of the fee is being internalized in land value.

TABLE 4 REGRESSION RESULTS FOR SARASOTA COUNTY, FLORIDA: FOR ONLY 29 CASES IN WHICH IMPACT FEES WOULD BE ASSESSED WHEN DEVELOPED

Independent Variables	B Coefficient	Beta	T-Value
Constant	-8.279	0.000	-0.996
LGUNITSZ	1.289	0.901	10.252
LGTAX	-0.136	-0.013	-0.158
LGINCOME	2.136	0.310	2.294
LGDENS	-0.229	-0.283	-2.268
LGDSARA	-0.735	-0.514	-2.979
LGDVEN	-0.470	-0.320	-1.456
LGDXCH	0.550	0.414	1.610
LGDSHOP	-0.137	-0.041	-0.563
LGDBEACH	0.181	0.138	0.549
ROAD	-0.207	-0.096	-1.016
SEWER	0.249	0.124	1.469
LGTIME	0.129	0.103	1.127
LGPOPCH	0.096	0.032	0.468
LGUNITFEE	0.018	0.163	1.936

$R^2 = 0.956$

Adjusted $R^2 = 0.912$

n = 29

TABLE 5 REGRESSION RESULTS FOR SARASOTA COUNTY, FLORIDA: FOR SAME 29 CASES, SUBSTITUTING LOCATION IN NMSTU AND SMSTU FOR IMPACT FEE

Independent Variables	B Coefficient	Beta	T-Value
Constant	-5.181	0.000	-0.429
LGUNITSZ	1.288	0.900	9.931
LGTAX	-0.112	-0.010	-0.126
LGINCOME	1.853	0.269	1.539
LGDENS	-0.241	-0.297	-2.221
LGDSARA	-1.023	-0.716	-1.311
LGDVEN	-0.036	-0.024	-0.031
LGDXCH	0.394	0.297	0.743
LGDSHOP	-0.175	-0.053	-0.649
LGDBEACH	0.127	0.097	0.347
ROAD	-0.245	-0.113	-1.058
SEWER	0.310	0.155	1.325
LGTIME	0.106	0.085	0.809
LGPOPCH	0.105	0.035	0.492
NMSTU	-0.711	-0.290	-0.259
SMSTU	0.375	0.199	1.906

$R^2 = 0.956$

Adjusted $R^2 = 0.906$

n = 29

In Table 3, distinction is made only in location of parcels and not in impact fees paid. Variables that are statistically significant at the 0.10 level include unit size, distance to Sarasota, presence of sewer, and location within the SMSTU. Variables that are significant using the one-tailed test are income of the census tract and location within the NMSTU. All statistically significant variables possess expected signs. Positive coefficients on MSTUs suggest that parcels in urbanizing, unincorporated Sarasota County command higher prices. Reasons include the availability of easily developable parcels relative to cities, where in-fill can be costly, and in rural areas, where urban services are not available. No direct impact fee interpretations should be inferred.

Table 4 presents the results for those 29 cases for which impact fees have been assessed since 1983. Variables that are statistically significant include unit size, income of census tract, neighborhood density, distance to Sarasota, and impact fee. Distance to nearest Interstate highway interchange is significant using the one-tailed test. All significant variables possess the expected signs. Interestingly, the coefficient on impact fee is not much different in Table 4 than in Table 2.

For Table 5, significant coefficients include home-site size, income of the census tract, neighborhood density, distance to Sarasota, distance to Venice, distance to the nearest Interstate interchange, distance to nearest shopping center, and presence of sewer systems within ¼ mi. The SMSTU coefficient is also significant and positive. All possess expected signs and have reasonable magnitudes.

POLICY IMPLICATIONS

In review, there are two reasons for positive price effects. These reasons are discussed in more detail in this section, focusing on some interesting policy implications and on the need for further research.

The payment of impact fees essentially establishes a contract between the fee payer and the local government (*16*). In return for the fee, the county promises to deliver public facilities and services more or less on demand, even if they are not present at the time the fee is paid. This exchange is a fundamental tenet of the impact fee law. (This connection between impact fee collection and service provision may have to be modified as Florida implements its statutorily required concurrency management.) The developer may give greater value to land on which impact fees will ultimately be paid because there is the expectation that facilities will be made available in exchange for the fee. Positive price effects thus reflect expectations of developability.

But it is the seller who reaps the windfall. In effect, the seller may believe that, because the property will have access to facilities upon payment of a fee (by someone else), the expectation of those facilities is worth an increment.

The possibility that properties on which impact fees would be paid could receive development permits faster than properties without such fees was investigated. If this could be demonstrated with reliability, it is possible that the impact fee serves as a proxy in part for time savings in seeking development approval. The owner of the land perceives that impact fee payments expedite the development-permitting process, which results in time savings and windfall profits to developers, which are then capitalized value in land (*17*). Informal analysis with local officials in Sarasota was inconclusive, however. No reliable figures exist on the extent to which development approvals were processed any faster than before after fees were imposed in the north and south MSTUs or whether permits are processed faster inside MSTUs than outside.

Another explanation for positive price effects is related to how impact fees may affect the shifting of the housing market. One effect of impact fees on markets in which buyers are relatively insensitive to price changes is to shift the fee forward to those buyers. Even when markets are relatively competitive, imperfections in the land market can result in impact fees being passed forward. Moreover, in Sarasota County the payment of the impact fee could be delayed until issuance of the certificate of occupancy, thereby sheltering all participants in the development process from payment of the fee until the sale of the home. (This option was changed in 1989 to require payment of impact fees no later than the issuance of the building permit. The fee is paid at the building permit stage in Loveland.) If the effect of impact fees is to cause an increase in house price or a reduction in house quality, then the fee would not be incurred by the seller of land but instead by the final consumer. If the fee results in a higher house price, then naturally builder markup is affected in proportion to the increase. Because land-to-house-price ratios remain relatively constant in any given housing market, a markup of housing price would be associated with a markup in land value. Unless sellers of land capitalize this benefit, developers and builders receive a windfall. Thus, positive price effects of the impact fee in the land market is the consequence of forward-shifted impact fees. The explanation is also related to theory on the optimal timing of house construction. Because the fee is a one-time payment made at the time of construction, a possible effect of the fee is a reduction in the rate of return realized by a developer or builder. The rate of return is restored only when construction is delayed to a time when values are higher and post-fee ratios are restored to their pre-fee levels.

Of course, positive price effects of the fee can be—and probably are—a combination of all these factors. More research is needed to properly attribute price effects and to assess the manner in which the actors in the development process shift or share the fee. Research should be undertaken in relatively competitive urban land markets so that the interactions between land owner and land developer, between land developer and builder, and between builder and consumer can be evaluated. Consideration might also be given to the timing of fee payment and the resulting interactions among the actors in shifting and sharing the fee. The present study is but a small step, but it lays the foundation for future work.

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Multimodal Financial Planning from a Regional Perspective: A Guide for Decision Making

CRAIG H. SCOTT

The San Diego Association of Governments (SANDAG) is a regional planning agency responsible for preparing the long-range Regional Transportation Plan (RTP) and related financial plans for the San Diego region. As in many other rapidly growing areas, transportation revenues from traditional sources have not matched the growing need for new and expanded transportation facilities and services to keep pace with growing travel demands. SANDAG has used the long-range planning process to develop the RTP as the mechanism for identifying funding shortfalls and recommending actions to obtain the revenues needed to implement the projects and programs recommended in the plan. An outgrowth of this process was SANDAG's successful establishment of a ½ percent transportation sales tax program. SANDAG is continuing to address remaining funding shortfalls by analyzing the potential implementation of a regional development impact fee program to fund major regional transportation capital projects.

The long-range planning for all modes of transportation in the San Diego region is performed by the San Diego Association of Governments (SANDAG). SANDAG was formed in 1966 through a joint powers agreement (JPA) to serve as the council of governments for a variety of regional planning activities. SANDAG's Board of Directors consists of an elected official from each of the 18 cities and the County Board of Supervisors, as well as nonvoting representatives from the California Department of Transportation (Caltrans), the U.S. Department of Defense, and Tijuana-Baja California Norte, Mexico. SANDAG is a multipurpose agency involved in a wide range of activities in addition to transportation planning, including land use and growth management planning, population and economic forecasting, and criminal justice monitoring.

Transportation planning represents one of SANDAG's most significant areas of responsibility. SANDAG is the recognized Metropolitan Planning Organization (MPO) from the federal perspective and the Regional Transportation Planning Agency (RTPA) from the state perspective. With these designations comes SANDAG's responsibilities for preparing and updating the long-range Regional Transportation Plan (RTP) and approving the Regional Transportation Improvement Program (RTIP). SANDAG also serves as the San Diego County Regional Transportation Commission, which administers the region's ½ percent transportation sales tax program. Through these various roles and responsibilities, SANDAG programs and administers over $500 million annually in federal, state, and local transportation revenues.

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RTP OVERVIEW

In September 1990 the SANDAG Board of Directors accepted the draft 1990 RTP (*1*), with adoption of the final RTP scheduled for December 1990. This RTP represents the most recent update of the original RTP approved in 1975. The RTP is updated every other year on the basis of state legislative requirements.

The RTP is the long-range plan for all major transportation projects and programs in the San Diego region over the next 20 years. It addresses all forms or modes of transportation. The facilities and programs recommended in the RTP are designed to meet the estimated increases in travel demand.

The San Diego region is growing rapidly. The 1990 RTP was based on projections of a 38 percent increase in population by 2010, a 47 percent increase in dwelling units, and a 60 percent increase in daily vehicle miles traveled (VMT). To address this rapid increase in travel demand, the RTP recommends a variety of highway, transit, bicycle, and local street and road facility improvements, as well as programs to more effectively manage both the existing transportation facilities and the level of travel demand placed on them. The financial element of the RTP identifies the total costs of implementing the recommended facility improvements, as well as the costs of operating and maintaining the regional transportation system over the 20-year period. These costs are then compared with the revenues expected to be available over the same period. The 1990 RTP financial element identifies the costs and revenues for three major areas—highways, transit, and local streets and roads—as presented in Table 1 and summarized in Figure 1.

When the need for additional revenues is identified, as is certainly the case in the 1990 RTP, the financial element recommends actions to be undertaken by SANDAG and other agencies to secure the needed revenues. The process used by SANDAG in developing the RTP financial element is described in the following sections. Examples of the actions taken by SANDAG and others to obtain increased transportation revenues are provided.

DEVELOPING THE FINANCIAL ELEMENT

Because the RTP is a long-range planning and policy document, there is no requirement that the financial element be

TABLE 1 MAJOR TRANSPORTATION FACILITY COSTS AND REVENUES, FY 1991–2010 (IN MILLIONS OF CONSTANT 1990 DOLLARS)

	Costs	Revenues	Shortfall
Highways	$5,230	$3,355	$1,875
Transit	$5,935	$4,710	$1,225
Local Streets & Roads	$4,610	$2,795	$1,815
Total	$15,775	$10,860	$4,915

balanced. For this reason, an interactive process, with projects being eliminated to balance costs with available revenues, is not followed. The projects and services are recommended in the RTP to achieve regional mobility objectives, with the related costs of these projects and services being taken as a given for the financial element. With such an approach, the development of the financial element is basically the last piece of the RTP and is based on the results and recommendations of the other elements of the RTP. As the recommendations for facility and service improvements are finalized for the highway element (which includes local streets and roads), the transit element, and other key elements of the RTP, these recommendations and the related costs are used as input for the financial element update. The preparation of the financial element is broken down into three major steps: identifying costs, forecasting available revenues, and developing recommended policies and actions for implementation.

Identifying Costs

Because the RTP is a long-range document that is updated every other year, many of the projects included in the previous RTP are carried forward and become part of the updated RTP recommendations. For these projects, the costs are escalated to the new base year dollars (constant dollars) and refined to reflect any changes in project scope or revised cost estimates. For new projects, the most recent cost estimate from the implementing agency is used.

In developing the cost estimates for the highway projects, SANDAG works closely with Caltrans to obtain the best available cost estimates. Through the Caltrans system planning process, route concept plans are developed for each state highway route. These plans identify recommended improvements and provide input to the RTP process. Caltrans also prepares annual cost estimate updates for the major highway improvements. For the financial element, highway cost information is available on an annual basis from the RTIP and the State Transportation Improvement Program (STIP) for the first 5 years of the long-range plan on the basis of construction schedules developed by Caltrans. The rest of the projects are grouped into two categories: (a) those that are planned to be implemented by the year 2000 and (b) those to be implemented by 2010. Maintenance costs are included in the financial element on the basis of projected increases from actual maintenance expenditures in FY 1990. Figure 2 shows the highway program costs and revenues.

A local street and road needs survey of the 18 cities and the county of San Diego has been used as the basis for the financial element update. The survey identified maintenance needs, rehabilitation and reconstruction needs, and new construction needs for the first 10 years. Average annual expenditure levels were used to project local street and road costs for the next 10 years to 2010. The RTP includes only public agency costs for the local street and road improvements. The costs of local street improvements built by private developers either directly or through local impact fee programs are not included. The local street and road costs and revenues are shown in Figure 3.

SANDAG works closely with the Metropolitan Transit Development Board (MTDB) and the North County Transit District (NCTD) in updating the costs of the recommended transit improvements. As with the highway program, the annual costs for the transit projects in the first 5 years of the plan are obtained from the RTIP on the basis of schedules developed by the transit operators. In addition, the operators' 5-year short-range transit plans provide input to the RTP both for capital projects as well as for service improvements. For projects beyond the first 5 years, annual capital costs are projected on the basis of assumed implementation schedules developed by the operators and aggregated to the same time periods as described for the highway projects. Annual operating costs are projected using the FY 1990 actual cost per mile, with service levels increasing to achieve RTP objectives

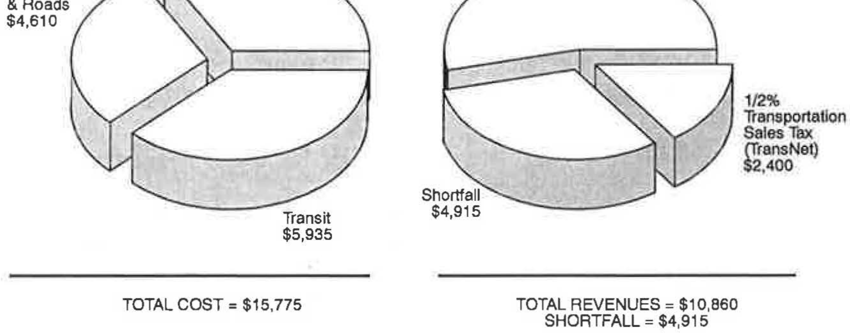

FIGURE 1 Highway and transit program 20-year costs and revenues, FY 1991–2010 (in millions of constant 1990 dollars).

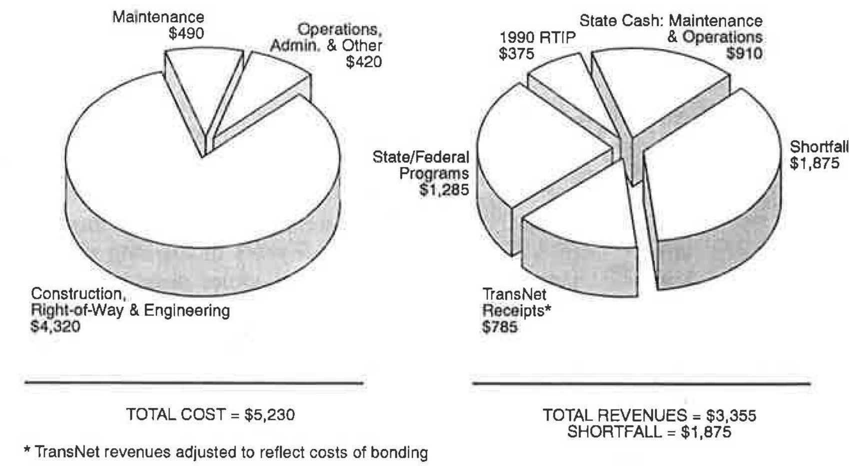

FIGURE 2 State highway program 20-year costs and revenues, FY 1991–2010 (in millions of constant 1990 dollars).

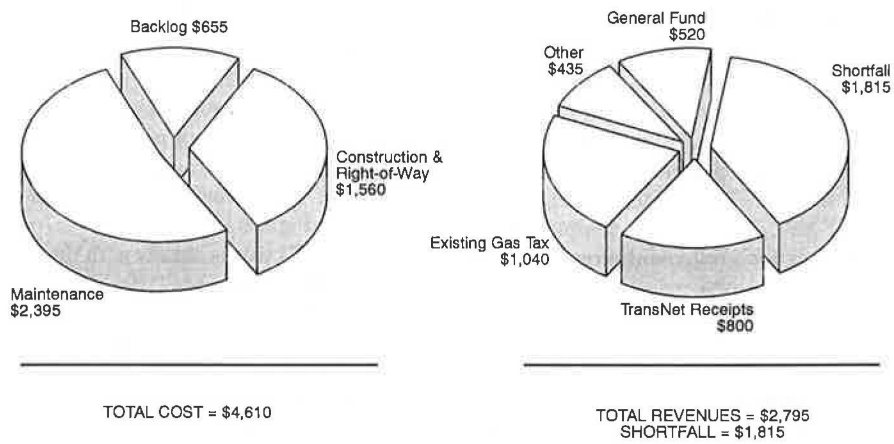

FIGURE 3 Public streets and roads program 20-year costs and revenues, FY 1991–2010 (in millions of constant 1990 dollars).

for increasing transit ridership levels. The transit project costs are generally updated each year with the annual short-range transit plan updates. Figure 4 shows the transit program costs and revenues.

Forecasting Available Revenues

In the past SANDAG has developed alternative scenarios with low (pessimistic), medium, and high (optimistic) funding levels as part of the financial element. In the most recent RTP updates, a single relatively conservative set of assumptions has been used to forecast revenues. In general, existing revenue sources with continuing legislative authority have been assumed to continue. New revenue sources requiring some future action by the legislature or by the electorate have not been assumed to be available, but rather have been included among the actions recommended to reduce the identified shortfalls. Like the cost estimates, the revenue forecasts are also updated and adjusted to a consistent base year in constant dollars. For revenue sources such as the gas tax that do not keep pace with inflation, this process involves deescalating the revenue stream to reflect the declining buying power of that revenue source.

The forecasting of certain revenues involves a substantial amount of educated guesswork. The high degree of uncertainty surrounding the future levels and direction of transportation funding at the federal level, and until recently at the state level as well, has made long-range financial planning a difficult task. Trying to predict what state and federal policies for transportation funding will be like next year is difficult enough, let alone trying to predict what policies will be in place in 2010. The general approach taken in recent RTP updates has been to stay on the pessimistic side for expectations of increases in state and federal transportation funding—an assumption that unfortunately has proven fairly accurate through the past decade. Following this approach, the assumptions in the financial element for the major state and federal formula funding programs for highway and transit were based on a continuation of recent trends, with no significant increases in the gas tax or other major sources assumed in the near future.

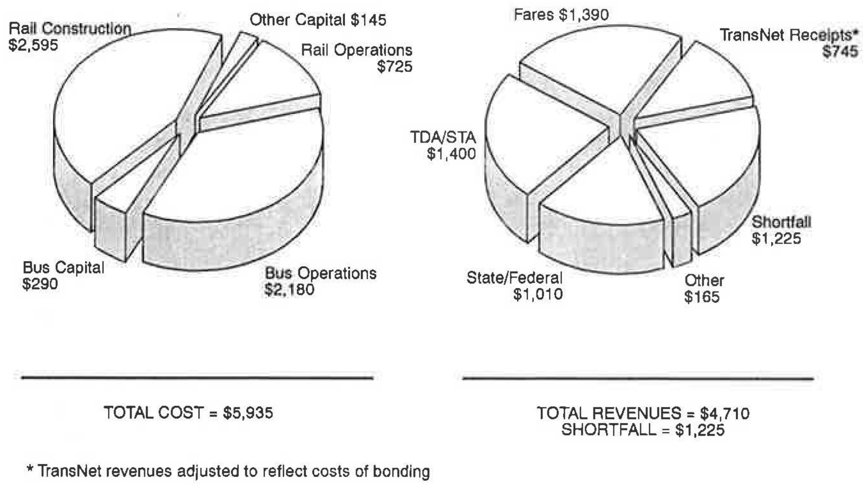

FIGURE 4 Public transit program 20-year costs and revenues, FY 1991–2010 (in millions of constant 1990 dollars).

Other revenues can be forecast on a somewhat more rational basis. For example, the region has two major funding sources based on the local sales tax. The sales tax increases with population, inflation, and general growth in the economy. One of SANDAG's major areas of responsibility is the development of population forecasts. On the basis of input assumptions from local jurisdiction general plans, SANDAG develops a set of regional population forecasts for a 20-year period. These population forecasts are widely used for a variety of planning purposes by local agencies. SANDAG uses the population forecasts in its transportation modeling process to project future traffic volumes for the RTP. For sales tax forecasts, these population forecasts become one of the key inputs to SANDAG's Demographic and Economic Forecasting Model (DEFM). The DEFM is a sophisticated econometric model that produces forecasts of a number of variables, including taxable retail sales. The DEFM provides the annual growth rates used to develop the sales tax revenue forecasts, as well as other factors such as long-range Consumer Price Index (CPI) factors, which are useful in developing other portions of the financial element. Because SANDAG's population forecasts, as well as other economic forecasts produced by the DEFM, are so widely used and accepted by Caltrans, the transit operators, and the local jurisdictions, the revenue projections contained in the RTP are generally accepted as well.

Developing Recommended Policies and Actions

Once the cost and revenue estimates are developed and compared, the next phase is to develop the recommendations for the necessary policies and actions to address the remaining funding shortfalls. At SANDAG, this phase has been approached in a number of ways. Through the early 1980s, the general approach was to determine the amount of the estimated shortfall, convert that shortfall into an equivalent level of increased gas tax revenues, and recommend support for a state or federal gas tax increase of the number of cents per gallon needed to balance the plan. However, as the shortfalls continued to increase each year and significant actions at the state and federal level to raise the gas tax were not forthcoming, it became apparent that the region could not continue to depend on the state and federal governments to meet all of the region's transportation needs. The size of the funding shortfall itself also pointed out the impracticality of expecting gas tax increases alone to meet the shortfall. For example, the nearly $5 billion shortfall (1990 dollars) identified in the 1990 RTP is equivalent to a 27 cent fixed-rate gas tax increase. Although future gas tax increases will continue to be critical to maintaining the state and federal commitment to the transportation system and will continue to be recommended and pursued as part of the RTP, it is clear that a wide range of alternative funding sources will need to be pursued if the improvements recommended in the RTP are to be implemented.

The financial element of the 1984 RTP (*2*) was the first to seriously address the exploration of alternative local funding sources to augment available state and federal revenues. The 1984 RTP also identified significant shortfalls in the funds needed to implement the recommended highway, transit, and local street and road improvements. The financial element recommended actions that focused on an evaluation of all potential revenue sources. It was recommended that, if voter approval of a long-range funding source was determined to be required, activities should be initiated to prepare such a funding measure for the 1986 ballot. This recommendation led directly to SANDAG's involvement in developing a ballot measure for a ½ percent local sales tax increase, with the revenues devoted solely to transportation purposes. The following section describes the process that was used to implement this key RTP recommendation and provides an example of how actions can be taken at a regional level to support and coordinate the financing needs of numerous local implementing agencies.

IMPLEMENTING THE FINANCIAL PLAN—THE TRANSPORTATION SALES TAX MEASURE

In response to the recommendations of the 1984 RTP, as well as a series of major statewide transportation needs studies and transportation financing legislative proposals in 1984, the SANDAG Board of Directors appointed a Transportation Financing Advisory Committee (TFAC) in January 1985. The TFAC consisted of an elected official from each of the 16 cities in the region at that time and the county of San Diego, as well as resource members from the San Diego Taxpayers Association, the League of Women Voters, the Greater San Diego Chamber of Commerce, the San Diego Highway Development Association, the North County Transportation Coalition, and Caltrans. The objective of the TFAC was to review the region's transportation financing needs and to make recommendations to the SANDAG Board of Directors on actions necessary to meet the identified needs. The TFAC met from March 1985 through March 1986 in an effort to resolve the region's transportation funding problems. The approach followed by the TFAC provides a good example of SANDAG's technique of using a task force or committee to resolve a problem, as well as a step-by-step approach to implementing a new funding source.

Understanding the Problem

The TFAC began its efforts by reviewing the costs of the region's needed transportation facilities, forecasts of available revenue, and the estimated funding shortfalls that were based on the RTP. The use of the RTP as the basis for the analysis was important for the success of the overall effort. Due to the involvement of local elected officials in the development and updating of the RTP over the years, there was a general consensus on the need for the projects recommended in the RTP. In addition, SANDAG had earned a high degree of credibility in the accuracy of its forecasts of population growth, economic trends, traffic volumes, and revenue availability. Because of the general consensus on the need for the projects and the acceptance of the forecasts that showed the need for new revenues, little time was spent debating projects or questioning the need for new funding sources, allowing the effort to focus on the identification of solutions.

Confronted with a significant funding shortfall at that time of $4.6 billion (1985 dollars), the TFAC reviewed the potential of increased state and federal revenues making up the difference. After considering the major funding shortfall in the state highway program at that time, the continuing delays in the implementation of important state highway projects, the lack of successful efforts to obtain a significant increase in the gas tax for highway and local street and road projects, and the ongoing cutbacks in federal transportation funding in the federal government's effort to reduce the nation's growing budget deficit, the TFAC determined that it was unlikely that any significant portion of the region's unmet needs would be met by increased state or federal revenues. In addition, given the dramatic fluctuations in state and federal funding in recent years and the great degree of uncertainty surrounding the future of many of the traditional state and federal transportation programs, the TFAC believed that a reliable, stable, and predictable local source of funding was necessary to provide the foundation for a long-range financing program to implement the region's needed transportation improvements. A revenue source with a viable bonding option was also believed to be important to accelerate the construction of the most critical major capital projects.

Analysis of Alternative Local Funding Options

Having identified the need for a local funding source, the TFAC began to examine the viability of alternative local funding sources. A number of sources were evaluated, including a local sales tax, a local gas tax, a local payroll tax, increased developer fees and charges, benefit assessment districts, and tax increment financing. Projections were made of the revenue-generating capabilities of each funding mechanism. The legal and administrative issues related to the implementation of each funding source were evaluated, and the political feasibility of implementation was considered. Overall, the local sales tax was considered to be the most appropriate source because it had the ability to generate the level of revenues necessary to meet the region's needs and because of the ability of the sales tax to grow with inflation, population growth, and income growth. An increase in the gas tax was not favored because such a tax does not increase with inflation, causing the buying power of the tax to decline significantly over a long period of time. In addition, a gallon-based gas tax fails to keep pace with the increase in travel demand due to increasing vehicle fuel efficiency. As an illustration, to generate the same amount of revenue as a ½ percent sales tax in escalated dollars over a 20-year period, the gas tax would have to be raised by 20 cents per gallon. The other development-related revenue sources were determined to be of value as additional or incremental sources of revenue, but could not be established at levels high enough to equal the revenue-generating capabilities of the sales tax for political and economic reasons.

Obtaining Legislative Authority

As is the case with many funding options, the necessary legal authority to implement the revenue source often does not exist. For this reason, once the local sales tax was selected as the preferred option, the TFAC recommended that the SANDAG Board of Directors support a recommendation to pursue enabling legislation to allow a local sales tax measure to be placed on the ballot. A SANDAG-sponsored bill was passed by the legislature and signed by the governor in October 1985. The legislation

- Created the San Diego County Regional Transportation Commission, which would administer the sales tax revenues if the tax increase were approved by a majority of the voters;
- Designated the SANDAG Board of Directors to act as the commission and to provide staff to it;
- Authorized the commission to determine the rate (up to 1 percent), purposes, and term (if any) of the tax to be included in the ballot measure; and
- Authorized the commission to issue bonds payable from the proceeds of the tax.

Developing and Refining the Ballot Measure Proposal

With the enabling legislation in place, the TFAC worked from fall 1985 through spring 1986 to develop a recommendation for such key decisions as the amount and duration of the tax and the specific uses of the tax revenues. The TFAC focused its efforts on developing a ballot measure proposal that could be agreed to by all the local jurisdictions, could be supported by the public, and would meet a significant portion of the region's needs. The structure of the ballot measure was based on updated needs (shortfall) information for transit, highway, and local street and road improvements on the basis of the RTP, the experiences of other areas that had previously pursued local sales taxes (Los Angeles, Santa Clara, and Orange counties in California and Maricopa County in Arizona), and the results of local public opinion surveys on the sales tax concept.

On the basis of these considerations, the TFAC approved forwarding a recommendation to the SANDAG Board of Directors for a ½ percent sales tax increase for a duration of 20 years with one-third of the revenues allocated for transit improvements, one-third for local street and road improvements, and one-third for highway improvements. The allocation of revenues by mode was the most hotly debated portion of the recommendation. The availability of credible needs information for each mode was a critical factor in the final decision to allocate the revenues on a basis that approximated the relative need. This recommendation was accepted by the SANDAG Board of Directors in April 1986 for review and comment by local jurisdictions and other interested agencies and groups. After substantial input from these groups, the board approved the ballot measure proposal, as recommended by the TFAC, in May 1986. The sales tax proposal also became the major recommendation of the 1986 RTP financial element (*3*).

The sales tax measure was originally scheduled for the November 1986 ballot, as recommended in the 1984 RTP. However, the County Board of Supervisors acted to place a ½ percent sales tax for court and jail facilities on the same ballot. Fearing that having two separate sales tax measures on the same ballot would cause both to fail, the SANDAG Board of Directors decided to postpone the transportation sales tax measure to the November 1987 ballot.

The extra year provided a valuable period of time in which to obtain broad support for the measure from a variety of groups, to strengthen the consensus developing on the proposal, and to refine the specific projects and programs to be funded by the measure. By the time the measure was submitted to the voters as Proposition A on November 3, 1987, it contained a specific description of improvements to be funded with the sales tax revenues. Figure 5 shows the map that was included in the ballot materials, highlighting the major highway and transit capital projects to be funded through the local transportation sales tax program (*4*).

Implementing the New Sales Tax

Proposition A was approved by a 53.17 percent majority. The ½ percent sales tax increase became effective on April 1, 1988, and revenues first became available for allocation by SANDAG, acting as the Regional Transportation Commission, to Caltrans, MTDB, NCTD, and the local jurisdictions in July 1988. Over the first 2 years of the sales tax program, nearly $215 million was received for use on regional transportation improvements. A total of $2.25 billion (1987 dollars) is expected to be generated by the sales tax program over its 20-year life. The transportation sales tax program is the largest public works effort ever undertaken in the San Diego region.

The passage of the sales tax measure created the need for an additional financial planning effort focused specifically on the sales tax–funded projects. A finance plan for the transportation sales tax program was prepared to determine the specific cash flow needs of the sales tax projects and the extent to which debt financing would be required to keep the projects on the fastest possible implementation schedules. This plan led to SANDAG's first bond issue of $175 million in October 1989. Several additional bond issues, all backed by the local sales tax revenues, are planned through the 1990s to meet the cash flow needs of the sales tax program.

Although considerable efforts remain to be made in obtaining additional revenues from other federal, state, local, and private-sector sources to cover the remaining funding shortfalls, the implementation of this major new revenue source provides the solid local foundation recommended in the RTP as the basis for the long-range financing program.

FUTURE DIRECTIONS FOR IMPLEMENTING THE FINANCIAL PLAN

Even with the sales tax program in place, the 1990 RTP financial element identified a funding shortfall of nearly $5 billion. Obtaining the revenues to meet such a shortfall will be a challenging task. The recommended actions in the RTP include increasing state and federal gas taxes, indexing the gas tax to keep pace with inflation, increasing flexibility in the uses of state and federal revenues, and leveraging the local transportation sales tax funds to the maximum extent possible to attract additional federal, state, local, and even private-sector revenues into the region. Several recommendations focus on obtaining additional revenues from the private sector, including the formation of benefit assessment districts and the analysis of potential joint development opportunities at proposed rail stations and other major facility sites. Significant achievements in all of these areas and more will be required to provide the revenues needed to fully implement the RTP.

One potentially significant recommendation of the 1990 RTP financial element is to conduct an evaluation of the establishment of a regional-level development impact fee program to help fund highway, transit, local street and road, and other transportation improvements and programs required as a result of travel growth generated by new development. Currently, many local jurisdictions have traffic impact fees that generate revenues to mitigate the impacts of new growth by funding signal improvements and improvements to city streets in the surrounding local area. However, these fee programs have not been extended to generate funds to help mitigate the impacts of new growth on the regional transportation system. The evaluation, which is currently under way, is attempting (a) to determine the legality of establishing such a fee on a regional basis; (b) to identify the fee level needed to fund improvements to regional highways, transit, and significant regional arterials; and (c) to review potential mechanisms for collecting and administering such a fee program.

From a practical point of view, it is unlikely that a regional fee can be established at a level high enough to cover the entire RTP capital project funding shortfall because the fee

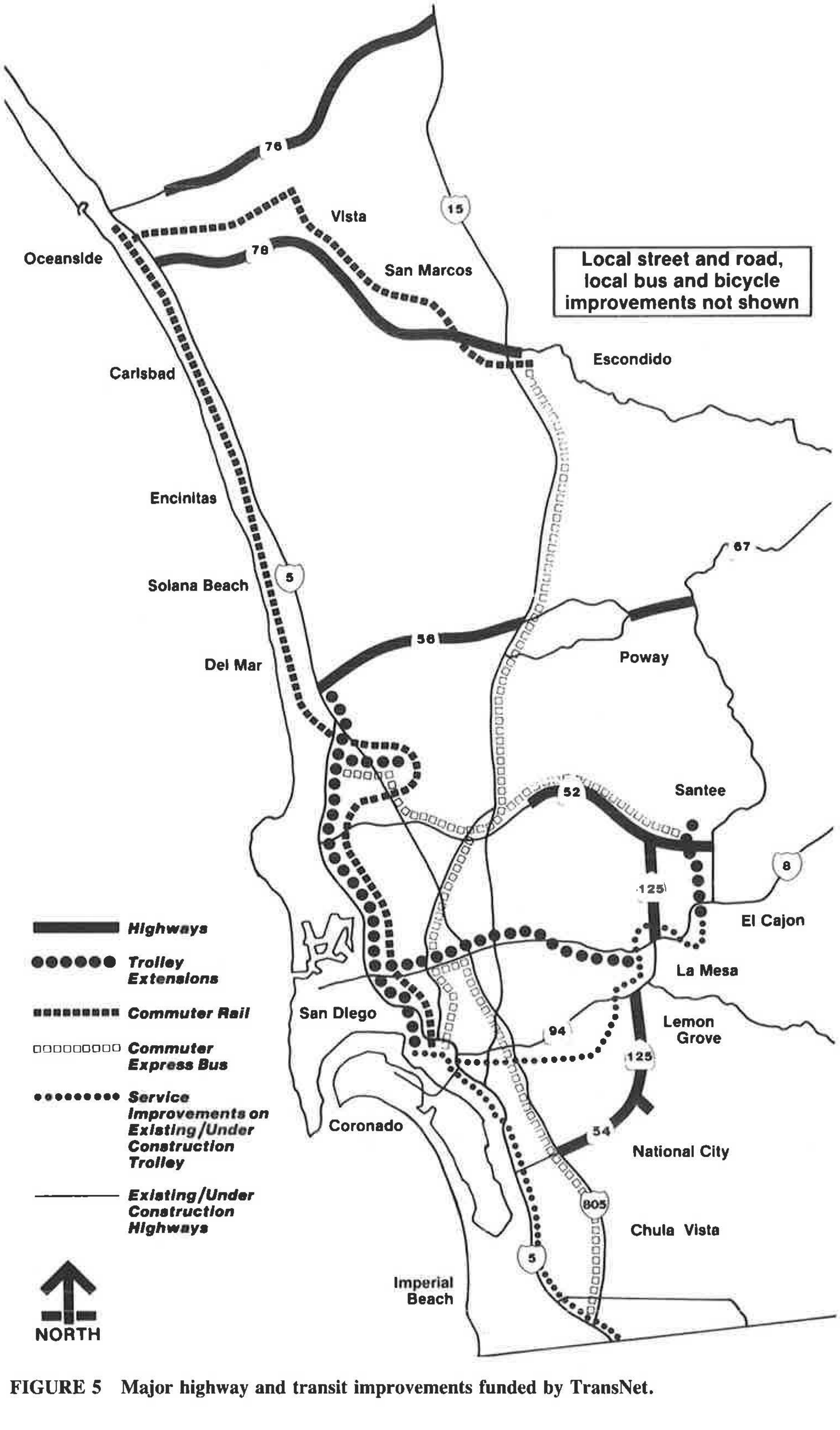

FIGURE 5 Major highway and transit improvements funded by TransNet.

would be economically and politically infeasible. However, even at a reduced level, a regional impact fee could provide another major source of local funding for transportation improvements and make up a significant portion of the remaining shortfall.

A final example of another potential future revenue source is a privately funded toll road facility. State legislation in 1989 (Assembly Bill 680) established a state privatization program that allowed private entities to develop four demonstration transportation projects within the state. The facilities will be leased to the private entities for up to 35 years, during which tolls may be charged to pay off private investment in the project (including a reasonable profit), to retire outstanding bonds, and to operate and maintain the facility. Following a competitive selection process, Caltrans selected one of the major highway projects identified in the RTP as one of the four demonstration projects statewide. The private consortium developing the project is currently negotiating a franchise agreement with Caltrans. If negotiations are successful, private financing for this project will provide another significant source of funding for implementation of the RTP. SANDAG has supported this privatization project as an alternative financing approach and will be looking for other innovative funding sources to complete the funding package for the RTP.

CONCLUSIONS

Multimodal long-range financial planning is an ongoing, dynamic process requiring multiple assumptions, which must be periodically reviewed and refined. In most cases, the number of projects proposed to keep pace with growing travel demands combined with the ever-increasing costs of project development results in total costs that exceed the revenues reasonably expected to be available, requiring consideration of actions to increase revenues or reduce costs. Regional planning agencies can play a key role in this process, not only by preparing the forecasts of costs and revenues but by becoming actively involved in seeking solutions to funding shortfalls.

It has become apparent in recent years that, although state and federal funding programs will always be major components of any long-range financial plan, they can no longer be the only components. A significant local commitment to transportation funding, both from the public and private sectors, will be needed to complete planned transportation improvements. The financial planning process must remain open to consideration of all reasonable alternative financing mechanisms to piece together a successful financial strategy.

The San Diego experience indicates that the long-range financial plan can be used as a guide for decision making on key actions to establish new revenue sources. To serve in such a capacity, the planning process must have a high degree of credibility. In the San Diego region, the RTP has been used as the basis for the long-range financial planning and related recommendations for action. Because the RTP has been in existence for over 15 years, a high degree of consensus has been established among the elected officials of the region as the plan has been reviewed, reexamined, and updated over the years. The credibility that has been established in the RTP, SANDAG's long-range forecasts, and the planning process in general has resulted in the actions recommended in the RTP being taken seriously. This process of building consensus and credibility has been a major contributing factor to SANDAG's success in establishing the local sales tax program, and in other areas as well. If these successes can carry over and lead to implementation of the regional development impact fee program and other new or expanded revenue sources, SANDAG will have made major strides toward achieving the objective of providing the revenue needed to implement the region's long-range transportation plan.

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Analysis of Corridor Traffic Peaking

WILLIAM G. ALLEN, JR.

In the past, many traffic forecasting efforts have focused on estimating 24-hr volumes, leaving the determination of design-hour volumes up to highway designers. These days, planners are becoming more involved in estimating peak-hour volumes, but the available techniques for calculating peak-hour traffic are somewhat limited. In particular, it is often assumed that the percentage of daily traffic occurring in the peak hour will not change in the future. In addition, planners sometimes forget that, for a given link, the peak-hour volume cannot exceed the link's capacity, regardless of the increase in daily volume. It is hypothesized that, as 24-hr traffic volumes continue to increase, peak-hour volumes will not increase at the same rate. In fact, future roadway capacity limitations (as well as other factors) will force drivers to modify their trip departure times, most likely so as to travel in the shoulders of the peak. Other researchers have also hypothesized this, but a literature review disclosed no practical methods for forecasting the future flattening or shifting of the peak hour on a link-specific basis in response to increased congestion. A methodology is presented for projecting such a change in temporal patterns, on the basis of research conducted in the I-80 corridor in northern New Jersey. This technique uses a modified Poisson distribution to describe the spread of 4-hr volumes across each 15-min period. Although the resulting model structure is not free of flaws, it represents a reasonable attempt to estimate future changes in peaking and will hopefully stimulate further research into this important subject.

Many efforts to predict future traffic volumes have focused on estimating the travel demand during the single peak hour. Early planning studies only provided values for 24-hr demand, leaving it up to highway designers to apply their own *K* and *D* factors to estimate peak-hour volumes by direction. More recently, planners are themselves taking on the task of estimating peak-hour traffic.

The ratio of future peak-hour volume to roadway capacity is commonly used as a key indicator of highway system performance and has always been an important part of the justification for expanding facilities. However, planners are often accused of ignoring a simple rule of transportation systems: demand cannot exceed capacity for a given time period. As a theoretical illustration of travelers' desire to use a particular facility, volume/capacity (V/C) ratios over 1 can be useful. However, design-hour volumes in excess of capacity have no basis in reality.

In the present era, in which inexorable future increases in traffic run hard up against the immovable budget limitations of many jurisdictions, the planner is still called on to provide realistic predictions of peak-hour traffic. It is theorized that, in locations where volumes are already at capacity, such volumes cannot increase on the existing roadway system. Without new capacity, increased travel demand must occur outside the peak hour, most likely in the shoulders of the peak.

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This concept has interesting implications for roadway design. If roadways are to be sized on the basis of peak-hour demand, and the peak volume does not increase but merely spreads over a longer period, why should roads be widened? Indeed, shouldn't peak spreading be encouraged, as a better use of existing facilities? Of course, this logic is circular: it is not necessary to expand roads because the peak volume will spread itself out due to congestion, which occurs because the decision not to expand the roads was made in the first place.

However, a philosophical discourse on the need for new roadways is not intended. Rather, a practical question at the heart of this dilemma is investigated: How can planners forecast the degree to which traffic growth might be served in the shoulders of the peak? A methodology for predicting this phenomenon is examined, using data from a recent study of the I-80 corridor in northern New Jersey.

STUDY OVERVIEW

Interstate 80 stretches across the entire northern part of New Jersey, from the Delaware Water Gap at the Pennsylvania line to the Hudson River at the New York line (see Figure 1). It is a major commuting and trucking route, serving both intraregional and intercity travel needs. The study reported on was concerned with the outer section of the road, from the Delaware River eastward to a point just west of I-287, in the middle of New Jersey. Due mainly to recent development patterns, traffic congestion has become as big a problem in this outer section as in the section closer to New York City. On many days, some of the most congested points along I-80 are those located 35 mi from the city.

In 1989 the New Jersey Department of Transportation (NJDOT) commissioned a study of methods that might be used to reduce congestion now and in the future, given the tremendous growth in population and employment expected to occur in the study area. Some parts of the road are currently being widened, but NJDOT anticipates that the options for reconstruction will be more restricted in the future, due to limitations in funding and available right-of-way. Thus, the study investigated alternative means of reducing vehicle trip demand, including expansion of existing bus and rail services and ways to increase high-occupancy vehicle (HOV) usage.

At the outset of the study, it was decided that a key measure of the success of these alternatives should be the degree to which they reduce the peak-hour vehicular volume at the major choke points along I-80. However, a parallel objective was to determine to what extent drivers might voluntarily shift their travel away from the peak 60 min in response to future conditions. Thus, a two-phase approach was taken to forecasting traffic volumes. The first phase is to estimate the total

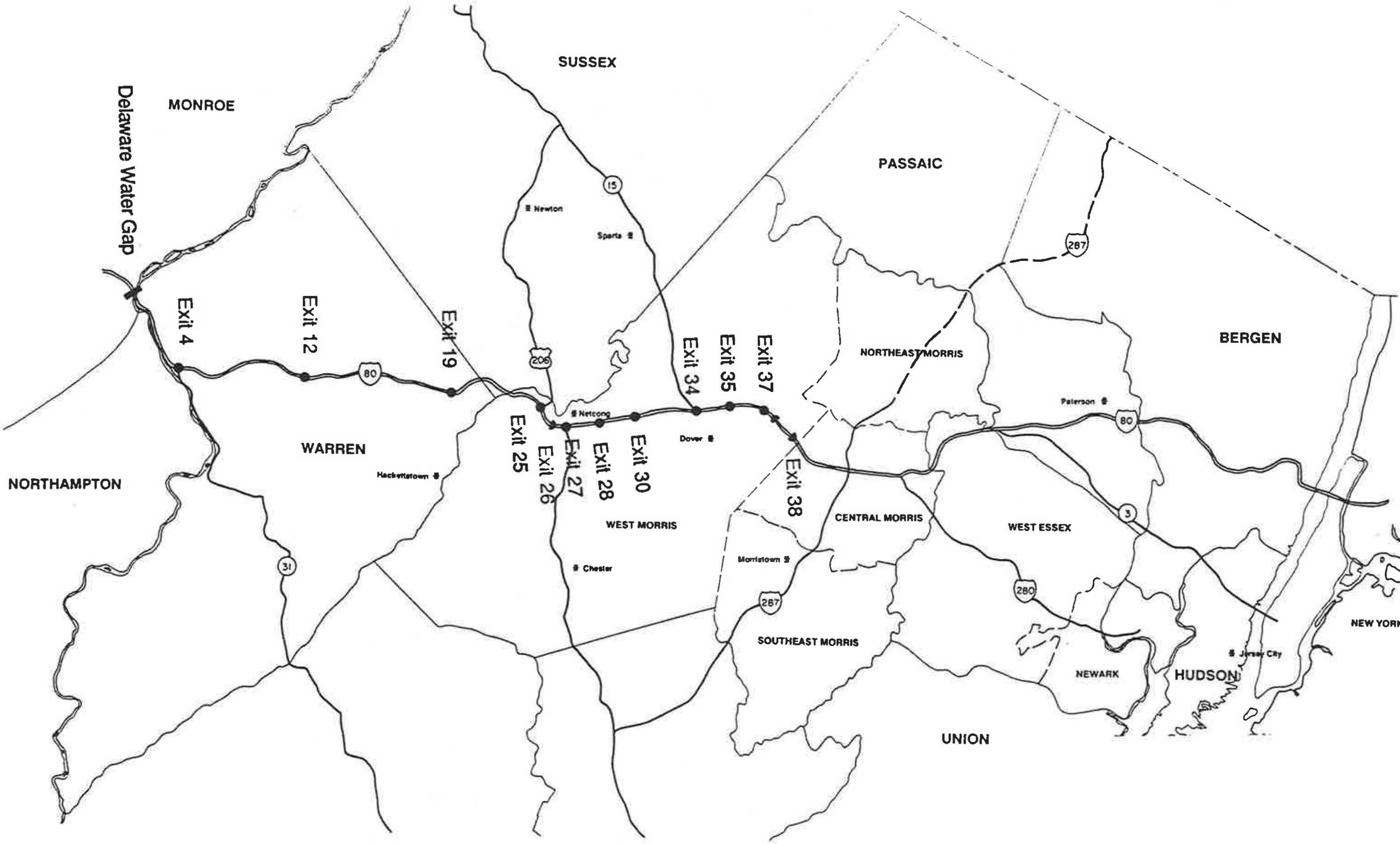

FIGURE 1 Study area.

volume from 6:00 to 10:00 a.m., which is the 4-hr period when the greatest level of traffic activity is seen in the corridor. The second phase is to estimate the highest consecutive 60-min volume during that time.

Many studies of future traffic assume that current peaking patterns will remain stable in the future. However, this study's investigators wanted to examine the premise that the future could bring noticeable changes in the temporal variation in a.m. traffic volumes. Increased peak-period congestion, changing lifestyles, and expanded use of flexible working hours might well lead to changes in peaking patterns over time. In addition, the changing development pattern along the corridor could by itself lead to a change in when the peak 60 min will occur at any given point (i.e., the rolling peak). It was thus necessary to develop a model that could be used to estimate the possible extent of the shift in peak traffic flow in the future.

To better understand corridor traffic flow and to support the development of this model, an extensive roadside survey was undertaken in the summer of 1989. Over 33,000 postage-paid postcards were distributed to all vehicles entering I-80 between 6:00 and 10:00 a.m., at all points between the Delaware Water Gap (Exit 0) and US-46 (Exit 38). Over 41 percent of these postcards were returned, providing information on trip origin, destination, purpose, vehicle occupancy, and other roadways used. Sufficient survey controls were maintained so that the time each driver entered I-80 was known by 15-min period. From this information, a data base was assembled providing trip origin and destination by 15-min period for each exit-to-exit segment along I-80. This information was then used to develop both future estimates of eastbound a.m. 4-hr traffic as well as the volume during the peak 60-min period, for each roadway link in the study area.

THEORY

It was hypothesized that highway peaking patterns in the I-80 corridor are influenced mainly by two things: the extent to which employees have flexible working hours (flex-time) and the level of traffic congestion. The extent of flex-time is a policy variable that indicates how many employees have enough variability in their work start time that they can travel to work at nonstandard times. Although this variable is intuitively important, little information is available to describe the extent of flex-time in this corridor. Moreover, it is not known if future values of this variable could be predicted on a corridorwide basis with any suitable accuracy.

The use of flex-time by employers is probably related to the type of employment, location, competition with other businesses for employees, individual employer philosophies, and other factors that are basically outside the realm of transportation planning. Thus, this variable was considered essentially unavailable for use.

Because of these and other related reasons, attention was focused on the other key factor, traffic congestion. Congestion has increased sharply in recent years in northern New Jersey and is frequently identified as a major problem in surveys of the motoring public. Thus, it was hypothesized that a prime reason individuals in the I-80 corridor vary their commuting times is to try to avoid the most congested periods. After all, even without flex-time, most employees do have the option of arriving at their jobs before their normal start time. Also, many morning nonwork travelers can delay the start of their trip until after the main peak period.

Another reason for focusing on congestion is that it is readily quantified for existing conditions and can reasonably be forecast for the target future year. These attributes make it suitable for use as a key independent variable in this model structure.

At first glance, this reasoning may seem like circular logic: peaking is dependent on congestion, which is a function of peaking. However, careful definition of the variables ensures that this situation will not be the case. At a micro level, congestion is a function of 5- or 10-min flow rates and the presence of accidents or other roadside incidents. But in the context of this study, congestion was defined in a larger sense as a function of the total traffic activity on I-80 during the 4-hr peak period. The dependent variable is the percentage of that 4-hr volume that occurs in each 15-min segment. This method is analogous to the long-standing practice among highway engineers of estimating the ratio of peak hour to average daily traffic (ADT) as a function of the ADT itself. Various ways of measuring this congestion effect were investigated.

In addition, the analysis considered other variables that are related to the relative distribution of households and jobs in the corridor. It was hypothesized that, in the future, the concentration of jobs will likely move westward, following the growth in housing in the western part of the corridor. This shift, in turn, would affect the timing of work trips on I-80. Thus, it was judged that a variable measuring this distribution effect might explain some of the base-year variation from link to link. (Ideally, this kind of analysis would benefit greatly from a longitudinal data base, which would capture the same information at two or more points in time. However, the study schedule did not permit this flexibility in data collection.)

The candidate independent variables are described in more detail in the following sections.

MODEL STRUCTURE

Previous Research

A brief literature review disclosed little previous research on this subject, although four recent papers were found that considered the problem. Replogle (*1*) estimated peaking patterns in terms of population and employment density, as a surrogate for congestion. This approach was interesting, and it highlighted the difficulty of measuring and forecasting peaking due to the variety of causal factors. Marshment and Sulsky (*2*) assumed different levels of peak curve flattening by freeway ramp location and travel direction. Although they stated the problem in clear terms, their analysis made rather broad assumptions about the nature of future peaking patterns, rather than trying to mathematically estimate such patterns. Kroes and Hamerslag (*3*) described a theoretical approach to modeling the impact of congestion inside the assignment process, using a logit model of trip departure times. They limited themselves to discussing how their approach could be accomplished in conceptual terms and did not attempt to provide a workable mechanism for its implementation.

In a particularly relevant effort, Loudon et al. (*4*) examined this phenomenon to the extent of developing a model of the ratio of the peak-hour volume to be 3-hr peak-period volume. Their research did conclude that peak-period congestion clearly affects this ratio and that a recognizable pattern of peak spreading does occur. One limitation of the model is that it is applied on a facility-type basis, so that discontinuities can (and probably will) occur in the predicted peak volumes for adjacent links on a roadway. The model also does not consider that the peaking on any one link might be influenced by congestion effects that occur elsewhere on the roadway. In any event, Loudon et al. advance the state of research into peak-hour spreading and provide some of the motivation for the more ambitious methodology examined here.

All of these efforts acknowledged the need to better understand peaking patterns as they affect the accuracy of traffic forecasts, but they also all fell somewhat short of providing a practical approach that could be readily adapted to produce usable results for the I-80 study.

Model Formulation

The model to be developed in this study was intended to calculate the change in the temporal distribution of a.m. peak-period traffic, given estimated changes in total peak-period traffic volume and other measurable traffic characteristics. In its most basic sense, the model must determine how the base year curve (dashed line) in Figure 2 might change over time into the future curve (solid line).

The unknown variable to be estimated in this case is not a single number, but rather the distribution described by the dashed line itself. Once the distribution is determined, the peak 60-min volume can be readily calculated. The literature review disclosed little about the inherent form of this curve, only that it should be expected to become flatter over time in response to increased flex-time and increased congestion. In addition to becoming flatter, it is of interest to investigate to what extent the curve might also shift to the right or left in response to these changes.

Upon reviewing the observed data and other sources of information, the Poisson function was identified as being sufficiently descriptive of the distribution of 1989 traffic volumes by time period. The basic Poisson distribution is described as follows:

$$P(x) = \frac{m^x * e^{-m}}{x!} \quad (1)$$

where

m = arithmetic mean of the distribution,
x = time period under study, and
$P(x)$ = probability of an event occurring in Period x.

The selection of this function is further supported by observing that the Poisson distribution is often used in traffic engineering to represent a variety of phenomena, such as queueing and distribution of speeds. Thus, it was judged appropriate for use. To use the Poisson function in this context, Equation 1 was modified as shown below:

$$P(s,x) = \frac{z * m^{(x+y)} * e^{-m}}{(x + y)!} + a \quad (2)$$

where

s = eastbound highway segment (from 1 to 13);
x = time period (1 = 6:00–6:15, 2 = 6:15–6:30, . . . , 16 = 9:45–10:00);
m = primary shape factor;
a, z, y = other scale coefficients; and
$P(s,x)$ = proportion of 4-hr traffic occurring in Period x on Link s.

This structure is described further in the following sections.

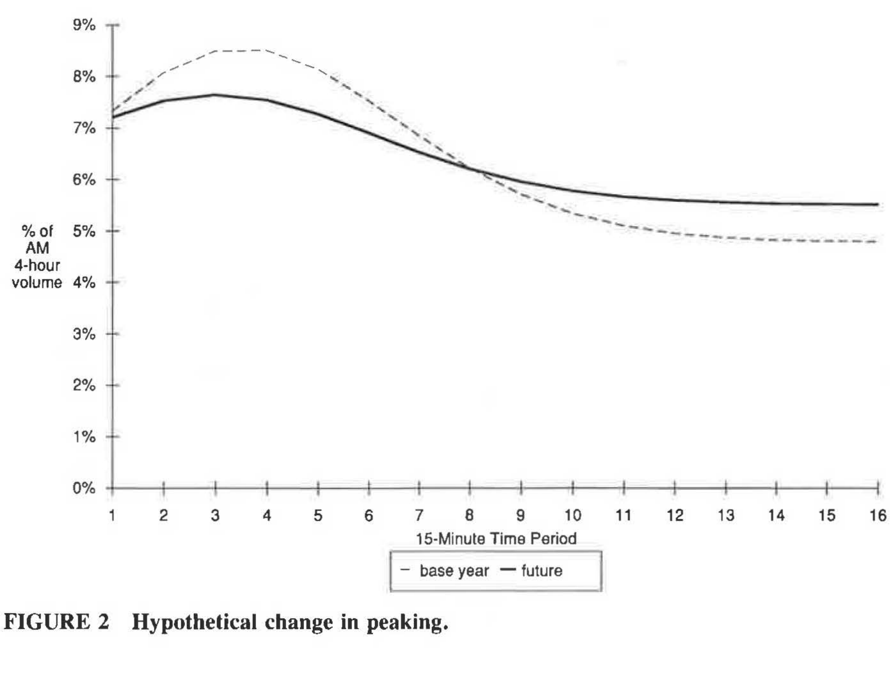

FIGURE 2 Hypothetical change in peaking.

CALIBRATION METHOD

Data Structure

The detailed traffic counts and the highway survey conducted for this project provided the base calibration data for the model. Because of the need to estimate specific peak-hour volumes for each segment of eastbound I-80 from the Delaware Water Gap to Denville, a link-based calibration file was established. The file includes values for the dependent and all available independent variables and consisted of the following data for each of the 13 highway segments under study:

- Milepost of segment's on-ramp (i.e., miles from the Pennsylvania line);
- Segment length;
- Counted 4-hr volume by 15-min period;
- Segment hourly capacity [Level of Service (LOS) E];
- Peak V/C ratio (highest 15-min period);
- Average V/C ratio (averaged over 4 hr);
- Average speed difference (free-flow minus congested, averaged for 4 hr);
- Delay on this link (based on average speed difference);
- Cumulative delay on this link, plus all links 2 mi downstream (i.e., eastbound);
- Cumulative delay on this link, plus all links 5 mi downstream (i.e., eastbound);
- Cumulative delay eastbound from the Delaware Water Gap;
- Average total trip time for all vehicles on this link;
- Average total trip time for all vehicles entering I-80 at the start of this link;
- Average access time to I-80 for all vehicles entering I-80 at the start of this link;
- Four-hour volume of vehicles entering I-80 at the start of this link;
- Percent trucks;
- Percent work trips;
- Percent of jobs within 5, 7, 10, 15, or 20 mi of this link's entry point; and
- Relative location of this link with respect to the whole trip, averaged across all trips using the link.

For these data, times are measured in minutes, distances in miles, and speed in miles per hour. All but the first two items represent data that exist only for the eastbound a.m. peak direction. Some of these variables are explained further in the following paragraphs.

Speed Difference

The standard Bureau of Public Roads (BPR) formula relating speed to *V/C* ratio was judged unacceptable. The BPR equation is as follows:

$$S = \frac{S(0)}{1 + 0.15 * (V/C)^4} \tag{3}$$

This equation did not provide congested speed values that were consistent with the investigators' observations and travel time runs. An alternative approach was developed on the basis of Figure 16.1 in the *ITE Transportation and Traffic Engineering Handbook* (*5*), using the following equation:

$$S = 65 - (4 * 10^{(V/C)}) \tag{4}$$

(valid only for *V/C* values of 1.2 or lower)

where *V/C* is the average a.m. 4-hr *V/C* ratio, based on capacity at LOS E.

Thus, the difference in speed is imply $4 * 10^{(V/C)}$.

Downstream Delay

It is hypothesized that motorists may adjust their travel times not only in response to congestion on any one link, but by considering congestion downstream from that link as well. This factor is reflected in two statistics: 2-mi and 5-mi downstream delay, which is the sum of the delay on each link plus the links that are 2 or 5 mi east of that link.

Average Trip Time

Average trip time is simply the total trip time (from the study area network), weighted by highway person trips and averaged over all the trips using each highway segment (or all the trips entering the highway at each on-ramp). Thus, it is a function of the origins and destinations of the trips using each link, as well as overall congestion in the corridor.

Average Relative Location

The highway survey contains information on each trip's origin zone, point of entry to and exit from I-80, and destination zone. By examining the relative lengths of the access, line-haul, and egress trip segments, it can be determined whether the I-80 portion is at the beginning, middle, or end of the trip. Averaging this information across all trips on the link might provide a statistic with power to explain the peaking phenomenon.

As noted, the dependent variable in this process consists of 13 sets of temporal distributions, one for each segment. Each distribution consists of the observed proportion of the total 4-hr volume occurring in each of sixteen 15-min periods. By definition, these fractions total to 1 for each link.

The calibration process assumes that the 13 highway segments exhibit some variation in temporal patterns and that this variation can somehow be explained by the available independent variables in a way that is both logical and mathematically appropriate. A priori examination of the observed distributions disclosed that they do, in fact, display intuitively rational patterns. The far western segments show a very early peaking (6:00–6:30 a.m.), which occurs later in time as one moves eastward. Also, the more congested segments tend to have a slightly flatter distribution than the less congested ones.

Technique

The sixteen 15-min traffic counts for each link were tabulated and graphed as a proportion of the total 4-hr volume. Next, a modified Poisson curve (Equation 2) was hand-fitted to each of the 13 graphs. This procedure was done by adjusting the *m*, *a*, *y*, and *z* values until the best fit was obtained. The adequacy of this fit was confirmed by checking the chi-square values for each link. The hand-fitted curves were defined in terms of 13 sets of coefficients.

These curves then became the observed data, to be fitted to one Poisson model for all links. The calibration file is shown in Table 1. It consists of the Poisson coefficients *m*, *a*, *y*, and *z* and the available independent variables for each link. The next step was to use those variables to estimate the coefficients.

A correlation table was calculated for all variables to provide a better understanding of the relationships that exist. Numerous two-dimensional graphs were prepared to display the relationships between the coefficients and the independent variables. Most important, the theories described previously were invoked to hypothesize the types of relationships that should exist among the variables.

Regression analysis was used to estimate each coefficient (*m*, *a*, *y*, and *z*) in terms of the available independent variables. Because there was no a priori judgment about these functions and the literature offered little guidance as to the forms, several regression models were tried. These models included linear, exponential, power, logarithmic, and 2nd- and 3rd-order polynomial. Certain transformations of the independent variables were tested as well.

The regression results were evaluated on the basis of the square of the correlation coefficient (r^2), examination of residuals, proper sign on the coefficients, and simplicity. Because the greatest congestion occurs on the segments from Exit 34 to 35 and Exit 35 to 37, those segments were assigned a slightly greater importance in determining the final coefficients.

RESULTS

Coefficients

Table 2 presents the final equations for estimating the four coefficients of Equation 2. These relationships are described in more detail in the following paragraphs. Overall, the functions used to estimate the coefficients are logical, use input variables that can be forecast, and have the proper signs on the coefficients.

m

The factor *m* is the most critical because it determines the basic shape of the curve. Lower values both increase the slope

TABLE 2 FINAL COEFFICIENT FUNCTIONS

Coefficient	Function	r^2
m =	$7.4613 + 0.2382 * \Delta S - 0.5593 * D_5 + 0.1930 * MP$	0.93
	ΔS = speed difference (mph) $= 4 * [10^{(V/C)}]$ for $V/C \le 1.2$ D_5 = total 5-mile downstream delay MP = 27 - entry milepost number, for mileposts 25-34 only (else 0)	
a =	$\frac{\Delta V}{20.9558 * \Delta V - 507.8082}$	0.55
	ΔV = ABS(4-hour volume - 15000)	
y =	$INT(4.4367 + 0.0622 * \Delta S)$	0.88
z =	$0.0794 * (\Delta V^{0.1399})$	0.70

TABLE 1 CALIBRATION FILE

Exit Number	0	4	12	19	25	26	27	28	30	34	35	37	38
Model Coefficients:													
a	0.047	0.050	0.047	0.048	0.048	0.048	0.049	0.049	0.050	0.055	0.051	0.046	0.045
y	5	5	5	5	5	5	5	5	5	6	6	6	6
z	0.290	0.260	0.300	0.265	0.265	0.250	0.240	0.250	0.240	0.140	0.210	0.275	0.295
m	8.9	8.0	8.8	9.3	9.4	9.9	9.9	9.2	8.9	9.6	10.5	12.3	12.0
Distance to Next Exit (mi.)	4.90	7.42	7.81	5.34	1.00	0.97	1.80	1.68	3.47	1.26	2.38	1.22	0.69
Speed Difference (mph)	7.8	6.2	7.1	8.2	10.2	10.4	13.8	11.5	11.7	21.3	23.3	28.2	22.2
Average V/C	0.29	0.19	0.25	0.31	0.41	0.42	0.54	0.46	0.47	0.73	0.77	0.85	0.74
Peak V/C	0.40	0.28	0.34	0.42	0.54	0.55	0.70	0.60	0.62	0.88	0.95	1.02	0.91
Average Delay (min.)	0.62	0.73	0.88	0.71	0.17	0.17	0.45	0.33	0.71	0.57	1.23	0.86	0.33
Delay for 5 Mi. Downstream	0.62	0.73	0.88	0.71	1.12	1.66	1.49	1.04	1.27	2.99	4.15	2.92	2.06
Delay for 2 Mi. Downstream	0.62	0.73	0.88	0.71	0.34	0.62	0.45	0.33	0.71	1.79	1.23	1.19	2.06
Average Trip Time (min.)	66.9	70.6	66.5	62.3	59.5	54.8	54.1	53.4	53.4	54.7	55.0	53.9	53.9
4-Hour Link Volume	4320	3923	5026	6382	8328	11317	10959	10331	10549	14819	15613	19120	16798
4-Hr. On-Ramp Volume	0	809	1260	1989	2336	2989	2057	2601	1217	6702	1893	4926	1462
Total Delay (min.)	2667	2847	4411	4555	1438	1936	4899	3437	7448	8404	19169	16455	5555
Tot. Cumulative Delay	2667	5514	9925	14479	15917	17853	22752	26189	33637	42041	61209	77664	83220
% Truck Trips	10.4%	9.8%	7.8%	6.4%	5.2%	4.2%	4.5%	4.7%	4.7%	4.2%	4.2%	3.6%	4.0%
% Work Trips	85.5%	85.1%	85.9%	87.2%	88.3%	88.7%	88.6%	88.2%	87.8%	88.7%	89.7%	90.2%	89.9%
Avg. Time This On-Ramp	51.5	49.5	52.0	47.4	49.1	40.6	44.2	42.7	39.3	51.2	44.6	46.9	39.4
Avg. Time to Access Ramp	8.3	15.8	22.7	17.4	16.5	13.1	14.2	12.3	11.1	22.8	16.1	18.9	9.4
% Jobs 15 Min. From Link	0.2	0.8	1.0	1.2	3.4	4.2	4.3	4.0	5.9	6.0	6.8	7.4	11.5
% Jobs 20 Min. From Link	0.8	1.2	3.9	4.7	4.7	6.7	6.4	7.7	10.9	13.2	14.5	15.7	19.0

of the curve and shift it to the left (i.e., earlier), whereas larger values flatten the distribution and shift it to the right. The best fit for this coefficient is as a function of the link's 4-hr average speed difference, the cumulative 5-mi downstream delay, and a dummy variable indicating the link's location. As the speed difference increases (i.e., greater congestion), m increases, flattening the peak demand, which is logical.

The negative coefficient on 5-mi total delay is somewhat less intuitive. This factor suggests that, as the 5-mi delay increases, m decreases, making the curve more peaked. However, it also means that increasing delay shifts the curve to the left, reflecting a desire to travel earlier to avoid the most congested periods.

Because the average speed difference and the 5-mi total delay measure essentially the same phenomenon and have opposite signs in the equation, it must be concluded that the effect of one variable is partially canceling out the effect of the other. According to the regression results, the speed difference has a much greater beta weight and t value than the 5-mi delay variable. Thus, the speed difference is the more significant of the two variables. A model using speed difference alone was also tested, but it did not give quite as good results as when 5-mi delay was added. Apparently, the 5-mi delay exerts a beneficial influence in counteracting some of the effect of the speed difference.

The final variable in the m equation is a dummy term representing the link's location in the corridor. In the calibration, it was discovered that something other than congestion or the available independent variables was affecting the model's fit from Exit 25 to Exit 34. The correction was a variable that is calculated as 27 minus the milepost of the link's entry point, for link entry points between Exits 25 and 34. It is assumed that this term represents something unique to the geography or physical layout of the road in this area and is thus not projected to change in the future.

y

The only variable in Equation 2 is x, the 15-min time period. In this analysis, the x values range simply from 1 (6:00–6:15) to 16 (9:45–10:00). However, these values do not result in the peak hump being in the proper location. An additional peak-shift factor is needed to help locate the hump in the correct place mathematically. As with m, y is related to the link's speed difference, for the same reasons. As the speed difference increases, y becomes larger, slightly flattening the curve and shifting it to the left. However, because y is in both the numerator and the denominator of the equation, the effect is somewhat muted. The equation for y in Table 2 includes the integer function because y must be an integer value.

z

The factor z can be thought of as a curve scale factor, needed to modify the Poisson function so as to produce values in the 5 to 9 percent range. This factor adjusts the vertical height of the distribution. It is somewhat difficult to attach a precise physical interpretation to this parameter, but it can best be thought of as describing the steepness of the curve. The observed data disclosed a distinct, but unusual, pattern for z: it is high for low-volume links and decreases with increasing volume, up to 15,000 vehicles (in 4 hr). Above that point, it increases again. The regression analysis indicated a fairly good power fit against the absolute value of the 4-hr volume minus 15,000.

The significance of the 15,000 figure could be related to the fact that this volume (and the cusp of the z versus volume curve) occurs on Segment 10 (Exit 34). This segment is the point at which NJ-15, the principal north-south arterial in northwest New Jersey, loads a large volume of eastbound traffic onto I-80 in the morning. It may be that the discontinuity in volume from this point eastward creates some kind of fundamental change in temporal patterns.

a

The coefficient a represents the asymptotic tail end of the distribution (i.e., 9:00–10:00). It is thus the minimum value that any 15-min proportion can take. The statistical analysis indicated that this value is closely, but inversely, related to the z coefficient. Thus, it was decided to use the same independent variable (absolute value of the difference between the 4-hr volume and 15,000) to estimate it.

The resulting nonlinear function is an inverse relationship that says, as the 4-hr volume increases, the value of a decreases. This decrease is sharp until the 4-hr volume reaches 20,000, then it levels off asymptotically to a value of about 0.048.

Observed and Estimated Comparisons

Three of the 13 observed distributions and the final estimated curves (one for each link) are shown in Figures 3–5. These three represent the link with the best fit, the worst fit, and an average fit, respectively. In general, these figures indicate a reasonable overall fit of the model. Table 3 presents the observed and estimated peak 60-min volumes. There is a slight (less than 5 percent) overestimation in the western part of the corridor, balanced by a slight underestimation (less than 5 percent) at the eastern end. However, this bias is not systematic enough to warrant additional external correction. In general, these estimates should be sufficiently accurate for design purposes.

Another comparison is presented in Table 4—the time when the peak 60-min period begins. This time matches exactly in the critical section from Exit 28 to Exit 35, but in general, the estimated start of the peak hour is 15 min later than the observed start. This difference may be due to discontinuities in the observed data.

On the basis of these comparisons, the model is judged to provide an accurate estimation of the temporal distribution of traffic in the I-80 corridor.

Sensitivity Analysis

Although base year observed and estimated comparisons are important in calibration, a true test of any model's forecasting

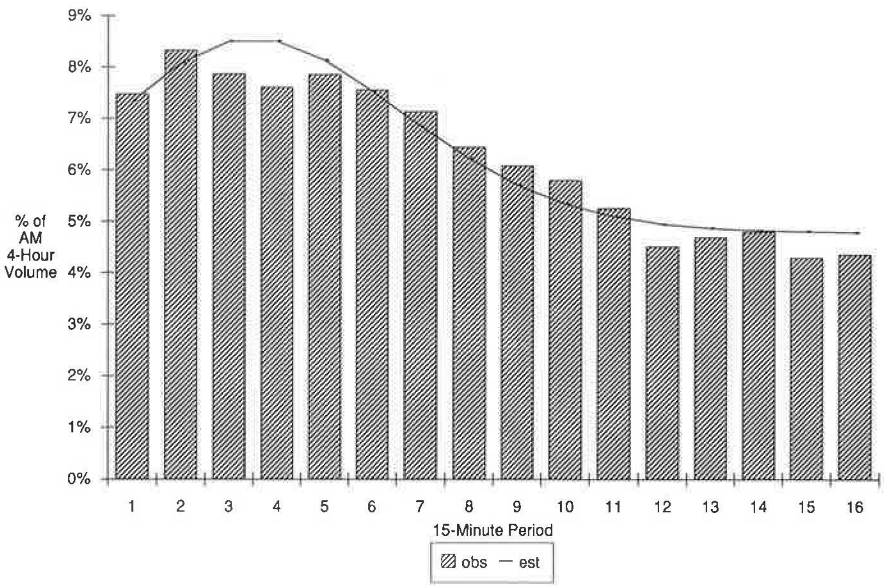

FIGURE 3 Observed versus estimated distribution: best fit.

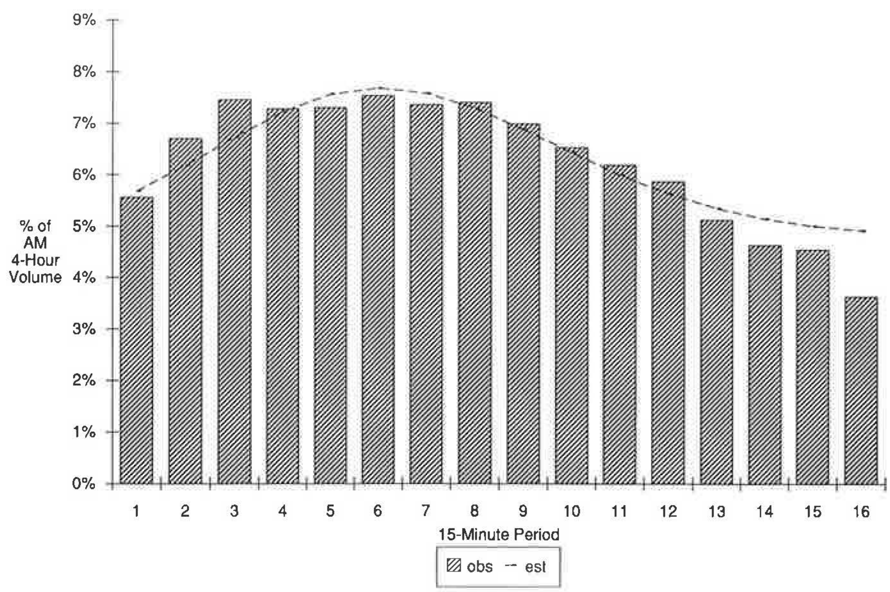

FIGURE 4 Observed versus estimated distribution: worst fit.

adequacy requires an assessment of its sensitivity to future changes in the independent variables. Thus, an analysis was performed to determine how potential changes in these variables would affect future estimates of the temporal distribution.

Because the link from Exit 34 to Exit 35 is an important one, it was selected to demonstrate how changes in the highway system would affect future traffic peaking patterns. The model was tested by varying the values of its key variables: link speed difference, average downstream 5-mi delay, and total 4-hr volume. Tests were done using 10 and 25 percent decreases in each of these values, and then 10 and 25 percent increases in each of them. Although the three variables are interrelated, these tests were performed by changing only one variable at a time so that the net effect of each could be more clearly seen.

Figures 6–8 show the results of this analysis. The model is clearly most sensitive to the difference between average congested and free speed on each link (Figure 6). From this curve it is apparent that most of the drivers on this link want to be there at 6:15–6:45. But increasing the speed difference from its base value of 21.3 mph strongly flattens the curve and shifts it slightly to the right; decreasing this value leads to a higher peak that occurs earlier. This finding suggests that drivers would use the link later in an attempt to avoid the increased congestion. If congestion were to abate, drivers might travel closer to their desired time (i.e., earlier), which is consistent with the basic theory of the model.

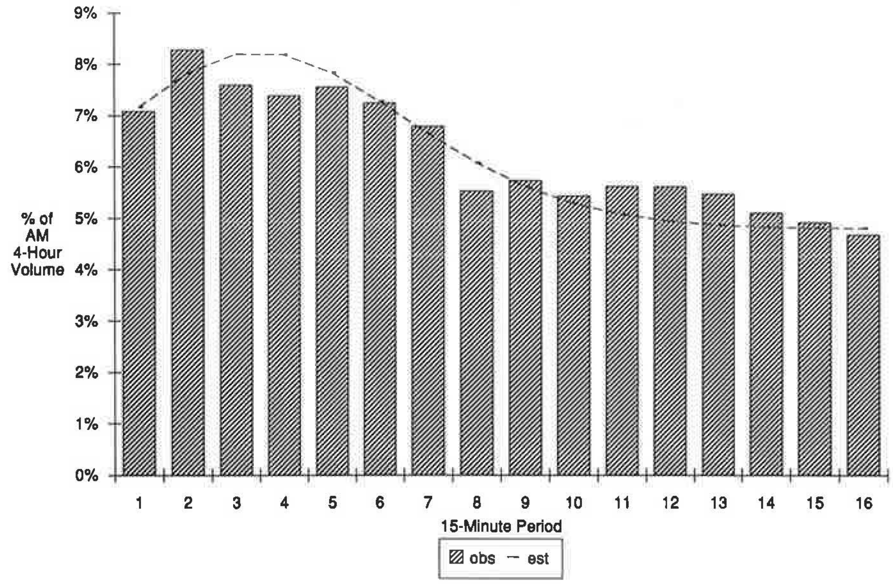

FIGURE 5 Observed versus estimated distribution: average fit.

TABLE 3 OBSERVED AND ESTIMATED PEAK-HOUR VOLUMES

Segment (Entry - Exit Milepost)	Observed	Estimated	Percent Difference
0 - 4	1,405	1,454	4%
4 - 12	1,303	1,332	2%
12 - 19	1,616	1,694	5%
19 - 25	2,019	2,119	5%
25 - 26	2,595	2,689	4%
26 - 27	3,497	3,570	2%
27 - 28	3,301	3,435	4%
28 - 30	3,258	3,277	1%
30 - 34	3,250	3,381	4%
34 - 35	4,299	4,443	3%
35 - 37	4,678	4,507	-4%
37 - 38	5,652	5,740	2%
38 - 39	5,091	4,939	-3%

TABLE 4 OBSERVED AND ESTIMATED START OF A.M. PEAK 60-min PERIOD

Segment (Entry - Exit Milepost)	Observed	Estimated	Difference
0 - 4	6:00	6:15	:15
4 - 12	6:00	6:15	:15
12 - 19	6:00	6:15	:15
19 - 25	6:15	6:15	0
25 - 26	6:15	6:30	:15
26 - 27	6:15	6:30	:15
27 - 28	6:15	6:30	:15
28 - 30	6:15	6:15	0
30 - 34	6:15	6:15	0
34 - 35	6:15	6:15	0
35 - 37	6:15	6:30	:15
37 - 38	6:30	7:00	:30
38 - 39	6:30	6:45	:15

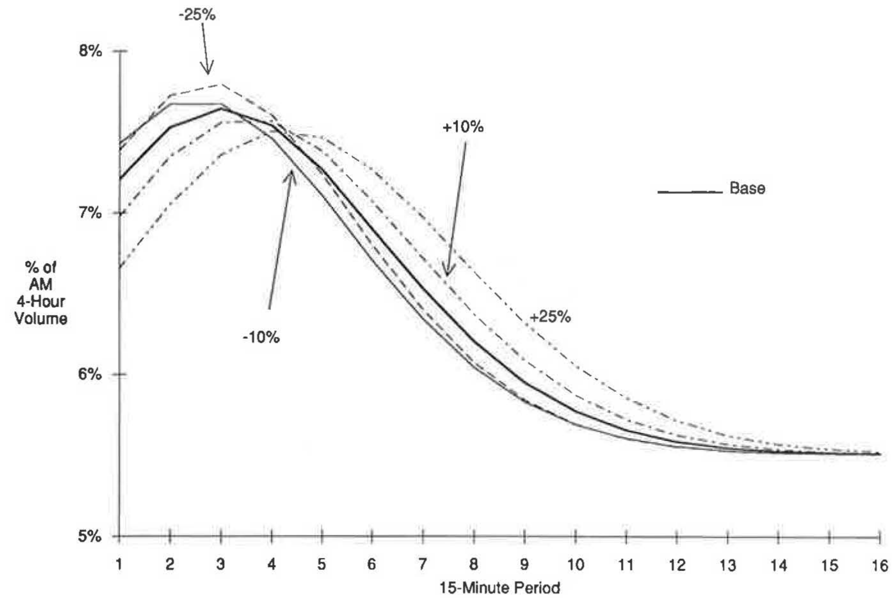

FIGURE 6 Sensitivity to change in speed difference, Exit 34 to 35.

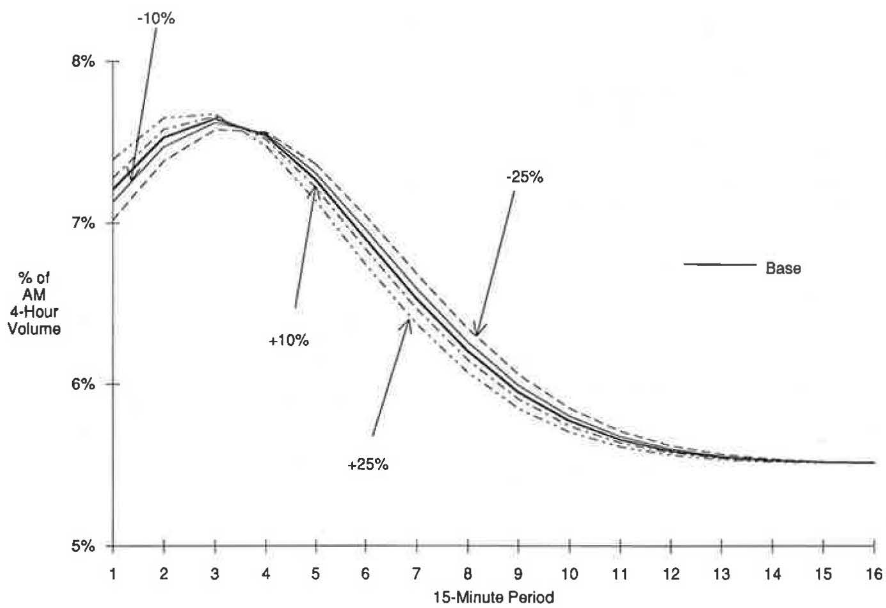

FIGURE 7 Sensitivity to change in average downstream 5-mi delay, Exit 34 to 35.

As Figure 6 shows, the model is indeed sensitive to changes in speed difference, although this sensitivity appears to be within reasonable bounds.

In examining Figure 7, however, the opposite effect is demonstrated, although to a much smaller degree. As downstream delay increases, the curve becomes sharper and peaks earlier. As noted previously, this effect serves to moderate the influence of changes in speed difference and helps ensure that the model does not give results that are too extreme in any direction.

Figure 8 shows the effect of changes in the total 4-hr volume. Because two of the model's coefficients are based on the absolute difference between this volume and 15,000, it can be seen that a 25 percent increase produces a similar effect as a 25 percent decrease. No apparent physical interpretation can readily be attached to this phenomenon; it is possibly a statistical aberration of this particular calibration data set. However, it is not a cause of great concern: as noted earlier, the total 4-hr volume is related to the other two variables, whose effect would moderate any unusual influence of this variable.

CONCLUSIONS

The question of future spread of peak-hour traffic volumes affects most current traffic forecasting efforts. Research into this topic asserts that it will become an increasingly important

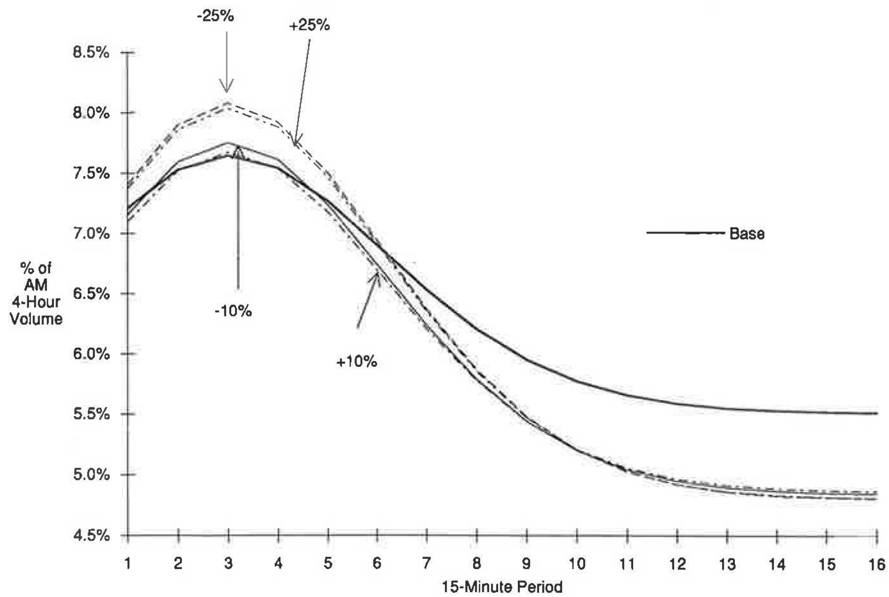

FIGURE 8 Sensitivity to change in total 4-hr volume, Exit 34 to 35.

issue that must be addressed by transportation planners. The research effort described is a somewhat awkward attempt to quantify and forecast peaking; as such, it should be viewed as merely an early step in what should become an expanding area of transportation planning research.

Although the I-80 corridor is, in many respects, not unlike other Interstate corridors around the country, the results described may be difficult to generalize for use elsewhere. It is explicitly recognized that the survey data and the planning framework of the I-80 study did not readily lend themselves to the kind of analysis that the investigators might have liked to pursue. The resulting model is thus perhaps not as theoretically sound or usable on other projects as hoped. Notwithstanding the model's shortcomings, it is important to expose this issue to a wide audience of planners and researchers in the hope of stimulating others to develop more rigorous procedures with which to forecast the traffic peaking phenomenon.

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Long-Range Temporal Stability of Trip Generation Rates Based on Selected Cross-Classification Models in the Delaware Valley Region

W. THOMAS WALKER AND HAIOU PENG

Results of a comparative trip generation rate analysis between a home interview survey conducted in the Delaware Valley region in 1987–1988 and the original 1960 survey are summarized. Selected stratification schemes based on combinations of trip purpose, family size, income, automobile ownership, and area type are tabulated and analyzed with cross-classification techniques to determine the impact of these input variables on the temporal stability of household trip generation rates. The selection of variables used in the cross-classification scheme affected the temporal stability of the resulting trip generation model. Household size stratifications were generally temporally unstable, income-based models more stable, and automobile ownership strata the most stable over time. A trip generation model based on appropriate cross-classifications by automobile ownership or area type, or both, produced reasonably stable trip generation results by trip purpose and when estimating total household travel.

Results of a comparative trip generation rate analysis between a home interview survey conducted in the Delaware Valley region in 1987–1988 and the original 1960 survey conducted by the Penn Jersey Transportation Study, precursor agency of the Delaware Valley Regional Planning Commission (DVRPC), are summarized. Selected stratification schemes based on trip purpose, family size, income, automobile ownership, and area type are tabulated and analyzed with cross-classification techniques to determine the impact of these input variables on the temporal stability of trip generation rates.

These variables were selected because they are determinants of trip making and for this reason are commonly used in regional trip generation models. Structure type, another variable often used, was not available for this analysis, but area type (i.e., central business district, urban, suburban, and rural) is largely a substitute. A discussion of the relative merits of each variable in cross-section analysis (for a single year) is provided by McDonald and Stopher (*1*) and Walker and Olanipekun (*2*).

Published results from the 1960 survey documented the short-run stability of trip generation models based on regression equations, the standard modeling technique at that time. Kannel and Heathington (*3*) reported that a linear regression model calibrated with 1964 household data from the Indianapolis region was able to reproduce the behavior of the same households when a small subsample of these households was reinterviewed in 1971. This model included family size and automobile ownership as independent variables but did not include trip purpose. The distribution of family sizes was stable, but automobile ownership increased significantly over this period. Similar results with regional regression equations based on land use and trip purpose were reported by Yunker (*4*) for the southeastern Wisconsin region for the period between 1963 and 1972.

The medium- to long-range stability (1965–1981) of two-dimensional cross-classification rate structures based on trip purpose versus household size, automobile ownership, and income was analyzed for the San Francisco Bay Area by Kollo and Purvis (*5*). They found that significant intertemporal changes in trip rates for a given socioeconomic strata were counterbalanced by shifts in the distribution of households between strata. As a result, total household trip generation rates did not change significantly.

Another approach to the evaluation of the temporal stability of trip generation behavior involves detailed factor analysis of variables thought to influence travel behavior. If the relative statistical importance of these variables changes over time, then the corresponding trip generation model may be unstable. Kitamura and Kostyniuk (*6*) present an analysis of changes in the relative importance of a number of household variables on the trip generation behavior measured in 1963 and 1974 home interview surveys for Rochester, New York. These factors include household size, income, the number of workers and drivers, automobile ownership (excluding zero-car households), and household life-cycle stage (i.e., age of adults and presence and age of children). On the basis of analysis of variance (ANOVA) techniques, it was concluded that the effect of automobile ownership has declined and that life-cycle stage has more influence on household travel behavior. Although focused on measures of statistical influence and significance rather than on actual rates, this study seems to indicate that trip generation rates in the higher automobile ownership categories, and perhaps overall trip rates, have declined over time. Lave (*7*) also predicts a leveling off of trip generation rates because of a growing saturation of the demand for automobiles, a stabilization of labor force participation rates especially among women, and the aging of the American population.

The 1980s were a decade of rapid growth in automobile travel, brought on by decentralization of population and em-

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ployment out of the urban core, abundant supplies of inexpensive gasoline, and large increases in automobile ownership. It is interesting to analyze the stability of trip generation rates over a long-range time interval that includes this decade.

SURVEY DATA AND STATISTICAL ANALYSIS METHODS

The 1987–1988 survey consisted of 2,424 telephone household interviews. The New Jersey portion (887 interviews) was collected during October and November 1987. The Pennsylvania counties (1,537 interviews) were surveyed during the same months in 1988. Although the interviews were conducted by different consultants, the data forms and interviewing techniques for the two groups were essentially the same. This 1987–1988 survey covered the entire nine-county DVRPC region (see Figure 1). The overall sample rate was 0.13 percent of the 1,847,000 households in the region; the rate varied somewhat by county, with the smallest rate (but the greatest number of interviews) in Philadelphia (0.075 percent) and the largest rate in Burlington County (0.20 percent). The survey was controlled by county and automobile ownership. An effort was made to reach zero-car, low-income households; however, the survey failed to achieve a completely representative sample from this group even after a supplemental contract with the consultant.

The Penn Jersey home interview survey consisted of 56,100 in-person household interviews conducted between June and November 1960. This survey also sampled dense urban areas at a lower rate than more sparsely settled suburban and rural areas. A uniform sampling rate of 4 percent was used in Philadelphia and Camden counties and in densely settled suburban areas. A rate of 10 percent was used in lower-density areas and in Mercer County. This survey was confined to the Penn Jersey study area, also shown in Figure 1.

The survey forms used in the 1960 and 1987–1988 surveys were compatible, with similar demographic information collected and the same categories used for trip purpose and travel mode. Identical trip linking procedures were used to eliminate change-mode and serve-passenger trips. Household income presented a minor problem in that meaningful comparisons require the use of constant (1988) dollars. The high cost of living index (320.2) required to translate 1960 dollars to current dollars caused some mismatches between the income categories of the two surveys. These income range overlaps were resolved for the most part by combining detailed categories.

The method used to compare the trip generation rates implicit in the 1987–1988 survey with those in the Penn Jersey survey is known as the cross-classification technique. This method is similar to the widely used multiple regression technique in that changes in trip rates are measured while changes in two or more independent variables are accounted for. In this case, however, an n dimensional matrix of mean or average trip rates is calculated whereby each variable (trip purpose, automobile ownership, area type, income, etc.) has at least two subcategories defined by contiguous ranges of the appropriate variable. Cross-classification analysis is inherently disaggregate in that rates are tabulated directly from household data rather than relying on zonal averages of trip rates or independent variables.

Trip rates from both surveys were based on unfactored household data to make the results comparable. The Penn Jersey survey records included a composite final trip factor based on the inverse of the sample rate and on the results of a screenline analysis that compared surveyed trip crossings with traffic counts. This screenline analysis determined that about 78 percent of total travel was recorded in the trip diaries, with the remainder unreported. The 1987–1988 survey could not be factored with screenline analysis because of the small sample rate. Because of the similarity of survey forms

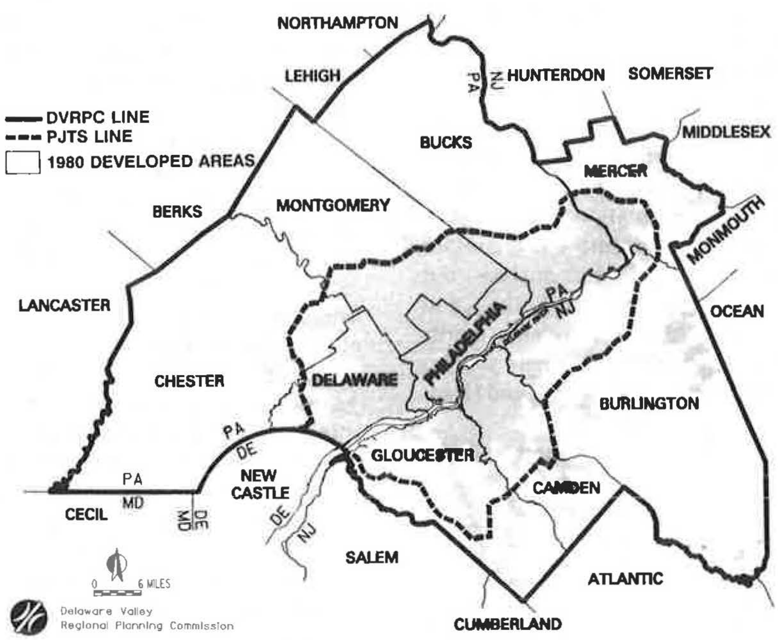

FIGURE 1 Penn Jersey transportation study and DVRPC regional cordon lines.

and data collection and processing techniques, it was assumed that the degree of trip underreporting is the same in both surveys.

The Penn Jersey survey data files only included travel internal to the Penn Jersey cordon area shown in Figure 1. For comparability, the 1987–1988 survey was also tabulated on this basis, unless indicated otherwise. This cordon line convention results in trip rates that are somewhat lower than those found through the more usual practice of tabulating all trips that are recorded on the trip diary.

Three statistical indicators are calculated for each trip rate cell in the cross-classification matrix: (a) the mean or average trip rate for households within that strata, (b) the number of observations, and (c) the cell standard deviation. The primary output is the cell mean trip rate. The number of observations in the cell and its standard deviation provide statistical measures of the accuracy of the rate (via confidence interval) and facilitate hypothesis tests on the difference between rates from each survey. The t-test of the statistical significance of differences between two mean trip rates is based on the idea that the hypothesis that trip rates differ must be rejected if their confidence intervals overlap. For this test to be valid, a sufficient number of observations must be available in each cell—at least 25 for practical purposes. This t-test does not directly measure the absolute magnitude of rate differences. A poor model with large standard deviations about the mean rates in each cell will have a greater tendency to be statistically stable than a more precise model with the same absolute rate differences.

Although more nebulous and difficult to define, rate differences may also be categorized in terms of planning significance. Planning significance relates to the magnitude of the difference more than to its statistical significance. For this reason, selected tables also contain estimates of percent difference between rates so that any logical patterns of these differences may be identified. A difference of 1 percent may be statistically significant, if the sample is large enough and the mean is tightly constrained by the cell standard deviation. This difference is of little planning significance, however. A difference of 10 percent or more was somewhat arbitrarily defined as being of planning significance, particularly if this difference is part of a logical overall pattern of trip rate variation. Because most studies ultimately use trip generation model results to produce travel volumes on transportation facilities, it is the total travel estimate rather than the estimates by trip purpose or socioeconomic strata that have real planning significance.

Table 1 presents a comparison of 1960 and 1987–1988 aggregate household trip rates stratified by trip purpose. Clearly, household trip making has increased significantly during this time period. Overall, household trip rates have increased by almost 25 percent. Home-based work trips have declined by about 10 percent, whereas home-based nonwork and non-home-based travel have increased by 33 and over 100 percent, respectively. These shifts may be interrelated and reflect survey tabulation conventions as well as trip-making decisions. For instance, a stop at a convenience store on the way home from work creates a non-home-based trip from work to shopping and a home-based shopping trip to reach home. These two trips replace the single home-based work trip recorded in the 1960 survey. In 1960, transit was a much bigger factor in work travel, and convenience stores were less common. However, this phenomenon does not completely explain the large increases in Table 1. Overall household trip generation rates seem to have increased significantly as a result of the automobile-oriented suburban life styles that have become much more prevalent since 1960.

The data in Table 1 must be interpreted carefully because aggregate regional trip rates are valid only if the sampled population reflects the distribution of demographic and economic characteristics in the regional population. Table 2 presents a comparison of the socioeconomic characteristics of the 1960 and 1987–1988 samples with those recorded in the 1980 census. From this table, it appears that the aggregate trip rates from the 1987–1988 survey may have been somewhat overestimated because of an underrepresentative sample of zero-auto, single-person households with incomes under $10,000. It is difficult to reach this type of household with telephone interviewing techniques. These aggregation problems largely disappear, however, when trip rate comparisons

TABLE 1 COMPARISON OF HOUSEHOLD TRIP RATES STRATIFIED BY DETAILED TRIP PURPOSE

TRIP PURPOSES	1960	1987-88	DIFF.	PCT.DIFF	"t" VALUE
Home-Based Work	1.86	1.66	-0.20	-10.75	4.96*
Home-Based Non-Work	2.12	2.82	0.70	33.02	9.04*
Home-Based Shopping	0.68	0.92	0.24	35.29	6.86*
Home-Based Social Rec.	0.77	0.52	-0.25	-32.47	5.84*
Home-Based Person Bus.	0.51	0.74	0.23	45.10	7.47*
Home-Based Eat Meal	0.01	0.24	0.23	2300.00	44.27*
Home-Based Other	0.15	0.39	0.24	160.00	11.93*
Home-Based School	0.41	0.41	0.00	0.00	0.17
Total Home Based	4.40	5.20	0.80	18.18	8.02*
Non-Home Based	0.64	1.35	0.71	110.94	16.55*
TOTAL	5.03	6.25	1.22	24.25	9.96*

* Indicates statistically significant difference between the two means at significance level 0.05.

TABLE 2 SOCIOECONOMIC CHARACTERISTICS OF THE 1960 AND 1987–1988 SURVEY SAMPLES

	1960 Survey	1980 Census	1987-88 Survey
Autos per Household	0.89	1.26	1.61
% of Households			
0 Auto	26.5%	20.3%	10.8%
1 Auto	54.8	42.8	34.7
2 Autos	16.6	29.1	40.3
3+ Autos	2.1%	7.8%	14.2%
Persons per Household	3.36	2.87	2.67
% of Households			
1 Person	12.5%	22.7%	18.4%
2 Persons	26.0	29.3	34.2
3 Persons	19.6	17.5	18.5
4 Persons	19.7	15.6	17.3
5 Persons	11.9	8.6	7.9
6 Persons	10.3%	6.3%	3.7%
Av. Household Income*	$20,100	$31,000	$39,400
% of Households			
Under $10,000	15.3%	21.3%	7.5%
$10,000 - $19,999	48.7	20.0	16.4
$20,000 - $29,999	26.3	13.9	18.3
$30,000 - $49,999	6.6	29.8	31.4
$50,000 - $69,999	2.1	9.9	15.6
Over $70,000	1.0%	5.1%	10.8%

* 1988 Constant Dollars

are cross-classified with these socioeconomic variables. The principal concern then is to obtain a statistically sufficient number of observations within each cell of an appropriate cross-class matrix.

The school trip rates exclude trips made by primary- and secondary-school students in district-sponsored (yellow) school buses. Only automobile and public transit school trips are included. None of the trip purposes include walk or bicycle travel. Also, the trip rates given in Table 1 only consider travel that is internal to the Penn Jersey study cordon line. By comparison, the 1987–1988 household trip rate for the total of all trip purposes increases from 6.25 to 7.33 when the cordon is expanded to DVRPC's nine-county region. The total household trip rate for the 1987–1988 survey (for the nine-county region) is 7.79 trips per household when all external-local travel is included.

TEMPORAL STABILITY OF SELECTED CROSS-CLASSIFICATION SCHEMES

Two analyses of temporal stability are presented in this section. The first deals with individual rates within a given cross-classification model. As discussed previously, the t value and percent difference determine the statistical and planning significance associated with individual rate differences. Because planning uses for trip generation data usually involve geographical aggregations of travel estimates (traffic zone, development district, etc.), individual rate differences may cancel out. To measure the planning significance of aggregated differences on trip estimates, the 1960 and 1987–1988 calibrations of each model are applied to traffic zone (census tract) data taken from the 1980 census. Resulting aggregate differences are summarized at the zonal level [root mean squared (RMS) difference] and with regional totals. Temporally stable models are characterized by similar regional totals and small RMS differences at the zonal level. Also included in this analysis are three useful decomposition measures of the mean square difference proposed by Theil (*8*): (a) UM measures the fraction of mean square difference attributable to discrepancies in the means, (b) US refers to the fraction of this difference resulting from unequal standard deviations, and (c) UC estimates the corresponding fraction resulting from incomplete covariation (scatter).

Temporal stability does not necessarily imply accuracy in the resulting trip estimates. Because of the uneconomically large sample sizes required to estimate actual zonal trip totals, error calculations cannot be made at this level. Even regional trip totals are difficult to estimate from survey data because these totals are often sensitive to the specific methods used to factor the survey. The simple cross-classifications presented in Tables 3–5 probably do not produce sufficient accuracy at the zonal level for travel simulation purposes except, perhaps, for regional control totals of non-home-based trips. However,

TABLE 3 COMPARISON OF TRIP RATES STRATIFIED BY HOUSEHOLD SIZE

	Persons Per Household					
	1	2	3	4	5	6-9
			Total Trips Per Household			
1987-88 Survey	2.66	5.13	7.05	8.70	10.15	13.61
1960 Survey	1.26	3.41	5.19	6.58	7.26	7.79
Percent Diff.	111.11	50.44	35.84	32.22	39.81	74.71
"t" Statistic	14.86*	12.51*	7.79*	6.85*	5.47*	6.67*
			Home Based Work Trips Per Household			
1987-88 Survey	0.59	1.48	2.06	2.30	2.53	2.58
1960 Survey	0.54	1.53	2.16	2.28	2.28	2.44
Percent Diff.	9.26	-3.27	-4.63	0.88	10.96	5.74
"t" Statistic	1.06	0.89	1.07	0.26	1.55	0.56
			Home Based Non-work Trips Per Household			
1987-88 Survey	1.25	2.26	3.01	4.06	4.64	6.63
1960 Survey	0.53	1.37	2.08	2.85	3.25	3.33
Percent Diff.	135.85	64.96	44.71	42.46	42.77	99.10
"t" Statistic	12.22*	10.30*	6.06*	5.68*	3.89*	5.67*
			Home Based School Trips Per Household			
1987-88 Survey	0.07	0.12	0.34	0.69	1.50	2.08
1960 Survey	0.02	0.04	0.26	0.59	0.86	1.18
Percent Diff.	250.00	200.00	30.77	16.95	74.42	76.27
"t" Statistic	4.10*	6.78*	1.81	1.26	4.15*	3.01*
			Non-Home Based Trips Per Household			
1987-88 Survey	0.75	1.27	1.65	1.66	1.45	2.32
1960 Survey	0.17	0.46	0.70	0.86	0.86	0.84
Percent Diff.	341.18	176.09	135.71	93.02	68.60	176.19
"t" Statistic	15.02*	12.63*	8.77*	6.93*	3.22*	5.38*

* Indicates statistically significant difference between the two means at significance level 0.05.

TABLE 4 COMPARISON OF TRIP RATES STRATIFIED BY INCOME

	Household Income Code					
	0	1	2	3	4	5
			Total Trips Per Household			
1987-88 Survey	2.84	3.91	4.88	5.68	7.63	8.53
1960 Survey	1.54	3.76	5.54	6.87	8.06	9.15
Percent Diff.	84.42	3.99	-11.91	-17.32	-5.33	-6.78
"t" Statistic	5.70*	0.43	1.66	3.56*	1.46	1.23
			Home Based Work Trips Per Household			
1987-88 Survey	0.39	0.80	1.08	1.60	2.03	2.49
1960 Survey	0.52	1.59	2.07	2.48	2.76	2.77
Percent Diff.	-25.00	-49.69	-47.83	-35.48	-26.45	-10.11
"t" Statistic	1.34	6.28*	7.75*	8.04*	7.12*	1.80
			Home Based Non-work Trips Per Household			
1987-88 Survey	1.70	1.95	2.30	2.59	3.54	3.53
1960 Survey	0.78	1.53	2.35	2.86	3.39	3.97
Percent Diff.	117.95	27.45	-2.13	-9.44	4.42	-11.08
"t" Statistic	6.05*	1.83	0.18	1.21	0.72	1.33
			Home Based School Trips Per Household			
1987-88 Survey	0.22	0.30	0.33	0.39	0.57	0.43
1960 Survey	0.10	0.26	0.46	0.60	0.67	0.91
Percent Diff.	120.00	15.38	-28.26	-35.00	-14.93	-52.75
"t" Statistic	2.08*	0.43	1.20	2.22*	1.39	3.41*
			Non-Home Based Trips Per Household			
1987-88 Survey	0.53	0.87	1.17	1.10	1.49	2.08
1960 Survey	0.14	0.38	0.66	0.94	1.24	1.50
Percent Diff.	278.57	128.95	77.27	17.02	20.16	38.67
"t" Statistic	6.17*	4.29*	3.34*	1.18	2.15*	3.06*

INCOME CODES 0: Under $10,000 1: $10,000 - $14,999 2: $15,000 - $19,999 3: $20,000 - $29,999
4: $30,000 - $49,999 5: $50,000 - $69,999

N:Indicates insufficient data (less than 25 observations).

* Indicates statistically significant difference between the two means at significance level 0.05.

TABLE 5 COMPARISON OF TRIP RATES STRATIFIED BY AUTOMOBILE OWNERSHIP

	Cars Per Household					
	0	1	2	3	4	5-9
			Total Trips Per Household			
1987-88 Survey	2.18	4.56	7.74	9.57	8.81	13.38[N]
1960 Survey	1.79	5.41	8.32	9.95	11.53	17.78[N]
Percent Diff.	21.79	-15.71	-6.97	-3.82	-23.59	-24.75
"t" Statistic	2.45*	4.57*	2.45*	0.76	2.96	1.35
			Home Based Work Trips Per Household			
1987-88 Survey	0.72	1.10	2.00	2.70	3.56	5.08[N]
1960 Survey	1.03	1.97	2.61	3.64	4.29	5.33[N]
Percent Diff.	-30.10	-44.16	-23.37	-25.82	-17.02	-4.69
"t" Statistic	3.17*	13.90*	8.41*	5.40*	1.29	0.20
			Home Based Non-work Trips Per Household			
1987-88 Survey	0.98	2.15	3.49	4.16	3.37	5.69[N]
1960 Survey	0.55	2.34	3.65	4.09	4.64	9.11[N]
Percent Diff.	78.18	-8.12	-4.38	1.71	-27.37	-37.54
"t" Statistic	4.66*	1.57	1.00	0.21	1.45	1.20
			Home Based School Trips Per Household			
1987-88 Survey	0.16	0.25	0.55	0.69	0.78	0.23[N]
1960 Survey	0.12	0.42	0.79	0.81	0.89	1.33[N]
Percent Diff.	33.33	-40.48	-30.38	-14.81	-12.36	-82.71
"t" Statistic	0.89	3.44*	3.60*	0.86	0.26	1.71
			Non-Home Based Trips Per Household			
1987-88 Survey	0.32	1.07	1.69	2.01	1.11	2.38[N]
1960 Survey	0.09	0.68	1.26	1.41	1.71	2.00[N]
Percent Diff.	255.56	57.35	34.13	42.55	-35.09	19.00
"t" Statistic	6.38*	5.71*	4.14*	3.26*	1.22	0.37

N:Indicates insufficient data (less than 25 observations).
* Indicates statistically significant difference between the two means at significance level 0.05.

the formulations selected for inclusion in subsequent sections have been used successfully in regional travel simulation models.

Simple Two-Dimensional Cross-Classification Models

Compared with stratification by trip purpose only (Table 1), the cross-classification by household size and trip purpose presented in Table 3 significantly increases the differences between trip rates in the 1960 and 1987–1988 surveys for all trip purposes except home-based work. For work trips, the decline in household size and the increase in labor force participation rates have compensated over time. All other trip rate comparisons show large differences with high levels of statistical and planning significance (from 32 to 111 percent increase in total travel). Even home-based school trips (excluding district-sponsored school bus trips), which were constant in aggregate, show large increases when stratified by family size.

Table 4 shows that an income-based cross-classification scheme produces dramatically different patterns of temporal stability. No longer do all nonwork trip purposes show large increases in trip rates. Generally, home-based nonwork and school trip rates for households with incomes below $15,000 increase and households with incomes greater than this level now make fewer trips. Work trips have significantly declined, and non-home-based trips have increased for all income categories with valid sample sizes. With the exception of households with incomes below $10,000, total trip rates per household are relatively stable over time. (As noted previously, the household incomes recorded in the 1960 survey were converted to 1988 constant dollars before computing the rates in Table 4.)

A similar pattern is shown for automobile ownership in Table 5. Except for home-based work travel, zero-car households now show much higher trip rates than those recorded in 1960, with a compensating decline in trip rates for all car-owning categories. The percent reductions in trip rates tend to increase with automobile ownership, perhaps indicating diminishing returns in automobile ownership brought about by increasing saturation of the demand for automobiles and smaller household sizes. As in the income stratification, work trip rates generally decline and non-home-based trips significantly increase over time.

These temporal shifts are similar in pattern to those reported by Kollo and Purvis (*5*) for the San Francisco Bay Area between 1965 and 1981, except that their data showed smaller declines in work trips per household over time. However, their finding of a constant total household trip rate regardless of stratification variable can be misleading. This result was based on trip rates calculated from factored survey data, but the distribution of socioeconomic household characteristics has changed greatly over time. Table 6 illustrates this change by calculating trip generation with 1960 and 1987–1988 rates by census tract (about 970 zones within the Penn Jersey cordon line) using the appropriate socioeconomic data taken from the 1980 census.

Table 6 shows that the variable used in cross-classification has enormous impact on both the total number of trips gen-

TABLE 6 DIFFERENCE BETWEEN 1980 ZONAL TRIP GENERATION ESTIMATES ON THE BASIS OF 1960 AND 1987–1988 HOUSEHOLD RATES

Trip Purposes	Region Trip Total (10^6)		% RMS	Theil Statistics		
	1960 Rates	1987-8 Rates	DIFF.	UM	US	UC
	Household Size Stratification					
Home Based Work	2.3	2.3	1.20	0.41	0.19	0.58
Home Based Non Work	2.5	4.1	45.72	0.69	0.30	0.01
Home Based School	0.4	0.7	45.50	0.67	0.33	0.00
Non-Home Based	0.8	1.9	71.36	0.69	0.30	0.01
TOTAL	6.1	9.2	39.51	0.69	0.30	0.01
	Income Stratification					
Home Based Work	2.8	2.1	45.86	0.66	0.28	0.06
Home Based Non Work	3.5	3.9	13.03	0.60	0.15	0.25
Home Based School	0.7	0.6	25.93	0.56	0.31	0.13
Non-Home Based	1.2	1.7	39.07	0.72	0.25	0.03
TOTAL	8.2	8.3	5.83	0.04	0.01	0.95
	Auto Ownership Stratification					
Home Based Work	3.0	2.1	55.64	0.69	0.30	0.01
Home Based Non Work	3.6	3.5	6.56	0.09	0.21	0.70
Home Based School	0.7	0.5	50.02	0.64	0.34	0.02
Non-Home Based	1.1	1.6	38.40	0.70	0.28	0.03
TOTAL	8.4	7.7	11.59	0.61	0.34	0.04

erated and the amount of forecast difference at the census tract level. Household size leads to a one-third underestimate of total trips and an almost 40 percent RMS difference at the tract level if 1960 rates are used to predict current travel. On the contrary, income (1980 census income categories were converted to 1988 dollars) produces only about a 1 percent overestimate of regional trips with just under 6 percent tract level RMS difference and automobile ownership produces an 8 percent underestimate with a 12 percent RMS difference.

By purpose, household size is the most stable variable for home-based work trips (1.2 percent RMS difference), automobile ownership for home-based nonwork (6.6 percent) and non-home-based travel (38.4 percent), and income for school travel (25.9 percent). The best models for home-based work and nonwork travel have temporal stabilities within the 10 percent planning limits, but school and non-home-based travel have large underestimates with 1960 rates, regardless of the stratification variable used.

In the Theil (*8*) tests, UM is the principal component of zonal trip differences between the 1960 and 1987–1988 rates for all models in Table 6 for which the percent RMS difference is large. Rate differences tend to average out for home-based nonwork travel with an automobile ownership stratification and for total travel when stratified by income, although significant differences in the standard deviations (US) still exist in the former case. Despite the small percentage RMS difference for work trips when stratified by household size, over 40 percent of the mean squared difference is attributable to differences in the mean and standard deviation, because of an almost perfect collinearity between the two sets of zonal trip estimates.

Impact of the Penn Jersey Cordon Line on Temporal Stability

Changes in the relationship of regional development patterns to the cordon line also influence the temporal stability of internal trip generation rates. As a result of the decentralization of population and employment that has occurred between 1960 and 1987, almost all of the rural land inside of the Penn Jersey cordon is now developed and large amounts of both residential and commercial development now exist outside of this cordon line (see Figure 1). This change significantly reduces internal work trip generation rates because many workers now cross the Penn Jersey cordon on the way to their place of employment.

Table 7 presents the impact of the Penn Jersey cordon on 1987–1988 work trips per employed resident. Current work trip rates increase significantly when the cordon line is extended to the nine-county boundary and even further when the cordon is eliminated entirely. As expected, the difference in current work trip rates is largest for rural areas near the cordon and smallest in Philadelphia's central business district. This, in part, explains the large reduction in 1987–1988 work trip rates compared with 1960 rates, as recorded in Tables 4 and 5. Home-based work trips display this tendency because of relatively long trip lengths. On the basis of the nine-county cordon, home-based work trips per employed resident have declined significantly since 1960, by about 14 percent overall.

Home-based nonwork trip lengths are much shorter and therefore are less influenced by the location of the cordon line. Table 8 shows that only small increases in trip rates occur when the cordon is extended to the entire region. As ex-

TABLE 7 STABILITY OF INTERNAL HOME-BASED WORK TRIP RATES PER EMPLOYED RESIDENT

	Area Type			
	CBD	Urban	Suburban	Rural
	1987-88 Rates for the Penn Jersey Cordon Line			
1987-88 Survey	0.65	1.27	1.27	1.02
1960 Survey	0.96	1.51	1.63	1.55
Percent Diff.	-32.29	-15.89	-22.09	-34.19
"t" Statistic	1.34	4.84*	9.93*	4.53*
	1987-88 Rates for the DVRPC Cordon Line			
1987-88 Survey	0.65	1.33	1.39	1.30
1960 Survey	0.96	1.51	1.63	1.55
Percent Diff.	-32.29	-11.92	-14.72	-16.13
"t" Statistic	1.34	3.65*	7.17*	4.58*
	1987-88 Rates Including All External Work Trips			
1987-88 Survey	0.72	1.38	1.46	1.44
1960 Survey	0.96	1.51	1.63	1.55
Percent Diff.	-25.00	-8.61	-10.43	-7.10
"t" Statistic	1.02	2.74*	4.98*	2.06*

* Indicates statistically significant difference between the two means at significance level 0.05.

TABLE 8 COMPARISON OF 1987–1988 HOME-BASED NONWORK HOUSEHOLD TRIP RATES BETWEEN DVRPC AND PENN JERSEY STUDY REGIONS

	Area Type			
	CBD	Urban	Suburban	Rural
DVRPC Region	1.00	2.12	3.40	3.65
Penn Jersey Region	0.96	2.03	3.18	3.44
Percent Diff.	4.17	4.43	6.92	6.10
"t" Statistic	0.09	0.57	1.55	0.51

	Cars Per Household					
	0	1	2	3	4	5-9
DVRPC Region	1.01	2.31	3.74	4.43	3.98	5.17
Penn Jersey Region	0.98	2.15	3.49	4.16	3.37	5.69
Percent Diff.	3.06	7.44	7.16	6.49	18.10	-9.14
"t" Statistic	0.17	1.23	1.38	0.74	0.75	0.37

* Indicates statistically significant difference between the two means at significance level 0.05.

pected, this increase is greatest for rural areas, but none of these differences are of planning or statistical significance. The location of the cordon line also has little effect on home-based nonwork trips when rates are stratified by automobile ownership.

Temporal Stability of Selected Multidimensional Cross-Classification Schemes for Home-Based Nonwork Travel

Travel simulations often model home-based nonwork travel with multidimensional cross-classification schemes that use combinations of trip purpose, family size, automobile ownership or income, and area type. Automobile ownership and income are rarely used together because of the high degree of collinearity between these variables. In this section, detailed trip rate tables stratified by income are omitted. Comparisons are limited to automobile ownership because fewer variable ranges are needed and because this variable is somewhat more temporally stable than income for home-based nonwork travel. Income displays much the same patterns of stability as automobile ownership. Income-based difference statistics are included in the summary tables, however.

Because of the relatively large number of cells in multidimensional cross-classifications, the entire 1987–1988 survey was used for comparison with 1960 data to improve the statistical significance of the results. Due to the relatively short average trip length, home-based nonwork trip rates do not differ greatly between the Penn Jersey and nine-county cordon areas (see Table 8).

Table 9 shows the stability of home-based nonwork trip generation rates cross-classified by automobile ownership and

TABLE 9 COMPARISON OF HOME-BASED NONWORK HOUSEHOLD TRIP RATES STRATIFIED BY AUTOMOBILE OWNERSHIP AND HOUSEHOLD SIZE

	Cars Per Household			
	0	1	2	3+
One-Person Households				
1987-88 Survey	0.74	1.50	1.17^N	1.40^N
1960 Survey	0.34	1.03	1.19^N	N
Percent Diff.	117.65	45.63	-1.68	N
"t" Statistic	5.14*	5.34*	0.05	N
Two-Person Households				
1987-88 Survey	0.84	2.45	2.63	2.60
1960 Survey	0.50	1.71	2.19	2.48
Percent Diff.	68.00	43.27	20.09	4.84
"t" Statistic	2.26*	5.50*	3.21*	0.25
Three-Person Households				
1987-88 Survey	0.75^N	2.76	3.50	4.13
1960 Survey	0.72	2.15	2.91	3.08
Percent Diff.	4.17	28.37	20.27	34.09
"t" Statistic	0.06	2.20*	2.70*	3.10*
Four-Person Households				
1987-88 Survey	2.13^N	2.99^N	4.60	4.64
1960 Survey	0.80	2.79	3.93	3.72
Percent Diff.	166.25	7.17	17.05	24.73
"t" Statistic	2.29*	0.46	2.52*	2.04*
Five or More Person Households				
1987-88 Survey	3.19^N	5.44^N	6.22^N	5.78
1960 Survey	0.86	3.18	4.70	5.11
Percent Diff.	270.93	71.07	32.34	13.11
"t" Statistic	4.94*	3.50*	3.61*	1.13

N: Indicates insufficient data (less than 25 observations).
* Indicates statistically significant difference between the two means at significance level 0.05.

household size. It might be argued that the temporal instability in household size rates shown in Table 3 resulted in part from not considering automobile ownership as well. Although somewhat more stable than the results with household size alone, the results in Table 9 still show a significant increase in trip rates calculated from the 1987–1988 survey data. Excluding cells with insufficient data, these rate increases range from about 13 percent to well over 100 percent. Cross-classification by automobile ownership does not eliminate the tendency of household size stratifications to be temporally unstable.

It is possible that cross-classification by area type as well might improve the stability of household size strata. This method would take into account the massive decentralization that has occurred since 1960. Households located in low-density areas of the region probably make more intensive use of their automobiles than do their urban counterparts. However, this three-way matrix contains far too many cells to be adequately estimated by the 2,424 responses from the 1987–1988 survey. Cross-classification by household size and area type alone does not improve the temporal stability of trip generation rates.

Because of decentralization, cross-classification by area type as well as by automobile ownership might be expected to improve temporal stability. In addition, accurate estimation of zonal home-based nonwork trip ends in cross-section (for a given year) often requires stratification by both automobile ownership and area type. Table 10 shows that this structure produced a relatively stable set of rates except for zero-car households, which have experienced a large increase in trip making in urban, suburban, and possibly rural areas (27 to 88 percent). Only four of these rates show significant statistical differences. Trip rate differences for car-owning households are almost always near or below the 10 percent limit for planning significance.

Table 11 presents the impact of these trip rate changes on census tract level home-based nonwork trip generation results on the basis of the 1980 census. Household size continues to be unstable, whether cross-classified by income or automobile ownership. Both models that include this variable have large RMS differences (30 and 34 percent) with significant UM and US components. Automobile ownership is somewhat more temporally stable than income. However, the introduction of area type as well produces slightly less stable rates for both variables, compared with simple stratifications (see Tables 4 and 5). Because of reductions in the trip rate standard deviations, there appears to be a small trade-off between accuracy in cross-section and temporal stability when area type stratifications are introduced. Automobile ownership continues to show temporal stability in regional totals for home-based nonwork travel.

However, the tendency of larger automobile ownership categories to have negative trip rate differences, seen in Table 5, largely disappears when area type strata are introduced. This change may result in part from the inclusion of the automobile-dependent portion of the nine-county region beyond the Penn Jersey cordon into the calculation of the 1987–1988 trip rates. When stratified by area type, there is little

TABLE 10 COMPARISON OF HOME-BASED NONWORK HOUSEHOLD TRIP RATES STRATIFIED BY AUTOMOBILE OWNERSHIP AND AREA TYPE

	Cars Per Household			
	0	1	2	3+
Central Business District				
1987-88 Survey	0.40^{N}	1.88^{N}	2.00^{N}	N
1960 Survey	0.41	1.29	1.76	2.00^{N}
Percent Diff.	-2.44	45.74	13.64	N
"t" Statistic	0.03	0.78	0.14	N
Urban				
1987-88 Survey	1.00	1.91	3.24	3.03
1960 Survey	0.53	1.73	2.64^{N}	3.43
Percent Diff.	88.68	10.40	22.73	-11.66
"t" Statistic	4.23*	1.06	2.07*	0.64
Suburban				
1987-88 Survey	1.19	2.47	3.83	4.63
1960 Survey	0.65	2.79	3.95	4.48
Percent Diff.	83.08	-11.47	-3.04	3.35
"t" Statistic	3.00*	1.99*	0.67	0.46
Rural				
1987-88 Survey	0.78^{N}	2.73	3.81	4.43^{N}
1960 Survey	0.61	2.83	3.79	3.83
Percent Diff.	27.87	-3.53	0.53	15.67
"t" Statistic	0.34	0.29	0.06	1.13

N: Indicates insufficient data (less than 25 observations).
* Indicates statistically significant difference between the two means at significance level 0.05.

TABLE 11 DIFFERENCE BETWEEN HOME-BASED NONWORK HOUSEHOLD ZONAL TRIP GENERATION ESTIMATES FOR SELECTED TWO-DIMENSIONAL STRATIFICATIONS

Stratification Scheme	Region Trip Total (10^{6})		% RMS	Theil Statistics		
	1960 Rates	1987-88 Rates	DIFF.	UM	US	UC
Auto Ownership by Household Size	3.0	4.0	30.20	0.68	0.26	0.06
Income by Household Size	3.1	4.4	34.10	0.70	0.25	0.04
Auto Ownership by Area Type	3.4	3.6	12.18	0.15	0.02	0.83
Income by Area Type	3.3	3.9	21.80	0.48	0.05	0.47

consistent evidence of the decline in automobile trip rates that is implied from the factor analyses of Kitamura and Kostyniuk (*6*) and others. The rapid development of rural areas on the fringe of the region significantly increases the automobile-related travel needs of households relocating from denser, less automobile-dependent areas. In addition, the high insurance and other operating costs associated with automobile ownership may tend to discourage households from keeping underused vehicles.

Temporal Stability of Total Travel Estimates from Composite Models

Most operational trip generation models are composites in the sense that different combinations of stratification variables are used for each trip purpose. This procedure allows differences in individual trip purpose models to cancel out in ways other than those shown in Tables 3, 4, and 5. Table 12 summarizes the differences in zonal total trip estimates from stylized composite models on the basis of income and automobile ownership. These differences resulted from the application of 1960 and 1987–1988 survey rates to 1980 census inputs. Home-based work rates (per employed resident) for the nine-county region were stratified by area type, home-based nonwork trip rates were cross-classified by area type and automobile ownership or income, and home-based school and non-home-based trips were stratified by automobile ownership or income. The automobile ownership composite model is similar to DVRPC's trip generation model (developed in the early 1970s during the resimulation study), except that in this model

TABLE 12 TOTAL TRIP GENERATION ESTIMATES FROM COMPOSITE MODELS

Model	Region Trip Total (10^6)		% RMS	Theil Statistics		
	1960 Rates	1987-88 Rates	DIFF.	UM	US	UC
Auto Ownership	7.6	7.8	6.98	0.08	0.03	0.89
Income	7.6	8.3	12.70	0.45	0.04	0.51

school travel is included with home-based nonwork travel and non-home-based trips are generated as zonal origins on the basis of employment and the number of occupied dwelling units. Because neither end of these trips is at the home, household variables cannot be applied except perhaps to produce non-home-based regional control totals.

Overall, the automobile ownership model showed good stability with only 3 percent difference in the regional total of trips and 7 percent RMS difference at the tract level, with most differences due to incomplete covariation. The income-based model was not quite as stable (9 percent difference at the regional level and 12.7 percent tract level RMS difference with a significant UM component) but was still reasonably good given that almost 30 years had passed between the surveys.

CONCLUSIONS

Clearly, the selection of variables used in the cross-classification scheme has great impact on the temporal stability of the resulting trip generation model in the Delaware Valley region:

- Internal to the Penn Jersey cordon area, home-based work trip rates were most stable when stratified by household size, as a result of compensating changes in household size and labor force participation rates and increases in the percentage of internal-external trips over time.
- The location of the cordon line has a significant impact on internal work trip rates because of a relatively long trip length and the large amount of residential and commercial development now located near or outside of the Penn Jersey cordon.
- When viewed from the perspective of work trips per employed resident, home-based work trips within the nine-county region have declined by about 14 percent, on average, since 1960.
- Household home-based nonwork trip rates stratified by household size were temporally unstable even when cross-classified by income, automobile ownership, or area type. A three-way cross-classification by household size, automobile ownership (or income), and area type may improve stability, but the sample size of the 1987–1988 survey was too small to estimate this model.
- Automobile ownership appears somewhat more temporally stable for home-based nonwork trip rates than income, although these variables have similar patterns of stability because of covariation.
- A home-based nonwork model, cross-classified by automobile ownership and area type, displayed reasonably good stability except for zero-car households, for which trip rates have increased significantly over time.
- Household non-home-based trip rates have increased significantly regardless of the variables used in cross-classification.
- A realistic composite trip generation model using appropriate combinations of automobile ownership and area type strata for each trip purpose displayed excellent temporal stability in the Delaware Valley region, with less than 7 percent RMS difference between zonal total trip estimates on the basis of the 1960 and 1987–1988 rates.

This apparent temporal stability in part results from compensating changes in individual rates and therefore does not guarantee accurate long-range forecasts, particularly when significant travel determinants, omitted from the model, change over time. In addition, errors in the forecasts of the socioeconomic trip generation inputs significantly influence the accuracy of trip forecasts. However, appropriately specified disaggregate trip generation models may be sufficiently stable to be valuable tools for testing long-range transportation plans.

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Impacts of Zonal Reconfigurations on Travel Demand Forecasts

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The question of whether travel demand estimates can be improved through the subdivision of certain traffic analysis zones for the future year projection period is investigated. Because traffic analysis zone systems were likely developed in the 1960s for most regional studies, the larger and less populated zones have probably experienced significant growth over the past 20 to 30 years. Criteria are needed to determine which traffic analysis zones should be subdivided in the process of forecasting future travel and to test whether increasing the number of zones improves the resultant regional forecasts. Subarea techniques have been developed and applied by others in attempts to develop more accurate traffic data for project-specific needs. The subarea approach suffices for project needs, but the adjustments and modifications are not usually fed back into the regional modeling process. Therefore, the time and effort expended in obtaining project data are not applied to the improvement of the overall travel demand forecasts on a studywide or regional basis. Under these conditions, system planning efforts and corridor analyses do not receive the benefit of updated information or system refinements. The findings presented evaluate the improvement in travel forecasts as a result of the subdivision of zones in a regional travel demand model. Link-by-link comparisons of traffic assignments based on the original zone system and the modified zone system are made. Two major sections are provided: (a) the development of techniques to identify zones that are candidates for subdivision and (b) a test of the results of the impact on subsequent traffic assignments for the original and modified zone systems.

In the early days of travel demand model development, the interaction among travel and population, land use, and socioeconomic characteristics was aggregated to establish an average relationship that could be applied on a geographical or areal basis. These spatial definitions were called traffic analysis zones. Zones were defined through criteria that suggested areas of homogeneous land use activity characteristics. For example, zones could be configured to contain a predetermined level of population. Physically, these zones were usually coincident with, or were subdivisions of, census tracts and enumeration districts. Where possible, zone boundaries followed natural and manmade barriers such as rivers, railroads, and highways.

Most of the traditional modeling processes were initially applied to a base year so that the predictive techniques could be compared with existing data, thus providing a basis for calibration of the models. For these models, an assumption was made that once the relationships were established and tested, the same associations would hold true for future time periods. A major feature of this procedure was that the spatial configuration of the traffic analysis zones would remain the same. Only the land use activity data assigned to each zone would vary between study years.

The question of whether travel demand estimates can be improved through the reconfiguration of traffic analysis zones for the future year projection period is investigated. Procedures are developed and applied to the travel demand forecasting process to assess whether more accurate traffic assignments can be achieved through structuring a more representative and reasonable spatial allocation of future land development (e.g., traffic analysis zones). The primary objectives are to develop criteria for use in deciding which traffic analysis zones should be reconfigured in the process of forecasting future travel and to test whether increasing the number of zones improves the resultant regional forecasts.

Because the original travel demand models were developed as a long-range, systemwide planning tool, little attention has been given to the task of establishing traffic analysis zones in comparison with other elements of the modeling process. In his paper on the design of zonal systems, Baass (*1*,p.1) found that a literature review revealed only general information on how zonal systems are to be defined. Openshaw (*2*,p.169) found that the configuration of the zonal system affects planning models more than is generally believed.

As applications of the travel demand forecasts evolved from a systems planning level to a project data level, attempts were made to refine the process and to reduce the labor and computer time required to generate more detailed traffic estimates. In *NCHRP Report 255* (*3*,p.14), Pedersen and Samdahl summarize the results of state and local planning agency surveys conducted to identify the best techniques in use for making the shift from system to project analyses. Few agencies reported the use of standardized procedures to refine system-level traffic forecasts for use at the project level. Most of the agencies used some type of comparison between model data and ground counts. The typical approach was to combine engineering judgment with a local knowledge of historical traffic data and changes in land use.

Pedersen and Samdahl (*3*) conclude that most agencies do not have procedures for developing traffic data for a network more detailed than that used for system-level forecasts. However, they do identify procedures to refine traffic forecasts and they make reference to the windowing and focusing techniques that have been used to develop improved travel forecasts for specific subareas.

A continuation of *NCHRP Report 255* was carried out by ITE Technical Council Committee 6F-34 (*4*,p.43). The objective of the research effort was to assess the use of systems-level, computer-generated traffic forecasts in project-level ap-

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plications. One of the commonly reported sources of error in traffic forecasts developed through the use of computer models was land use forecasts. Significant indicators restricting the use of forecasts were the route-level assignments and compensation for excessively large traffic zones. It is also significant that only one-half of the respondents to the ITE survey indicated that the preparer of the forecasts and the user were the same, which supports the contention that refinements made for project-level data do not find their way back into the predictive models.

The majority of areawide transportation studies were originated in the early 1960s. Little attention has been given to applying and testing techniques for determining the sensitivity and impact of realigning or reconfiguring the traffic analysis zone. When this concept has been applied, the motivation has been provided by a need for detailed project data. There is still a need for improved travel forecast data to provide accurate answers to questions that arise in evaluating alternative corridor studies.

In assessing the functionality and utility of the data available from older studies and their application to alternative corridor evaluations, it seems appropriate that the windowing and focusing techniques might be applied to a larger-scale analysis in contrast to being limited to local project data. This study is directed to determining whether there is a benefit to reexamining the traffic analysis zone structure in a regional study area context and whether the traffic assignments resulting from the reconfiguration of traffic analysis zones will yield improved results.

LITERATURE REVIEW

Early literature on travel demand processes focuses on travel inventories and trip generation techniques. A U.S. Department of Transportation publication (*5*,p.55) that documents the development of trip generation relationships devotes a few sentences to the purpose and importance of the traffic analysis zone. The early trip generation models are based on aggregate relationships, represented by studywide averages that were then applied at the traffic analysis zone level. The report states that enough observations must be aggregated to have statistically stable data to discern consistent group travel patterns.

A later study (*6*,p.14) that documented the process for urban origin-destination (O-D) surveys, the basic data from which trip generation relationships are derived, recognized the importance of the traffic analysis zone in terms of the need for statistical reliability and particularly its relationship to the street and highway network. The study also acknowledges that the traffic analysis zone must be suitable for coding, tabulating, modeling, and analyzing the resultant travel forecasts. A significant statement made in the report is that traffic analysis zone configurations might have to be changed at some time to allow more detailed analyses, to more nearly reflect land use and transportation changes that have occurred in the area, or simply to improve an initial zonal system that may not be adequate. The cited work also states that, for different levels of planning, different zone sizes are often used. The final advice offered in the report is that zones must be small enough to avoid the possibility of a large percentage of trips being intrazonal trips, preferably not to exceed 15 percent of total trips.

A document (*7*) that details the process of coding a network for trip distribution and assignment glosses over the traffic analysis zone development procedures and only makes reference to the centroid and the importance of its location within the zone.

Rowan et al. (*8*,p.4-1) highlight the policy implications of land use and transportation relationships and the interaction between activity patterns and travel demand. These considerations directly translate into similar characteristics in the modeling process. How land use is represented in the models, via the traffic analysis zone configurations, and how it interfaces with the transportation network establishes the framework for testing future alternative transportation system improvements.

Lockwood (*9*,p.521) suggests that procedures for highway and transit project planning should be revised to reflect the fact that many of the more detailed decisions will be made at the corridor planning level. Thus, it might be necessary to undertake major revisions in regional systems plans. Associated simulation models must be capable of testing alternatives relatively quickly and at a low cost.

A survey of urban policy issues, as summarized by Sosslau et al. (*10*), indicates an acknowledgment of shifts in emphasis within the transportation planning process by participating planning agencies. Key to the topic of this proposed research are changes from (a) regional scale to subarea or corridor scales, (b) coarse measures to detailed measures, (c) expensive processes to less costly processes, (d) new O-D data to use of old data with updated land use, and (e) voluminous output data to summaries and graphics.

Each of the preceding documents, in one aspect or another, indicates a need for improving the reliability and acceptability of travel demand forecasts. Practitioners and academicians recognize the weaknesses inherent in using aged data supplemented only by small-scale updates, which promotes the proposition that the zonal structure and associated transportation system connections need revisiting.

Other references discuss the development of zonal structure—some dealing with the early studies and some with later efforts to refine travel forecasts. The most definitive explanation of a method to develop traffic analysis zones is provided by Sosslau et al. (*11*) in a traffic assignment manual. The manual states that the establishment of zones should be consistent with the objectives of the desired results. Larger zones are suitable for regional-level planning needs, whereas more detailed studies require smaller zones. The manual further declares that, within practical limits of accuracy and reliability, smaller zones will achieve better results. At the time of publication in 1973, computer technology and capacity had improved, but not to the point at which large transportation networks could be processed efficiently. This limitation is the basis for the caution provided in the literature regarding zone size and numbers. Sosslau et al. predict that more improvements would be made in subarea analysis to provide detailed assignments. They also suggest that it is necessary to design the zone and network base systems to react to specific uses and needs. The manual includes a description of procedures for establishment of traffic analysis zones.

Golob et al. (*12*,p.16) suggest a technique whereby a large, complex urban region can be reduced to smaller subregions for transportation planning purposes. However, the statistical method operates on the trip matrix and does not alter the basic zone structure or transportation network.

The transition from long-range planning models to an emphasis on smaller areas within an urban region is examined by Norris and Nihan (*13*,p.589). They discuss a process whereby analysis zones to be studied in greater detail are subdivided and those outside the area are aggregated. The basic philosophy in developing a subarea zone structure was to divide each traffic analysis zone into two or three subzones along lines that typify homogeneous areas.

Other techniques were developed in the early 1980s in which small areas were modeled to develop traffic estimates for subdivisions or other development projects. Kahn (*14*,p.18) reports on such a technique to prepare peak-hour traffic impacts. The procedure is an option to the areawide studies previously conducted that do not have the level of detail required for assessing environmental impacts of traffic, noise, and air.

The literature review reveals that there is a need for refined traffic data for project-related demands and that the areawide studies that provide the base information are too coarse. Further, the techniques used for subarea analysis are isolated from the areawide studies, and refinements are not generally fed back into the regional travel demand modeling process. Therefore, it is common that impacts identified in one area are not considered in the development of data for some other subarea analysis nearby.

The lack of importance given to the traffic analysis zone as the backbone of the modeling process is also apparent. Once an analysis zone has been identified, its configuration usually remains intact. Growth in land use activity data is allocated to the future year for updates, but the zones are not subdivided to provide a more logical representation of existing and, subsequently, future conditions.

APPROACH

The practical application focuses on the development of a process through which traffic analysis zones in a selected travel demand model will be reconfigured to account for changes in population and land use activity data.

Past research has skirted the issue of traffic analysis zone changes. Practitioners and academicians have concentrated on trip generation techniques, reviewed the trip distribution models, and advanced the state-of-the-art of traffic assignment algorithms and techniques. Although each of these elements has improved the models considerably, the basic traffic analysis zone structure has remained unchanged in the planning process.

Consider a traffic analysis zone that in the early 1960s was open space with wetland areas. The transportation planner likely considered the area developable, because at that time it was not unusual to fill wetlands for development. Traffic analysis zones were defined, and the typical land use activity data were allocated for the conditions that existed at the time. Similar processes were followed for forecast years, usually in increments of 5 years, to introduce the feedback effect of land development and transportation system improvements. At some future point in time, the planner was able to assess the accuracy of the model by comparing the assigned traffic to actual ground counts.

However, current regulations on land development and the environment represent constraints that did not exist when the original models were developed. In 1990 the transportation planner would function under a different set of constraints and the zones would likely have different boundaries, sizes, and centroid connections than those defined by planners in the early 1960s.

The basic goals addressed in the following paragraphs center on the identification of criteria that can be used as guidelines for deciding whether to subdivide zones and for assessing the accuracy of traffic assignments that result from a subdivided zone system. The general approach taken is to use the traffic assignments from an existing model as a base condition against which assignments resulting from the developed techniques can be tested.

To test the proposition that subdivision of certain zones for the forecast year of the travel demand estimating procedure will yield more accurate traffic assignments, it is necessary to have a baseline set of conditions against which the results of any particular method can be measured. This approach requires a reasonably contemporary model so that ground counts are available for verifying that the model does in fact synthesize travel to approximate existing data. To establish the necessary base conditions, a travel demand model that is functional and considered to be calibrated sufficiently to replicate existing conditions is used. To avoid confusion, 1970 has been termed the historical year and 1985 the forecast year.

To test methods for identifying which zones should be subdivided, the approach steps back in time to 1970 and proceeds as if 1985 were the forecast year in a so-called "back-to-the-future" scenario. This method enables land use activity changes to be analyzed using the 1985 values as projected data.

There are constants in this approach that isolate and focus the traffic analysis zone changes as being responsible for any improvements in the traffic assignment:

- The relationships between trip making and land use activity data that are established in the trip generation equations remain unchanged.
- The travel time factors used in the trip distribution technique, in this case the gravity model, remain unchanged.
- Through trips, represented by the external-to-external cells in the trip table, remain unchanged.
- The travel time changes resulting from roadway system improvements between 1970 and 1985 are the same for the baseline conditions and the test forecast scenarios, thus nullifying any impacts in the trip assignment phase that might result from system improvements.

These conditions serve to support the desired objective—that of testing the influence of traffic analysis zone reconfigurations on traffic assignments.

The ultimate test of whether the manipulation of certain traffic analysis zone data improves traffic assignments is determined through a comparative analysis of selected link volumes that are represented by ground counts, original assignments, and an alternative assignment that results from changing the number of zones in the system. Figure 1 shows the efforts required to identify and subdivide certain zones and to test the resultant traffic forecasts.

The models and data used to develop the techniques suggested for improving travel forecasts were developed for New Castle County by the Delaware Department of Transportation. New Castle County comprises approximately the northern half of the state of Delaware. The study area for this region contains 204 internal traffic analysis zones and 24 external zones.

This model was selected because of the following features:

- The study area size and number of zones are manageable for manipulation.
- An ambitious traffic counting program by the department provides an abundance of locations that have current average annual daily traffic (AADT) data on roadways in the study area.
- The models have been calibrated to replicate existing conditions.
- The traffic forecasts produced by the models provide data for planning projects and for the evaluation of travel conditions throughout the county.
- The central region of the New Castle County study area, between Wilmington and Newark, has undergone rapid growth in the past few years, particularly in areas that were relatively undeveloped and were initially represented by relatively few traffic analysis zones.
- The process uses the traditional four-step process of trip generation, modal split, trip distribution, and trip assignment.

ZONE IDENTIFICATION CRITERIA

The analysis of the household and employment data characteristics used for estimating future travel form the basis for the identification of traffic analysis zones that are candidates for reduction into smaller units.

Key to this determination is the establishment of threshold levels of increases in the variables between the base and forecast years. For the New Castle County system of 204 internal traffic analysis zones, a systematic approach to evaluating the impact of growth on projected travel is developed so that realistic decisions can be made. The values and stratification of data will vary among regions in other areas of the country, and the techniques developed can be applied to different studies within the values of the specific travel demand forecasts for those studies.

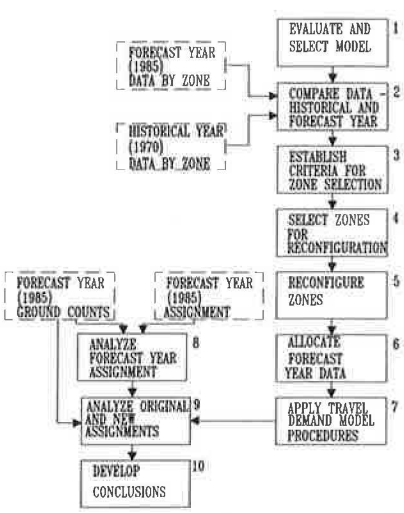

FIGURE 1 Techniques development and testing process.

The main objective is to assess which land use activity data indicate a level of traffic analysis zone growth that differs significantly from other zones and that might influence travel patterns in the more immediate area.

Six approaches were developed to achieve this objective. The different methods and procedures are described in the following paragraphs.

Method 1

Household and employment characteristics are used in Method 1 to identify traffic analysis zones that will produce greater than average travel in the future. The availability of these data, by traffic analysis zones for 1970 and 1985, provide an opportunity to assume the present is 1970. The task is to determine what the traffic analysis zone structure should be like in 1985. The initial assumption is that some zones will likely develop in a manner inconsistent with the planner's 1970 viewpoint of the future.

A first cut at screening the 204 zones for reconfiguration candidates is accomplished by setting up spreadsheets on a microcomputer and establishing a base file for the following two sets of data:

- Household characteristics:
  - Population,
  - Dwelling units, and
  - Automobiles.
- Employment characteristics:
  - Manufacturing,
  - Industrial,
  - Commercial,
  - Community service, and
  - Retail.

The spreadsheets are arranged to facilitate the calculation of the absolute change and the percent change between 1970 and 1985 for each of the preceding characteristics.

Because decreases typically occurred in some center-city zones between 1970 and 1985, a number of the 204 observations had negative differences. These are deleted from the universe of observations as nonfunctional for the intended purpose.

The next step is to sort on the absolute difference column of each characteristic in ascending order. This secondary screening promptly made obvious those zones that were to experience reasonable growth. The term "reasonable" requires definition at this point. For an initial evaluation, zones that had an increase in activity greater than an absolute value of equal to or greater than 1,000 and a percent increase greater than or equal to 100 percent were highlighted. The use of the absolute difference or percentage difference alone is not as meaningful as when used in combination. A large increase in absolute value could represent a small percent increase for a large zone, which means that activity within the zone did not increase much over that existing in 1970. Conversely, a large percent increase could be caused by the doubling or tripling of a small number. The most significant and meaningful relationship as a potential indicator is one that has a large increase in both absolute and percent values.

To establish preliminary criteria for screening candidate zones, the absolute and percent changes of each of the independent variables used in the trip generation process are evaluated. The variables are plotted individually on a base map of the traffic analysis zones to assess the potential impact on certain zones. The changes in land use activity that are expected to occur over the 15-year period indicated no discernible pattern and did not result in a clear picture of candidate zones.

At first, this method appeared to be a quick screening technique. However, it was judged to be nonindicative: evaluating seven land use activity increases as separate quantities lessens the significance one might expect, as opposed to evaluating a collective or aggregate measure. Combining the employment into a total value somewhat improved this deficiency, but only reduced the number of values to be evaluated without improving the significance of the approach as an indicator of growth.

Method 2

Method 2 assumes that land use activity, expressed in terms of trip productions and attractions, is more closely related to the eventual traffic assignment that is to be tested against a base condition.

In Method 2, productions and attractions are generated for 1970 and 1985; the growth, represented by the increase between the two time periods, is then evaluated. A spreadsheet is also used for this procedure. Through a manipulation of the base files created for Method 1, the calculation of productions and attractions is performed for each trip purpose and totaled for each zone. Zones in which negative values are experienced are eliminated. The balance of the zones with positive values are sorted into ascending order. For a preliminary screening of the results, the following arbitrary limits for absolute and percent changes in values were established on the basis of the resulting data:

- Absolute change ≥ 1,000 and percent change ≥ 25 and < 50.
- Absolute change ≥ 1,000 and percent change ≥ 50 and < 100.
- Absolute change ≥ 1,000 and percent change ≥ 100.

An inspection of the sorted data reveals that approximately 60 zones meet the combined tests of the absolute value greater than or equal to 1,000 and a greater than or equal to 50 percent increase. These values for productions and attractions were plotted on a traffic analysis zone map and color coded. Following this step, an inspection of zones with production and attraction values of reasonable magnitude begins to emerge into a pattern of zones that form two geographically distinct areas.

To refine the process, the sorted values are again assessed and reduced to those zones that represent 10,000 or more trip ends. These zones are identified graphically by color, and three geographical groups of zones become obvious. One of the zone groups is located near the city of Wilmington, where the zones are significantly smaller than in the other two areas. The absolute increase and percent increase typical of the zones in these groups are greater than or equal to 11,000 and 128 percent, respectively. Again, these limits are probably significant only in New Castle County. Through a similar process, specific limits can be established for application in other study areas.

Method 3

Method 3 also considers the change in productions and attractions between 1970 and 1985. Those zones with a total of productions and attractions greater than 19,000 are plotted on a zone map. The value of 19,000 is arbitrary and of significance only to New Castle County. Other regions will likely produce a different threshold, depending on their basic characteristics.

Six zones meet this criterion, with values ranging from 19,151 to 31,190.

Method 4

A variation of Method 3, this approach considers those zones that demonstrate a total production and attraction value greater than 30,000 for 1985. Normally, a difference in two time periods demonstrates growth, as in Method 3. However, an evaluation of zones that generate a large number of trip ends is thought to possibly provide an indication of the total measure of traffic for the future, which is the value that is eventually evaluated against actual conditions.

This method identified six zones as meeting this criterion, with values ranging from 30,318 to 40,925.

Method 5

Method 5 uses the total trip ends generated for each traffic analysis zone and their relationship to the geographic area of each zone. The area of each zone, except for those classified as City, is measured in acres using a planimeter. The ratio of total trip ends to the acreage of each zone represents a trip-end density measure that can be used to screen candidate zones and to identify those that are to be considered for reconfiguration.

To establish a basis for evaluating which zones are to be considered further, center-city zones are deleted from the trip-end density list because of their small areas and therefore are not candidates for subdivision. A file is created from the remaining zones to produce a list of trip-end densities. Trip-end densities range from a low of 0.11 trip ends per acre to a high of 60.23 trip ends per acre.

Kahn (*15*,p.284) reports a national average trip generation rate of approximately 26 trip ends per acre. An arbitrary value approximately 50 percent greater than this rate, or 40 trip ends per acre, is used to screen zones with trip-end densities that, in 1985, are candidates for reconfiguration. Fourteen zones had trip-end densities ranging from 40 to 60 trip ends per acre.

Some of the zones identified by this means have areas ranging from 195 to 590 acres, resulting in higher trip end per acre values than some zones that have larger acreage values with comparable trip-end values. These conditions must be considered in the final candidate zone selection procedure.

Method 6

The final approach to evaluating criteria to determine which zones are to be reconfigured used the change in trip ends from 1970 to 1985 and the size of each zone in acres. Trip-end densities, expressed in trip ends per acre, are calculated. An inspection of the resultant ratios indicated that a group of six zones have trip densities greater than 20 trip ends per acre. These six zones are plotted on a zone map to examine their distribution within the New Castle County study area. There is no distinct grouping; the zones are scattered about the region. For these six zones, the change in trip ends per acre between 1970 and 1985 ranges from 21 to 35.

With the exception of Method 1, each approach generates a set of zones to be considered for reconfiguration. In some cases, multiple methods identify common zones. However, these techniques are screening processes, and the final decision of which zones are to be reconfigured must be tempered with sound planning judgment.

Graphically plotting the zones that meet each of the criteria is helpful in visually assessing the results. Common zones become apparent, as do groupings of zones in certain geographical areas. Table 1 presents the zones that are identified by each method, with the exception of Method 1, and the commonality between methods. Acres and trip ends are also presented to assist in further evaluating the candidacy of the zones.

An examination of the data in Table 1, specifically the size of the zone in acres and the magnitude of travel activity in terms of trip ends, indicates some zones that could be eliminated from further consideration. Zones 105, 110, and 118 are three of the smallest in area and were not likely candidates for reconfiguration on that basis alone. The highway network in these zones is detailed, and subdivision will not likely improve traffic assignments to roadway segments in the immediate area.

TABLE 1 CANDIDATE ZONES

Zone	Method	Acres	Increase In Trip Ends (1970 to 1985)
105	2,6	400	14,100
109	2,4	1,240	14,500
110	5,6	200	5,800
117	2	1,910	16,700
118	2,4,5,6	590	18,100
139	4	1,750	30,300
142	4	1,750	40,900
146	3	2,150	26,300
150	2,3	1,430	27,300
151	2,3,4,6	970	31,200
157	2,3,4	1,860	25,800
159	2,3,6	920	19,200
167	3	2,120	20,700

ZONE RECONFIGURATION PROCEDURE

Before identifying the traffic analysis zones that are to be subdivided, some process must be applied to redefine the candidate zones into two or more new zones. Because each zone has a unique configuration, the 10 zones selected are individually analyzed. This approach provides an opportunity to consider a number of variables, in contrast to computer-generated procedures that deprive the practitioner of the ability to exercise judgment and apply knowledge of the area.

Components of the zone structure to be evaluated include, but are not necessarily limited to, its shape, natural and man-made barriers, public parklands, golf courses, cemeteries, water bodies, other land forms typically considered undevelopable, and the streets and highways that are part of the boundaries and that provide access to or through the zone. The number of trips generated in each zone and the physical size of the zone also need to be considered.

Each of the 10 zones identified were individually inspected and assessed according to the basic concepts described previously. When Zone 139 was inspected on the 1970 base map, it was revealed that half of the zone was wetlands and all of the land use activity was concentrated in the other half, which left little room for reconfiguration. Zone 139 was dropped from further consideration, reducing the list of candidate zones to nine. Attempts were made to establish commonalities that might exist so that threshold criteria might develop out of this procedure. The zones are taken from a 1970 base map to maintain consistency with the back-to-the-future concept. Approximately 6,000 to 8,000 trip ends constitute a basis for new zones. An allocation of the amount of growth projected to occur in each new zone was made and subsequently translated into productions and attractions to facilitate application of the travel demand process. Centroids and centroid connectors for the new zones were located in accordance with accepted methods for network development.

Following the subdivision of the selected traffic analysis zones, the population and land use activity data were reallocated. Zone numbering was modified to account for the additional units. Within this scheme, the last internal zone changes from 204 to 218. This change requires that the external centroids, which represent loading nodes for external trips, be renumbered from the existing range of 205–228 to a new range of 219–242. To accommodate the zone changes, centroids for the newly created zones, and in some cases the existing zone centroids, needed to be relocated for the 1985 future year highway network. Each zone was evaluated to determine which points on the highway network best represent access to the system for the new zones. When the addition of a node to provide a centroid connection was found to be necessary, the existing link is broken to accommodate a new node. Each of these changes is coded in accordance with the minimum path-building program to ensure compatibility with the original 1985 network description. The reallocated zonal land use activity and the highway network modifications described in this section were input to the model process to develop a 1985 future trip assignment.

ANALYSIS

To establish a naming convention for the described assignments, the New Castle County assignment for the original model forecast year is referred to as the 1985 NCC assignment. The 1985 traffic volume counts extracted from the Delaware Department of Transportation traffic summary (*16*) for selected links throughout the study area are called the 1985 GC (ground counts) volumes. Finally, the traffic assignments generated for the reconfigured zonal system are referred to as the 1985 CCC assignment (for the author, C. C. Crevo).

The benchmark traffic volumes (1985 GC) were selected by an inspection of the 1985 simulated highway network and a state system map that designated roadways by administrative classification. There are four such classifications: federal-aid primary (FAP), federal-aid secondary (FAS), federal-aid urban (FAU), and local jurisdiction roadway (LOC).

Because the 1985 GC data recorded in the traffic summary report provide comprehensive coverage of all administrative classifications, sections of roadway are selected from the state roadway map to create a list for each of the four groups. Between 30 and 60 segments in each classification are so identified. Each segment is then related to a link in the 1985 simulated highway network. These data are used as input to the analyses that follow to determine whether the 1985 NCC or 1985 CCC assignments more realistically and accurately approximate the 1985 GC data.

The objective of applying statistical measurements to the two traffic assignments, 1985 NCC and 1985 CCC, is to evaluate each against known values, represented by the traffic count data, 1985 GC. The evaluation sought is to determine whether the 1985 CCC assignment reveals any improvement in contrast to the 1985 NCC assignment. In the simplest and most laborious form, the analysis could be conducted by comparing link volumes for each of the two assignments against the ground counts for the link and judging whether or not there is an improvement.

This technique, using quantitative comparisons and absolute comparisons, is applied to obtain a general assessment of the differences that exist for the study area as a whole and to determine if subclasses of link data need to be evaluated to reveal more localized differences in link assignments. In addition to the quantitative comparisons, a statistical technique that results in recognizable measures needs to be employed. A review of statistical techniques reveals that a limited number of options are available. Because an evaluation of causation is not the objective of this analysis, most statistical techniques do not satisfy the needs of this study. The technique selected for the comparison of the effectiveness of the 1985 NCC and CCC model assignments is to apply separate linear regression analyses to 1985 GC versus 1985 NCC and 1985 GC versus 1985 CCC.

This approach provides certain measures of the relationship of the pairs of observations; by performing calculations for 1985 GC versus 1985 NCC and 1985 GC versus 1985 CCC, the ability of each assignment to more nearly replicate the 1985 GC can be determined on a relative basis. The coefficient of correlation is a value that can be compared as an indicator of relative improvement. Also, using a scatter plot with a regression line of best fit graphically represents the relative relationships of the two generated traffic assignments to the actual traffic counts.

Although the suggested application of linear regression analysis to this case might not be considered rigorous in terms of pure statistics, it serves to establish a measure of the applicability of the proposition set forth in this research. The intended outcome is to develop a pragmatic approach to improve travel demand forecasts so that practitioners might apply them with some degree of confidence, at least mentally if not statistically.

In summary, the objective of the analysis at this point is not to try to establish how well each of the forecasting methods approximates actual conditions, but whether one (1985 NCC or 1985 CCC) set of assignments can be considered better than the other for replicating the 1985 ground counts.

A review of the travel characteristics summarized in the gravity model output provides an overview of how the two assignments compare in general. For this comparison, the internal-internal person-trip data are used. These trips represent those that are most affected by zone subdivisions and the trip generation process. The total trips vary slightly between the NCC and CCC systems due to rounding in calculations. Table 2 presents the comparisons of internal-internal person trips for total trips, trip hours, average trip length in minutes, and intrazonal trips.

There are few significant differences between the assignments. Interestingly, the intrazonal trips for each purpose, except shopping, are less for the CCC system. Although the difference is not great, it was expected that there would be fewer intrazonal trips. The data present no explanation as to why the shopping trips generate more intrazonals for the CCC system than for the NCC system. The cause could be that, in the New Castle County model, shopping trips are generated with retail employment in the city zones and with commercial employment in the county zones where the selected reconfigured zones are located. Preliminary indications are that subdividing a few zones, less than 4 percent in this case, will not impact overall travel in a large study area such as New Castle County.

TABLE 2 TRAVEL CHARACTERISTICS COMPARISONS

		Internal-Internal Person Trips			
		Total Trips	Trips Hours	Avg. Trip Length	Intrazonal Trips
Work	NCC	226,501	58,088	15.39	2,571
	CCC	226,468	58,241	15.43	2,435
Shop	NCC	214,638	32,497	10.76	4,811
	CCC	214,752	36,660	10.24	5,724
Other	NCC	336,670	66,788	11.90	9,231
	CCC	336,826	66,840	11.91	9,066
NHB	NCC	210,714	38,652	11.01	7,241
	CCC	211,190	38,597	10.97	7,157

A sample of 185 network system links was randomly selected to evaluate the difference between the 1985 NCC and 1985 CCC assignments. Because the zones selected for reconfiguration represent approximately 4 percent of the total and are generally located in the same geographical area, a comparison of the 185 links would probably not yield significant differences. More subtle changes are likely to occur in a comparison of the four administrative classifications (FAP, FAS, FAU, and LOC). A summary of the comparison of each of these classifications and the total for percent difference ranges is presented in Table 3.

Inspection and comparison of the data contained in the cells of the table show no significant improvement when tabulated by percent change groups, particularly when evaluated at the administrative classification levels. Not only is there no significant improvement represented by the CCC assignment in contrast to the NCC data, but in most cases, the CCC assignment is less representative.

An examination of statistics of the pairs of data, as discussed previously, does not necessarily suggest a predictive association of the two, but rather provides an opportunity to assess which theoretical set of data, the 1985 NCC or the 1985 CCC assignment, is most like the 1985 GC on a link-by-link comparison for each of the administrative classifications. These values are derived by subjecting the data to a linear regression analysis in which the 1985 GC is considered to be the independent variable and the NCC and CCC assignments are each dependent variables.

Table 4 presents a comparison of the coefficients of correlation and other data for each assignment in contrast to the ground counts. As in the other comparisons, there is little indication that reconfiguration of zones has any significant positive impact on traffic assignments. An interesting side observation is that the New Castle County model, whether the original with 228 zones or the revised with 242 zones, performs best for assignments to local roads. Coefficient of correlation (R) values better than 0.9 indicate a closer correlation between the projected volumes and the ground counts for the local system compared with similar values for the federal-aid system components.

TABLE 3 TRAFFIC ASSIGNMENT COMPARISONS

	<+10% No.	<+10% %	+11-20% No.	+11-20% %	+21-30% No.	+21-30% %	>+30% No.	>+30% %	Total No.	Total %
FAP1985 GC/NCC	18	32	11	20	8	14	19	34	56	100
1985 GC/CCC	17	30	8	14	10	18	21	38	56	100
FAS1985 GC/NCC	4	9	5	11	4	9	31	71	44	100
1985 GC/CCC	7	16	3	7	1	2	33	75	44	100
FAU1985 GC/NCC	8	15	9	16	5	9	33	60	55	100
1985 GC/CCC	10	18	6	11	7	13	32	58	55	100
LOC1985 GC/NCC	4	13	3	10	6	20	17	57	30	100
1985 GC/CCC	2	7	4	13	4	13	20	67	30	100
TOT1985 GC/NCC	34	18	28	15	23	12	100	55	185	100
1985 GC/CCC	36	19	21	11	22	12	100	58	185	100

TABLE 4 CORRELATION COMPARISONS

	R	R^2	Slope	Intercept
FAP 1985GC/NCC	0.713	0.508	0.547	10115
1985GC/CCC	0.722	0.521	0.545	9936
FAS 1985GC/NCC	0.445	0.198	0.606	2406
1985GC/CCC	0.457	0.209	0.545	2206
FAU 1985GC/NCC	0.549	0.302	0.653	4798
1985GC/CCC	0.520	0.271	0.616	5043
LOC 1985GC/NCC	0.934	0.872	1.047	46
1985GC/CCC	0.927	0.860	1.020	49

The R value indicates a measure of the goodness of fit between the dependent and independent variables. The closer R is to a value of 1.0, the closer the relationship of the total of the observations. The square of the coefficient of correlation (R^2) is a representation of the percent of variation in the dependent variable that is explained by its association with the independent variable. The slope of the regression line can be viewed as a graphical representation of the best fit of the two sets of data. For data with perfect correlation, in which each pair of observations is equal, the slope of the line is 1.0. However, a slope of 1.0 does not guarantee that each set of dependent and independent observations is equal. The intercept, or the point at which the regression line intercepts the independent variable axis, would be zero for the ideal situation in which dependent and independent pairs of observations are equal. The significance of the intercept value, as applied here, is to observe whether the intercept moves in the direction of zero when compared for the NCC and CCC assignments.

CONCLUSIONS

The evaluation of the traffic assignments (NCC and CCC) compared with the ground counts on the selected network links reveals that, for the nine zones subdivided in this exercise, the resulting assignments do not exhibit an improvement. In fact, the CCC assignment shows a lesser ability to replicate the ground counts than does the NCC assignment. The differences are so slight that the results of the statistical tests do not represent any clear advantages to the reconfigured zonal system.

However, there are some circumstances that might be influencing the outcome of the comparisons. One of the more obvious is that only nine zones were selected and subdivided into 23 new units. Although the techniques advanced here identified only the nine, it is possible that lower assumed threshold values could have increased the number of candidates for reconfiguration. The evidence available from the traffic assignment comparisons still does not offer a positive indication that a greater number of zones would increase the ability of the assignment to more nearly replicate the ground counts.

In the case of the New Castle County model, the subdivision of zones had no impact on the network. The simulated highway system is coded to such a level of detail that there were few, if any, opportunities to refine the network. Without additional simulated street segments within the newly defined zones, the traffic continues to be loaded onto a system that offers no alternatives; thus, little improvement can be expected in the assignments. When subarea focusing techniques are applied to develop project data, the network is usually expanded and refined in the process.

It was expected that smaller zones would generate fewer intrazonal trips, which they do, but again the relatively few zones that were subdivided made little difference in decreasing intrazonal trips in the New Castle County study area as a whole.

From the results of this effort, the impacts of zonal reconfigurations on travel demand forecasts appear to be negligible. However, there is no clear evidence that a greater number of subdivided zones will not produce improved forecasts, only that a reconfiguration of 9 zones of a 228-zone system that has a thoroughly detailed network will not do so.

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Highway Needs for the Year 2005

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Results of a study aimed at estimating the highway needs for 2005 are presented. The study approach is based on forecasting the travel demand using socioeconomic variables and translating the growth into lane-miles of required highway facilities. The Highway Performance Monitoring System (HPMS) data set is used to obtain information on current conditions and recent trends in usage and supply (lane-miles) of urban highway systems. The lane-miles of highway facilities, stratified by highway functional class and urban location, required to meet the expected growth in travel in urban areas of different sizes are presented. Urban travel is expected to increase at an average annual rate of between 2.36 and 2.72 percent. To accommodate this travel growth, it is estimated that, depending on the level of service desired, between 75,211 and 220,284 lane-mi of additional capacity will be required by 2005. The primary highway system (freeways, expressways, and principal arterials) accounts for over 70 percent of these needs. Freeway and expressway needs are estimated to be between 40,000 and 50,000 lane-mi. The analysis performed suggests that the suburbs of large urban areas will require the most additions in capacity, particularly of primary highway types, in future years.

The continuing suburbanization of society is overburdening the urban highway system. In 1985, for example, in metropolitan areas with more than 1 million in population, nearly 50 percent of travel on freeways and expressways occurred at volume/capacity ratios of 0.85 or greater (*1*). Many suburban or newly urbanizing areas are doing even worse as this travel continues to shift from the dominant journey of suburb to central business district (CBD) to both intra- and intersuburb trips. The highway systems in suburban areas, consisting primarily of minor arterials and local roads, are in many cases not well suited for suburb-to-suburb commuting. As the nation moves into the 1990s, urban and suburban mobility will continue to be challenged by the growth in travel demand and the shift in travel patterns. To formulate a framework of policy and program options for future highway system design, questions such as the following must be answered:

- What will be the growth rate of travel in the urban areas? How will this growth vary by urban areas of different sizes and by different regions of the country?
- What will it cost to maintain an acceptable quality of travel service in urban areas in the 1990s and beyond?
- What is the most cost-effective mix of highway facilities by functional class and by location within urbanized areas?
- What level of service (LOS) would be more economically efficient?
- Given estimates of available capital, what LOS can be expected in the future?
- How much new construction is required?

A study was undertaken as part of an ongoing research effort aimed at identifying optimal highway network configurations to accommodate future highway needs (*2*). The objective of this study was to develop a procedure for forecasting future highway travel demand in urban areas, with particular emphasis on suburban areas, and then to use that procedure to estimate suburban highway needs for 2005. The approach used to achieve this objective is based on forecasting travel demand [daily vehicle miles of travel (DVMT)] through the use of socioeconomic variables and translating the travel growth into lane-miles of required highway facilities. The Highway Performance Monitoring System (HPMS) data set is used to obtain information on current conditions and recent trends in usage and supply of urban highways.

An overview of the study methodology and its data sources is provided in the following paragraphs, along with estimates of the highway needs derived from the analysis. The future highway needs are a function of present conditions, future travel growth and its pattern, future investment (supply), and a desired LOS, among other things. The needs forecasts are presented in terms of lane-miles of highway facilities, stratified by facility type (i.e., highway functional class) and location within urban areas, required to meet the expected growth in travel in urban areas of different sizes. To account for the dynamics of urban system growth, and to illustrate the sensitivity of supply needs to LOS, a scenario analysis has been performed to estimate a range of needs resulting from different LOS and over a range of future travel growth. For example, one of the scenarios is the highway needs required to maintain the 1987 LOS in all highway functional classes.

RELATED RESEARCH

The Federal-Aid Highway Act of 1987 continues the federal-aid highway program through September 30, 1991. In advance of congressional debates in 1990 and 1991 on new highway legislation, future highway needs and the federal role in the nation's highway program have been carefully examined by FHWA. Several studies have been performed or are currently under way to identify the issues, needs, trends, technologies, and program options that will affect the nation's future highway systems. This effort is titled the Future National Highway Program (FNHP). Mid-range (2005) and long-range (2020)

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forecasts are being prepared to develop a transportation program and to define the federal role in meeting future needs. To assist the federal policy makers, a series of 19 working papers was commissioned by FHWA (*3*). Most of these papers have been completed and are being reviewed within and outside FHWA. On the basis of the findings of these papers, FHWA has prepared two reports: an interim report on the nation's future highway needs (*4*) and a report to the U.S. Congress from the Secretary of Transportation (*5*).

This research complements Working Papers 1, 2, 13, and 14 in that series. Working Papers 1 and 2 provide information on the current status of the nation's highway system and attempt to quantify the magnitude of problems expected in the future (*6,7*). In Working Paper 13 (*3*), an economic analysis was done to compare benefit-cost ratios of investment by highway functional class within urban areas. The analysis indicated that additional expenditures could be justified on all functional systems. It was suggested that, depending on the functional class, each dollar invested in capacity improvements would return \$5 to \$12 in benefits. However, the study did not differentiate the higher costs (including right-of-way costs) in the urban core versus the lower costs of development at the urban fringe. Working Paper 14 (*8*) attempted to address the shift in travel between highway functional classes. The economic analyses presented in that study relied on the current trends in share of travel to estimate the potential for shift between functional classes as the population of the urban area grows. As in the previous study, it was suggested that investments in higher functional classes (freeways and expressways) would be more economically efficient than in lower-order facilities. However, this assessment is not necessarily appropriate because the incremental utility of adding a new facility is a function of level of usage, which itself is a function of the current supply.

Other studies by Fleet and DeCorla-Souza (*1*) and by the FHWA planning Support Branch (*9,10*) looked further into current urban travel-supply relationships and the changing trends in these relationships. These studies noted a general upward trend in travel share on freeways and expressways as urban areas increase in size and concluded that LOS C was generally more economically efficient than LOS D on these facilities. The studies identified past trends in shares of travel and supply between highway functional classes and urban locations. Fleet and DeCorla-Souza developed future suburban needs assessments on the basis of aggregate population forecasts translated into square miles of density-specific land development and, thus, needed lane-miles of highway facilities. This methodology was the first such effort to estimate highway infrastructure needs from surrogate measures of land development. It included disaggregation of future travel by population ranges, and its estimate of needs by facility type was an extrapolation of the existing network found in suburban areas.

The research documented in the following paragraph is also an attempt to assess the trends in urban travel-supply relationships and to use that information in estimating future urban needs disaggregated by facility type (i.e., highway functional class), urban area size, and location within urban areas. However, a somewhat different approach is used than in the previous FHWA studies. The approach is based on working with disaggregate data (i.e., at individual urban area level) and relying more on mathematical relationships to depict the trends in future urban travel and its distribution across categories of interest.

The estimation of future highway needs requires an estimation of future travel demand. A comprehensive review of forecasting models for vehicle miles of travel (VMT) is provided by Southworth (*11*). This review covers post-1974 studies of national VMT forecasting. Traditionally, econometric forecasting approaches are used to forecast travel demand. However, these approaches do not recognize the constrained nature of travel, especially the availability of time for travel. Greene (*12*) suggests a demographic approach to long-run forecasting of highway vehicle travel. Chan (*13*) developed national urban and rural forecasting models using time-series data on VMT. An interesting three-tier approach was adapted by COMSIS (*14*). Their intent was to alleviate the difficulties associated with capturing both micro-level (individual and household) behavioral factors and macro-level (demographic and economic) trends within a single equation framework. Recently, models for short- and long-range forecasting of VMT and vehicle stocks were developed by Jack Faucett Associates (*15*). These models are capable of forecasting national VMT through 2020 and of disaggregating it by state, regions, or highway functional classes.

A final relevant research area is the modeling of urban system dynamics, particularly the evolution of urban systems over time. There is extensive literature, both theoretical and empirical, on the nature of urban growth (*16–18*). Theories cover the expansion over time of residential, industrial, and commercial development, seen as a result of population growth and demands for greater living space and in response to increasing commuting times. Griffith (*16*), for example, modeled the urban population distribution pattern using population density and activity center locations. For the purposes of this study, however, approaches based on urban system dynamics were not considered because of the unavailability of the data sources required to model the urban growth patterns, at least within the time constraints and resources available. Also, such studies have not yet seen such an application in practice.

METHODOLOGY

Typically, national highway needs estimation and investment and performance analysis studies are performed using HPMS data and analytical procedures (*19,20*). The HPMS analytical process simulates future capacity needs as needed lane-miles of improvement on the existing facilities. Thus, this procedure assumes that the growth in traffic will occur in a static network. Due to this static network configuration, the HPMS analytical process suboptimally determines the urban highway needs in three ways. First, the procedure does not include new highway facilities, that is, the new construction that may be planned in an expanding urban area. Second, the procedure does not provide the investment levels required to meet the specified needs because it only reflects the unit costs for improvements on facilities for which right-of-way is deemed to be readily available. Third, the HPMS forecasting approach does not consider the expansion of urban area boundaries, erroneously attributing much of the suburban growth to rural areas.

Despite these limitations, only HPMS contains the necessary information about the condition and use of the national highway system and about the capital investments on these highways. Because future highway travel and system requirements are a function of current conditions, such information will be necessary regardless of the forecasting procedure employed. With these considerations in mind, an approach based on supplementing the HPMS data with socioeconomic data from other sources is established.

Figure 1 is an abbreviated flow chart of the study procedure. The approach to forecasting future urban highway needs is based on estimating the growth in VMT and translating this growth into the required lane-miles of highway facilities. The methodology consists of three major analysis components: (a) forecasting growth in the levels of daily travel (DVMT) for urban areas, (b) distributing the forecast DVMT across various highway functional classes and locations within urban areas, and (c) estimating the lane-miles of highway facilities by functional class required to accommodate the growth in DVMT at specified levels of service. The detailed analysis procedure is outlined in the following paragraphs.

Step 1

Using HPMS areawide and sample data, DVMT and lane-mile data are obtained for each individual urbanized area in the United States for 1982–1988. The data are cross-tabulated by highway functional class, by location within urban areas, and by urban area size. The urban highways are categorized into four classes: freeways and expressways (HPMS Codes 11 and 12), other principal arterials (Code 14), minor arterials (Code 16), and collectors (Code 17). Three urban location categories are used: core (Codes 1 and 2), suburb (codes 2 and 3), and fringe (Codes 4 and 5). Urban areas are divided into three population groups: greater than 0.5 million (large), between 0.1 and 0.5 million (medium), and less than 0.1 million (small).

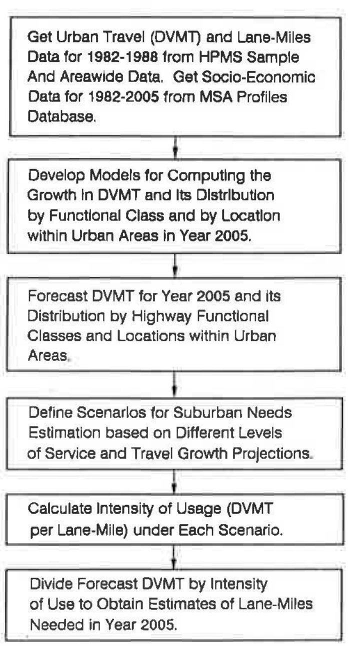

FIGURE 1 Study procedure.

Step 2

The socioeconomic data and forecasts for every metropolitan statistical area (MSA) in the United States through 2005 are obtained from MSA profiles published by Woods and Poole Economics, Inc. (*21*). The MSA data are used as a proxy for the urban areas contained by the MSA.

Step 3

Using 1982–1988 data for 339 urban areas, a pooled time-series, cross-sectional regression model is developed for forecasting total DVMT for the urban areas. In this model, DVMT per capita is used as the dependent variable, and the socioeconomic variables (number of driver licenses per 1,000 persons, household size, real income, and employment) and a measure of highway supply deficiency are used as independent variables. The supply deficiency of the primary highway system is included as an independent variable to account for the impact of constrained supply on demand for travel.

Step 4

On the basis of forecasts of socioeconomic variables for 2005, the future DVMT for each urban area is estimated. Depending on the scenario analyzed, DVMT is estimated for constrained or unconstrained conditions (by highway supply) and by high or low rates of travel growth.

Step 5

The dynamics of shift in urban travel between highway functional classes and locations within urban areas as the urban area increases in size is modeled through conditional logit models in which population is used as an explanatory variable. These logit models, together with the forecast population of the urban areas, are then used to predict the shares of travel by functional classes and by locations within urban areas in 2005. Initially, the current supply (lane-miles) was also included as an independent variable in these models. However, it was found to be highly correlated to population and had little impact on the distribution of DVMT by itself.

Step 6

The estimate of suburban needs (lane-miles) is then obtained by dividing the forecast DVMT in each category by a service index (DVMT per lane-mile) corresponding to desired LOS in five different scenarios:

1. 1987 service index, constrained demand, and low rate of travel growth;

2. 1987 service index, constrained demand, and high rate of travel growth;
3. Desired service index (DSI), constrained demand, and low travel growth;
4. DSI, constrained demand, and high travel growth; and
5. DSI, unconstrained demand, and high travel growth.

The term "service index" has the same meaning as average intensity of use in other studies. Here, the service index represents the level of service desired by the policy makers or planners. DSI is a service level comparable to LOS C on highway segments in small and medium-size urban areas and LOS D in large urban areas.

MODELS

Three models were developed in this study. The first is a regression model for forecasting DVMT for urban areas in 2005. The second and third models are conditional logit models that forecast the future shares of travel across highway functional classes and locations within urban areas, respectively. A brief description of these models is given in this section. The major findings derived from these models are presented in the following section. A companion paper (*22*) describes these models in detail.

DVMT Forecasting Model

The choice of DVMT forecasting model is based on several factors: (a) forecast horizon (midrange), (b) available time-series and cross-sectional data, (c) differences in travel demand among urban areas, and (d) future forecasts as more time-series data become available. The final model of choice is one in which a varying intercept term is assumed to capture the differences in travel behavior over individual urban areas and the slope coefficients are assumed to be constant within a group of urban areas with similar populations. The model has the following form:

$$Y_{it} = \beta_{0i} + \sum_{j=1}^{6} \sum_{g=1}^{G_j} \beta_j^g \cdot X_{jit}^g + e_{it} \tag{1}$$

where

i = urban area index (1, 2, . . . , 339);
t = yearly time index taking on a value from 1 to 8 (1 for 1981);
g = population group index from 1 to G_j (within each group the regression coefficient β_j can be considered constant);
j = index for independent variable X (all variables in natural log form):
  1 = real income per capita (1982 dollars);
  2 = number of persons employed per 1,000 population;
  3 = number of persons per household;
  4 = number of driver licenses per 1,000 population;
  5 = time variable, i.e., in (t); and
  6 = supply deficiency of primary highway system;
Y = natural log of DVMT per capita for population between ages 15 and 65 years;
X = independent variable (if urban area i belongs to group g, $X_{jit}^g = X_{jit}$, otherwise $X_{jit}^g = 0$);
e = model residual; and
β_j = regression coefficients.

The first four independent variables (j = 1, 2, 3, and 4) represent the influence of socioeconomic variables on DVMT that could be readily quantified. Some less readily quantified influences that could be significant include the percentage of people traveling to and from work by public transit, the amount of car- and vanpooling, the land area of an urban area, and the population distribution within an urban area. Although these influences are implicitly reflected in the varying intercept term of the model, changes in any of these variables over time could influence travel behavior and could result in a time trend in DVMT that would not be picked up by the first four explanatory variables and by the intercept term. The yearly time index (j = 5) is used as a proxy to represent the combined time trend as a result of the changes in these less readily quantified variables over time. The supply deficiency variable captures the impact of constrained supply on demand, which applies primarily to large and medium-size urban areas. This restrained travel is referred to as latent demand because it may surface given adequate supply.

The model is quite flexible in structure. For example, by setting the number of population groups (G_j) to the number of urban areas for all explanatory variables, a regression model results that allows the slope coefficients to vary over each individual urban area. If it is further assumed that model errors are uncorrelated between urban areas, the process is then equivalent to building a time-series regression model for each individual urban area. This feature is attractive because, as more time-series data become available for each urban area, more weight can be placed on each area's time-series data to forecast its future travel and less weight can be placed on the data from other urban areas.

Logit Model of Travel Shares by Functional Class

The model is intended to forecast the total shares (summed over urban locations) of travel on different highway functional classes in the future. A logit model based on 1981–1988 data of shares of highway use by function classes in 339 urbanized areas was developed. Logit models have been widely used in travel choice and behavioral analysis. With urban area population as a dependent variable, this model captures the variation in shares of travel on highway functional classes as the size of the urban area grows. The model is of the following form:

$$S_{it}^f = \frac{\exp[\beta_{0i}^f + \beta_1^f \ln(P_{it})]}{\sum_{m=1}^{4} \exp[\beta_{0i}^m + \beta_1^m \ln(P_{it})]} \tag{2}$$

where

f = highway functional class index, (1 = freeways and expressways, 2 = other principal arterials, 3 = minor arterials, and 4 = collectors);

S = share of DVMT; and
P = urban area population (in thousands).

Logit Model of Travel Shares by Urban Location

This model is similar in form to the functional class shares model. It estimates the total shares of travel (summed over functional classes) for different locations within an urban area for 2005. Unlike the functional class shares model, however, this model is based on 1982, 1984, and 1987 data on shares of DVMT by location for 169 urban areas only. (The urban location data are contained in the HPMS sample data. Within the short time frame in which this study was performed, only these 3 years of HPMS data were available. Useful data on shares of urban travel by location were available for only 169 urban areas for the 3 years. However, these 169 urban areas contained a fairly representative sample of all urban area sizes.) The travel shares model is of the following form:

$$S_{it}^{l} = \frac{\exp[\beta_{0i}^{l} + \beta_{1}^{l} \ln(P_{it})]}{\sum_{n=1}^{3} \exp[\beta_{0i}^{n} + \beta_{1}^{n} \ln(P_{it})]} \tag{3}$$

where

i = urban area index (1, 2, . . . , 169);
t = yearly time index (2 = 1982, 4 = 1984, and 7 = 1987); and
l = urban area location index (1 = core, 2 = suburbs, and 3 = fringe).

FUTURE URBAN TRAVEL DEMAND

This section presents the notable findings from the estimation of future DVMT and its distribution across highway functional classes and locations within urban areas, derived on the basis of the models previously described. Before proceeding, however, some words of caution are necessary. The estimates for future level (DVMT) and the resulting suburban highway needs estimates are based primarily on the forecasts of socioeconomic variables. However, there is always considerable uncertainty associated with the future economic variables on which the estimation of future travel is based. In addition, the travel demand data (DVMT), highway usage, and supply data are derived from the HPMS. The information derived from the HPMS is based on sample data, and all the cautions that are normally applied to estimations from samples apply. Also, since the data has been stratified across categories (i.e., urban location) not initially incorporated within the HPMS sampling scheme, the application of HMPS expansion factors to these cells is questionable. Also, the urban locational indexes "core," "suburb," and "fringe" are strictly as defined in HPMS urban location codes for sample sections. For individual urban areas, these definitions may be different from the common meaning of the terms. Because it is difficult to establish absolute locations of the sample sections from the HPMS, the location codes submitted by the states must be used. Rathi et al. (*23*) provide further discussion on locational data, including suggestions for HPMS improvement.

Growth in Urban DVMT Through 2005

Urban DVMT is expected to increase at an average annual rate of 2.72 percent between 1985 and 2005. Of that increase, population growth will contribute approximately 1.12 percent, the increase in the number of driver licenses 0.65 percent, better income 0.45 percent, and employment another 0.10 percent. In addition, 0.4 percent will come from those less readily quantified factors represented by the time variable. This annual growth amounts to a total travel growth of 56 percent by 2005 over 1987 DVMT, in which population alone accounts for about 22 percent of the growth.

For the 339 urban areas examined, DVMT in 1987 was 15.9 mi/capita and is expected to increase to 20.8 mi/capita by 2005.

The Pacific West, Mountain, and South Atlantic regions will experience relatively higher growth rates than the rest of the nation.

The analysis of the impact of highway supply on DVMT suggests some latent demand for large and medium-size urban areas. It was estimated that travel demand may be constrained below a supply level of approximately 2.15 lane-mi of primary highways (freeways and expressways and other principal arterials) per 1,000 population.

The number of driver licenses is forecast by FHWA (*15*) to increase at an average annual growth rate of 0.57 percent from 1985 to 2005. However, recent trends indicate a slight decline (*15*), suggesting that past increases may be slowing down and that the forecast based on Model 1 (which includes this variable) may be high. Another estimate of growth in DVMT is obtained without this variable. This model indicates a smaller average annual growth rate of 2.36 percent, an estimated latent demand of approximately 13 percent, and an estimated DVMT per capita of 19.4 in 2005.

During 1982–1988, the intensity of highway use (DVMT per lane-mile) for urban areas increased annually by 3.0 percent on freeways and expressways, 2.4 percent on other principal arterials, 2.12 percent on minor arterials, and 1.3 percent on collectors.

These are based on an assumption that the current levels of highway supply will be maintained in the future. A lower growth in travel should be expected if highway supply falls below current levels. On the other hand, if the future highway system can be improved to accommodate all latent demand by 2005, the urban DVMT could increase by an average annual growth rate as high as 3.48 percent. Although this constraint-free highway travel scenario is unrealistic in practice, it provides an upper bound of expected travel growth.

DVMT Shares by Functional Class and Urban Location

Table 1 presents the shares of DVMT of an average urban area in each population group by highway functional class and by urban location for 1987 and 2005. The 1987 shares are based on HPMS data, whereas the 2005 shares are estimations based on the logit models described previously.

Table 1 indicates that nearly two-thirds of DVMT in urban areas is carried by the primary highway system. For urban areas greater than 0.5 million in population, this share is expected to increase to nearly 70 percent by 2005. This es-

TABLE 1 AVERAGE DVMT SHARES

Urban Area Size (Population)	Year	Average Urban Population	Functional Class				Location		
			F&E	OPA	MA	COL	Core	Suburb	Fringe
Large (≥0.5M)	1987 2005	1.928M 2.314M	0.412 0.430	0.264 0.267	0.225 0.216	0.099 0.087	0.186 0.180	0.634 0.599	0.180 0.221
Medium (0.1-0.5M)	1987 2005	0.224M 0.261M	0.299 0.309	0.338 0.333	0.251 0.249	0.112 0.108	0.185 0.151	0.589 0.578	0.226 0.271
Small (0.05-0.1M)	1987 2005	0.076M 0.088M	0.196 0.211	0.414 0.409	0.270 0.262	0.120 0.118	0.172 0.177	0.621 0.612	0.207 0.210

F&E: Freeways and Expressways; OPA: Other Principal Arterials; MA: Minor Arterials; COL: Collectors.

timate assumes, of course, that the highway supply level in 2005 will remain the same as in 1987 and that any change is due to the increase in urban area size only.

Freeways and expressways carry a significantly larger portion of travel in large urban areas than in small and medium-size urban areas and will continue to do so in the future. On the basis of 1982–1988 data used in this analysis, nearly 40 percent of DVMT occurs on freeways and expressways in urban areas greater than 0.5 million in population, compared with only 30 percent in medium-size urban areas and 20 percent in small urban areas. This trend is similar to that observed by Fleet and DeCorla-Souza (*1*).

Between 1987 and 2005, the DVMT shares of freeways and expressways for all urban sizes are estimated to increase. All other functional classes will decrease except the other principal arterial in the large population group.

In 1987 nearly 80 percent of all urban travel occurred outside the core area (i.e., in the suburbs and fringe). This share will increase somewhat in 2005. For large and medium-size urban areas, the DVMT shares will decrease in the urban core and suburbs but increase considerably in the fringe for all population groups.

By computing the direct elasticities of DVMT shares to a change in the log-population, it is estimated that, for an average urban area with a population greater than 0.5 million in 1987, a 10 percent increase in population will result in a 1 percent increase (above 1987) shares) in DVMT share in freeways and expressways; a 2 percent increase in travel share in the fringe; and a commensurate decrease in travel share in the suburbs, core, and on lower order facilities.

For an average urban area in each population group, the DVMT shares of freeways and expressways will increase between 1987 and 2005 by 1.8 percent and 1.0 percent for large and medium-size urban areas, respectively, as a result of population growth. The increase in urban fringe DVMT shares in the same category is estimated to be 4.1 percent and 4.5 percent, respectively.

SUBURBAN HIGHWAY NEEDS FOR 2005

The suburban highway needs estimates for 2005, categorized by urban area size and highway functional class, are presented. Because the objective is to determine the needs for both the existing suburban areas and the newly suburbanizing areas, HPMS urban location codes 3 (outlying business district), 4 (residential), and 5 (rural in character) have been combined into a single category—suburb and fringe. For simplicity of presentation, the highway functional classes have been coalesced into three groups: freeways and expressways, other principal arterials, and minor arterials/collectors. Urban areas are divided into three population groups: greater than 0.5 million (large), between 0.1 and 0.5 million (medium), and less than 0.1 million (small).

Service Indexes

Highway needs are expressed as lane-miles of additional highway facilities required to meet the anticipated future travel demand. The procedure that translates the forecast DVMT into needs estimates is described in this subsection. The translation is based on the concept of service index (SI), a measure that can also be tied to the LOS concept. LOS is a qualitative measure used commonly by transportation professionals to indicate the quality of traffic flow. Associated with each LOS is a service flow rate, which is the maximum hourly rate of flow that can be accommodated by various highway facilities. An SI is a daily equivalent of the hourly service flow rate. For a given highway functional class, urban area size, and location within urban area, the SI is computed as follows.

Step 1

For the base year (1987) service level, the average DVMT per lane-mile is obtained from the HPMS data and used as the base year service index (BSI).

Step 2

The DSI is computed, reflecting a desired LOS that is equivalent to a systemwide LOS C for small and medium-size urban areas and LOS D for large urban areas. These levels are arbitrarily selected for the purposes of estimation and scenario analysis. For a specified service level (LOS C or D), the maximum service flow rate per hour per lane is obtained for the given highway facility type and design speed from the *Highway Capacity Manual* (HCM) (*24*). For example, Table 3-1 of the HCM is used to calculate the hourly flow rate on freeways and expressways. This flow rate is then adjusted for the presence of heavy vehicles, restricted lane widths, and other factors as applicable. The average DVMT per lane-mile for the target LOS is then obtained by dividing the hourly maximum flow rates by the peak-hour travel shares derived from the time-of-day travel percentages and directional split (*3*). The peak-hour travel shares were assumed to be the same for all locations within urban areas. The average DVMT per lane-mile for various highway functional classes, stratified by urban area size and LOS, is presented in Table 2.

Step 3

The future lane-miles are estimated by dividing the forecast DVMT by the corresponding SI (BSI or DSI). The highway needs are then estimated as the difference between the future lane-miles and the base year lane-miles. It is possible to have no highway needs for an urban area despite growth in travel demand if its forecast SI (future DVMT per current mileage) is lower than the DSI in Scenarios 3, 4, and 5 (described in the following paragraphs).

Scenarios

The suburban highway needs are estimated for five different scenarios comprising different service levels and rates of future travel growth:

Scenario 1

Scenario 1 is based on BSI, a service index based on 1987 quality of traffic flow, under a projected 2.36 percent average annual travel growth rate (AATGR) in future travel. This scenario represents a condition in which the LOS in large urban areas does not deteriorate as in the recent past, and in which the small urban areas continue to enjoy the good LOS they do today. The average 1987 DVMT per lane-mile for various highway functional classes stratified by urban area size is also presented in Table 2.

Scenario 2

Scenario 2 is the same as Scenario 1 except that it is based on a 2.72% AATGR, representing a high travel growth projection. Thus, this scenario represents an upper bound of needs estimates when maintaining the same level of performance as in 1987.

Scenario 3

Scenario 3 is based on DSI, a service index associated with maintaining LOS D in large urban areas and LOS C in small and medium-size urban areas across all functional classes and locations. As in Scenario 1, an AATGR of 2.36 percent is used to estimate future DVMT. In terms of the quality of service, this scenario represents a condition for which the LOS of small urban areas will deteriorate considerably. The LOS will remain the same for most of the medium-size and large urban areas but will be improved for those large urban areas that are currently experiencing severe congestion.

Scenario 4

Scenario 4 is the same as Scenario 3 except that it is based on a 2.72 percent AATGR, representing a high travel growth projection. This scenario represents an upper bound of needs estimates when maintaining DSI.

Scenario 5

Scenario 5 is the same as Scenario 3 and 4 except that it is based on an even higher growth rate projection. A 3.48 percent AATGR is used in estimating future DVMT. This high travel growth is obtained when the supply deficiency is excluded from the DVMT forecasting model. Scenario 5 represents a condition in which demand is not constrained due to supply and thus the current latent demand in large urban areas will materialize in the future.

Needs Estimates

Before presenting the needs estimates derived from the analysis, some remarks about the interpretation of these results

TABLE 2 AVERAGE DVMT PER LANE-MILE FOR DIFFERENT LEVELS OF SERVICE

Urban Population	LOS	F&E	OPA	MA/COL
Large ($\geq$0.5M)	C	12,000	7,500	5,000
	D	14,500	9,500	6,500
	1987	13,000	6,100	3,100
Medium (0.1-0.5M)	C	11,000	7,000	5,000
	D	13,000	8.500	6,000
	1987	8,300	4,800	2,500
Small (0.05-0.1M)	C	9,000	6,500	4,500
	D	11,000	7,500	5,000
	1987	5,300	4,100	2,000

Notes: (1) LOS: Level of Service; F&E: Freeways and Expressways; OPA: Other Principal Arterials; MA: Minor Arterials; COL: Collectors.
(2) DVMT/Lane-Mile for LOS C and D are derived from 1985 Highway Capacity Manual [24] assuming the following:
F&E: 5% trucks, 60 mph design speed, 11-ft wide lanes;
OPA: no trucks, 0.7 adjustment factor for development environment, 11-ft wide lanes, 45 mph design speed;
MA/COL: intermediate design category, no trucks, saturation flow for LOS D = 1500 vphpl, saturation flow for LOS C = 1200 vphpl, g/c ratio =0.5.
(3) DVMT/Lane-Mile numbers are rounded to nearest 100.

are in order. The estimates of lane-miles for 2005 are simply an indication of the extent of the urban highway system in the forecast year. These estimates are constrained neither by a static network configuration as in the HPMS analytical procedure nor by any fiscal or geopolitical constraints that may affect the growth of individual urban areas. An urban growth dynamic is inherent in the needs forecast because it is assumed that not only will the DVMT grow but also its distribution by highway functional class and urban location will change as a result of the population growth. For example, the share of travel on freeways and expressways would increase from 19.6 percent to nearly 30 percent if an urban area is forecast to increase in size from small to medium by 2005 (see Table 1). Furthermore, the future travel demand itself is forecast by factors exogenous to urban boundaries or location of sample sections, allowing these estimates to be free from any fiscal or geopolitical constraints. Figure 2 shows a schematic representation of the needs estimates.

Also, the difference between current lane-miles and forecast lane-miles represents an estimate of the additional capacity that will be required to accommodate the anticipated travel growth. This additional capacity will be provided in practice through new construction, upgrades along existing right-of-way, and in some cases reclassification of a road from rural to urban. Within the scope of current research, the capacity realized through each of these sources has not been distinguished. Consequently, the work does not address the investments required to meet these future highway needs. Rather, the objective is to generate an important and improved set of mileage inputs to such a forecast.

The results of the analysis are summarized in Tables 3–10. Table 3 presents a distribution of 1987 lane-miles by urban area size, location, and highway facility type. Tables 4–8 present the estimate of additional lane-miles (over 1987 conditions) needed to accommodate travel growth through 2005 under Scenarios 1 through 5. Table 9 presents the additional lane-miles (over the 1987 condition) by highway functional class along with an earlier FHWA estimate (*8*) for comparison purposes. Table 10 presents the 1987 and estimated 2005 lane-miles by highway functional class and by urban location compared with the FHWA estimate. Examination of these tables suggests the following:

1. The suburban highway needs estimates range from 75,211 lane-mi (Scenario 3) to 220,284 lane-mi (Scenario 2). The low estimation—75,211 mi, or 18 percent over 1987 conditions—is based on a level of performance that would allow the LOS in small urban areas to deteriorate to the levels currently experienced in medium-size and large urban areas. On the other hand, it would mean significant improvement in LOS in urban areas that are experiencing acute congestion today. Essentially, this scenario represents a desire to address the needs of urban areas greater than 0.5 million in population at the expense of letting the quality of service in small urban areas deteriorate. The estimate of 220,284 lane-mi (54 percent over 1987 conditions) is based on maintaining the 1987 LOS in 2005 in all urban areas and highway functional classes. This estimate may be unrealistic, because maintaining today's quality of service in small urban areas is neither necessary nor possible given current trends in highway financing.

2. Suburban needs account for 75 to 88 percent of all urban needs. In Scenarios 1 and 2, the suburban needs are 88 percent of all urban needs compared with nearly 75 percent in Scenarios 3 through 5. This difference can be attributed mainly to the higher estimates of needs for nonfreeway facilities when maintaining the 1987 level of performance.

3. For large urban areas and for the same level of future travel growth, the suburban needs to maintain 1987 LOS (Scenario 1) are nearly twice the needs when maintaining DSI (Scenario 3). This finding indicates that, on average, over all functional classes the BSI in the suburbs and fringe of large urban areas is still better than the DSI (equivalent to LOS D in large urban areas). However, more lane-miles of freeways and expressways are required to maintain DSI than to maintain the 1987 LOS. On the other hand, to maintain 1987 LOS in highway functional classes, other principal arterials would

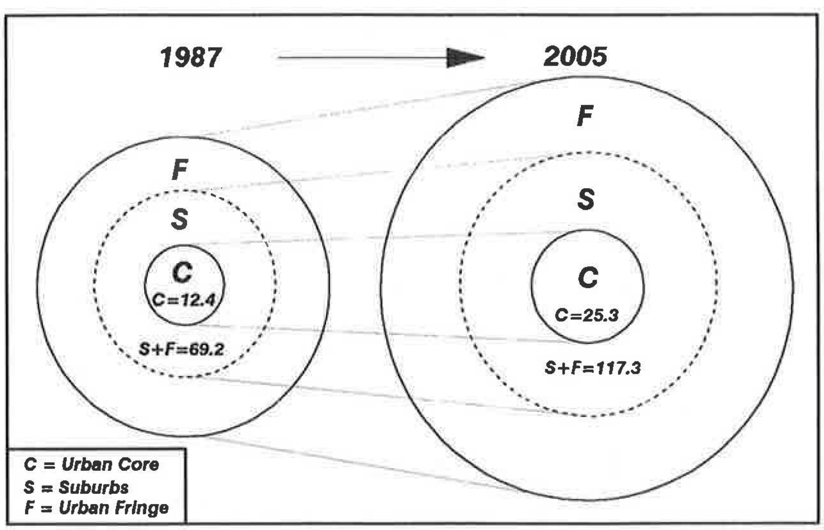

FIGURE 2 Current and future freeway and expressway lane-miles for Scenario 4 (in thousands).

TABLE 3 1987 HIGHWAY LANE-MILES

Urban Area Size (Population)	No. of Urban Areas	Location	Freeways and Expressways	Other Principal Arterials	Minor Arterials and Collectors	Total
Large (≥0.5M)	54	Core	7,990	10,875	23,704	42,569
		Suburb+Fringe	47,137	64,504	142,711	254,352
Medium (0.1-0.5M)	149	Core	3,481	6,294	12,819	22,594
		Suburb+Fringe	17,158	30,678	63,530	111,366
Small (0.05-0.1M)	136	Core	892	2,077	4,091	7,060
		Suburb+Fringe	4,887	12,311	24,641	41,839
All	339	Core	12,363	19,246	40,614	72,223
		Suburb+Fringe	69,182	107,493	230,882	407,557

TABLE 4 ESTIMATE OF URBAN HIGHWAY NEEDS FOR 2005 UNDER SCENARIO 1

ADDITIONAL REQUIREMENTS OVER 1987 LANE-MILES						
Urban Area Size (Population)	No. of Urban Areas	Location	Freeways and Expressways	Other Principal Arterials	Minor Arterials and Collectors	Total
Large (≥0.5M)	54	Core	3,826 (48%)	4,633 (43%)	7,258 (31%)	15,717 (37%)
		Suburb+Fringe	26,466 (56%)	32,000 (50%)	53,349 (37%)	111,815 (44%)
Medium (0.1-0.5M)	149	Core	807 (23%)	1,159 (18%)	2,242 (17%)	4,208 (19%)
		Suburb+Fringe	8,584 (50%)	12,401 (40%)	26,771 (42%)	47,756 (43%)
Small (0.05-0.1M)	136	Core	496 (56%)	1,013 (49%)	1,919 (47%)	3,428 (49%)
		Suburb+Fringe	2,661 (54%)	5,054 (41%)	10,342 (42%)	18,057 (43%)
All	339	Core	5,129 (41%)	6,805 (35%)	11,419 (28%)	23,353 (32%)
		Suburb+Fringe	37,711 (55%)	49,455 (46%)	90,462 (39%)	177,628 (44%)

Needs with BSI (1987 level of service for all urban areas) under a projected 2.36% average annual growth rate in highway travel.

TABLE 5 ESTIMATE OF URBAN HIGHWAY NEEDS FOR 2005 UNDER SCENARIO 2

ADDITIONAL REQUIREMENTS OVER 1987 LANE-MILES						
Urban Area Size (Population)	No. of Urban Areas	Location	Freeways and Expressways	Other Principal Arterials	Minor Arterials and Collectors	Total
Large (≥0.5M)	54	Core	4,700 (59%)	5,781 (53%)	9,481 (40%)	19,962 (47%)
		Suburb+Fringe	31,925 (68%)	39,178 (61%)	67,804 (48%)	138,907 (55%)
Medium (0.1-0.5M)	149	Core	1055 (30%)	1,560 (25%)	3,049 (24%)	5,664 (25%)
		Suburb+Fringe	10,448 (61%)	15,489 (50%)	33,166 (52%)	59,103 (53%)
Small (0.05-0.1M)	136	Core	595 (67%)	1,236 (59%)	2,342 (57%)	4,173 (59%)
		Suburb+Fringe	3,193 (65%)	6,307 (51%)	12,774 (52%)	22,274 (53%)
All	339	Core	6,350 (51%)	8,577 (45%)	14,872 (37%)	29,799 (41%)
		Suburb+Fringe	45,566 (66%)	60,974 (57%)	113,744 (49%)	220,284 (54%)

Needs with BSI (1987 level of service for all urban areas) under a projected 2.72% average annual growth rate in highway travel.

TABLE 6 ESTIMATE OF URBAN HIGHWAY NEEDS FOR 2005 UNDER SCENARIO 3

ADDITIONAL REQUIREMENTS OVER 1987 LANE-MILES						
Urban Area Size (Population)	No. of Urban Areas	Location	Freeways and Expressways	Other Principal Arterials	Minor Arterials and Collectors	Total
Large (≥0.5M)	54	Core	10,435 (131%)	6,575 (60%)	5,360 (23%)	22,370 (53%)
		Suburb+Fringe	35,686 (76%)	15,949 (25%)	10,141 (7%)	61,776 (24%)
Medium (0.1-0.5M)	149	Core	605 (17%)	481 (8%)	376 (3%)	1,462 (6%)
		Suburb+Fringe	4,459 (26%)	3,214 (10%)	3,143 (5%)	10,816 (10%)
Small (0.05-0.1M)	136	Core	284 (32%)	442 (21%)	299 (7%)	1,025 (15%)
		Suburb+Fringe	835 (17%)	1,110 (9%)	674 (3%)	2,619 (6%)
All	339	Core	11,324 (92%)	7,498 (39%)	6,035 (15%)	24,857 (34%)
		Suburb+Fringe	40,980 (59%)	20,273 (19%)	13,958 (6%)	75,211 (18%)

Needs with DSI (LOS D for large urban areas and LOS C for medium and small urban areas) under a projected 2.36% average annual growth rate in highway travel.

TABLE 7 ESTIMATE OF URBAN HIGHWAY NEEDS FOR 2005 UNDER SCENARIO 4

ADDITIONAL REQUIREMENTS OVER 1987 LANE-MILES						
Urban Area Size (Population)	No. of Urban Areas	Location	Freeways and Expressways	Other Principal Arterials	Minor Arterials and Collectors	Total
Large (≥0.5M)	54	Core	11,794 (148%)	7,841 (72%)	6,744 (28%)	26,379 (62%)
		Suburb+Fringe	41,631 (88%)	21,081 (33%)	13,965 (10%)	76,677 (30%)
Medium (0.1-0.5M)	149	Core	765 (22%)	647 (10%)	535 (4%)	1,947 (9%)
		Suburb+Fringe	5,457 (32%)	4,325 (14%)	4,334 (7%)	14,116 (8%)
Small (0.05-0.1M)	136	Core	331 (37%)	550 (26%)	382 (9%)	1,263 (18%)
		Suburb+Fringe	1009 (21%)	1,423 (12%)	870 (4%)	3,302 (8%)
All	339	Core	12,890 (104%)	9,038 (47%)	7,661 (19%)	29,589 (41%)
		Suburb+Fringe	48,097 (70%)	26,829 (25%)	19,169 (8%)	94,095 (23%)

Needs with DSI (LOS D for large urban areas and LOS C for medium and small urban areas) under a projected 2.72% average annual growth rate in highway travel.

require twice as many lane-miles and minor arterials and collectors nearly four times the lane-miles required under comparable DSI scenarios.

4. Large urban areas account for nearly 85 percent of urban needs in Scenarios 3 through 5, compared with only 64 percent under Scenarios 1 and 2. Similarly, the freeway and expressway needs are only 20 percent of all urban needs in Scenarios 1 and 2, compared with over 50 percent in Scenarios 3 through 5. For both 1987 LOS (Scenarios 1 and 2) and DSI scenarios (3, 4, and 5) at the same level of future travel growth, the highway needs for freeways and expressways are not as radically different as they are for other functional classes. These numbers illustrate the extent of primary highway system needs in large urban areas in the future.

5. Freeway and expressway needs in suburban areas are estimated to be from a low of 37,711 lane-mi in Scenario 1 to a high of 66,856 lane-mi in Scenario 5, with most needs being in large urban areas. In Scenarios 1 and 2, nearly 70 percent of the freeway and expressway needs are in large urban areas. For Scenarios 3, 4, and 5, this proportion is nearly 85 percent. The methodology employed did not include the cost-effectiveness aspects of various highway functional classes. Instead, the analysis relied on the shift in highway usage as a function of population.

6. The urban highway needs estimates range from 100,068 lane-mi (Scenario 3) to 250,000 lane-mi (Scenario 2). An estimate of 171,392 unconstrained lane-mi for the period between 1985 and 2005 is indicated in FHWA Working Paper 14 (*9*). The term "unconstrained" implies that additional lane-miles can be provided regardless of feasibility of capacity expansion on the HPMS segments. However, the procedure as well as the assumptions made in deriving these needs es-

TABLE 8 ESTIMATE OF URBAN HIGHWAY NEEDS FOR 2005 UNDER SCENARIO 5

ADDITIONAL REQUIREMENTS OVER 1987 LANE-MILES						
Urban Area Size (Population)	No. of Urban Areas	Location	Freeways and Expressways	Other Principal Arterials	Minor Arterials and Collectors	Total
Large (≥0.5M)	54	Core	15,533 (194%)	11,357 (104%)	10,863 (46%)	37,753 (89%)
		Suburb+Fringe	58,190 (123%)	36,244 (56%)	28,728 (20%)	123,162 (48%)
Medium (0.1-0.5M)	149	Core	1105 (32%)	1054 (17%)	955 (7%)	3,114 (14%)
		Suburb+Fringe	7,657 (45%)	7,106 (23%)	7,474 (12%)	22,237 (20%)
Small (0.05-0.1M)	136	Core	331 (37%)	550 (26%)	382 (9%)	1,263 (18%)
		Suburb+Fringe	1009 (21%)	1,423 (12%)	870 (4%)	3,302 (8%)
All	339	Core	16,969 (137%)	12,961 (67%)	12,200 (30%)	42,130 (58%)
		Suburb+Fringe	66,856 (97%)	44,773 (42%)	37,072 (16%)	148,701 (36%)

Needs with DSI (LOS D for large urban areas and LOS C for medium and small urban areas) under a projected **3.48%** average annual growth rate of highway travel (free from supply constraints).

TABLE 9 ESTIMATE OF URBAN HIGHWAY NEEDS FOR 2005—ALL SCENARIOS AND FHWA ESTIMATE (*9*)

Highway Functional Class	Additional Requirements over 1987 Lane-Miles by Scenario					FHWA* Estimate (1985-2005)
	1	2	3	4	5	
Freeways & Expressways	42,840 (53%)	51,916 (64%)	52,304 (64%)	60,987 (75%)	83,825 (103%)	60,406
Other Principal Arterials	56,260 (44%)	69,551 (55%)	27,771 (22%)	35,867 (28%)	57,735 (46%)	52,685
Minor Arterials & Collectors	101,881 (38%)	128,616 (47%)	19,993 (7%)	26,830 (10%)	49,272 (18%)	58,301

TABLE 10 SUMMARY OF 1987 AND 2005 LANE-MILES FOR 339 URBAN AREAS

Highway Functional Class	Location	1987	Future Lane-Miles by Scenario					FHWA* Estimate
			1	2	3	4	5	
Freeways & Expressways	Core	12,363	17,492	18,713	23,687	25,253	29,332	
	Suburb+Fringe	69,182	106,893	114,748	110,162	117,279	136,038	
	Total	81,545	124,385	133,461	133,849	142,532	165,370	139,057
Other Principal Arterials	Core	19,246	26,051	27,823	26,744	28,284	32,207	
	Suburb+Fringe	107,493	156,948	168,467	127,766	134,322	152,266	
	Total	126,739	182,999	196,290	154,510	162,606	184,473	177,078
Minor Arterials & Collectors	Core	40,614	52,033	55,486	46,649	48,275	52,814	
	Suburb+Fringe	230,882	321,344	344,626	244,840	250,051	267,954	
	Total	271,496	373,377	400,112	291,489	298,326	320,768	321,779

Notes: (1) Scenario 1: BSI (1987 service level), constrained demand, annual travel growth = 2.36%.
(2) Scenario 2: Same as above, but with annual travel growth = 2.72%.
(3) Scenario 3: DSI (LOS D for large and LOS C for medium/small urban areas), constrained demand, annual travel growth = 2.36%.
(4) Scenario 4: Same as (3) but with annual travel growth = 2.72%.
(5) Scenario 5: Same as (4) but with unconstrained demand and annual travel growth = 3.48%.
(6) * The numbers are obtained by adding the 1985 lane-miles from the 339 urban areas to the highway needs estimate in "The Future National Highway Program 1991 and Beyond," Working Paper No. 14 [9].

timates are not clear from the working paper. In any case, the freeway and expressway needs estimates given in the working paper are nearly the same as the Scenario 3 and 4 estimates, which are perhaps more realistic than the other scenarios. For the same scenarios, however, the estimates for nonfreeway facilities are considerably higher. Without a good understanding of the study methodology, such differences or similarities cannot be explained.

SUMMARY AND CONCLUSIONS

The results of this study suggest that urban travel will increase at an average annual rate of between 2.36 and 2.72 percent by 2005. The annual growth in urban travel could be as much as 3.48 percent if sufficient supply of the primary highway system can be provided in urban areas with a population greater than 0.5 million (i.e., the latent demand could be accommodated). A forecast of 2.72 percent annual travel growth, which is equivalent to a total growth of nearly 56 percent between 1987 and 2005, is used as the basis for the discussion.

To accommodate this travel growth while maintaining the 1987 level of performance, it is estimated that 220,284 lane-mi of additional highway capacity will be needed in suburban areas. Over 70 percent (138,907 lane-mi) of this additional capacity will be needed in urban areas with a population greater than 0.5 million. The primary highway system accounts for nearly 50 percent (106,540 lane-mi) of these needs. Suburban needs are nearly 90 percent of all urban needs under this scenario. For the scenario based on the DSI, suburban highway needs are estimated to be 94,095 lane-mi with over 80 percent needed in large urban areas. The findings suggest that, without further addition of highway capacity, the average LOS in small and medium-size urban areas can be expected to be slightly worse than those reflected by the DSI (LOS C) by 2005. The primary highway system accounts for nearly 80 percent of needs in this DSI scenario. Regardless of the LOS desired, the total freeway and expressway needs estimates are nearly the same.

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Cordon Line Highway Survey for the Delaware Valley Region

THABET ZAKARIA

Described are the design, conduct, and results of a cordon line highway survey for the Delaware Valley region. The survey was successfully conducted in 1989 by the Delaware Valley Regional Planning Commission (DVRPC) in cooperation with the state departments of transportation, county planning departments, and turnpike and bridge commissions. The purpose of the survey was to update traffic data collected in 1960 by the Penn-Jersey Transportation Study for the development of regional highway plans, especially for facilities in the growing areas near the cordon line of the region. In order to minimize cost and traffic delay, selected motorists at 26 sampled cordon line stations were interviewed or handed survey questionnaires and requested to return the completed forms to DVRPC, postage paid. Questions dealt with trip origin, destination and purpose, vehicle type and registration, and highways used by motorists to reach the destinations from the survey points. The survey on each highway was conducted for 2 days, 1 day to sample traffic in the morning peak and off-peak, and another in the evening peak and off-peak hours. The survey results indicate that traffic volumes and patterns have changed significantly since 1960. The findings are being used to validate DVRPC simulation models for forecasting external and through trips, and to develop plans and programs for improving highway facilities throughout the region.

Cordon line traffic volumes, patterns, and forecasts are required for the development of transportation plans and facility designs that are scaled to future travel demand and available resources. The most recent comprehensive regional cordon line traffic survey conducted in the Delaware Valley region was done in 1960 by the Penn-Jersey Transportation Study (PJTS), the predecessor agency to the Delaware Valley Regional Planning Commission (DVRPC). The 1960 survey data are of limited use today because they do not reflect major growth in the suburbs that has occurred since, and were collected on the PJTS cordon line, which is well inside the line used today by DVRPC (see map shown in Figure 1).

As shown in Figure 1, the DVRPC region includes four suburban counties in Pennsylvania (Bucks, Chester, Delaware, and Montgomery); four suburban counties in New Jersey (Burlington, Camden, Gloucester, and Mercer), and Philadelphia. The DVRPC region includes an area of 3,833 mi^2 and a population of more than 5.2 million. There are 352 minor civil divisions or municipalities, including such large cities as Camden, Trenton, and Chester. The old cordon area used by PJTS encompasses about one-third of the area of the DVRPC region and includes the heavily urbanized area and major cities.

In FY1989, as part of a major update of its traffic data, DVRPC conducted a cordon line survey on the nine-county boundary. The survey was designed to collect information on traffic volumes and patterns generated by vehicles entering and exiting the DVRPC region at 128 points, or cordon stations. The survey asked about trip origin, destination, and purpose, the highways used, and the vehicle type, registration and occupancy. It was conducted with the cooperation of the Pennsylvania, New Jersey, and Delaware departments of transportation; the nine county governments served by DVRPC, the New Jersey Turnpike Authority, the Pennsylvania Turnpike Commission, the Atlantic City Expressway Authority, and the Delaware River Joint Toll Bridge Commission. Most of the survey information was collected by direct roadside interview. On a few highways, however, motorists were handed questionnaires and asked to answer the questions and return the completed survey forms by mail, postage paid.

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In order to minimize cost and traffic delay, a representative sample of cordon line stations, including freeways, arterials, and local roads, was chosen for the survey. The interviews on each selected highway were conducted on two different days, one day to sample traffic in the morning peak and off-peak periods, and another in the afternoon to collect information on traffic patterns during the evening peak and off-peak hours.

The survey procedures and results are described, with particular emphasis on sample size, data collection, and major findings. The findings are essential for developing regional and local plans and capital improvement programs, especially for highways and roads located in the growing residential, commercial, and industrial areas near the perimeter of the region.

SURVEY DESIGN, PREPARATION, AND CONDUCT

Travel to or from points outside the cordon line of the region can be divided into two types: trips that pass through the region with no major stops (through trips), and those crossing the cordon line with origins or destinations inside the region (internal-external or external-internal trips). In 1987, the sum of the numbers of these two types of trips was about 1.1 million per day. Through trips by automobiles and trucks make up a significant portion of total vehicle miles of travel (VMT) because of their longer trip length. Some drivers may need to travel more than 80 mi or spend over 2 hr to traverse the region from one end to another. On the other hand, external trips, which include most of the trips entering or leaving the region, are bound for destinations in or near major towns or centers scattered around the cordon line.

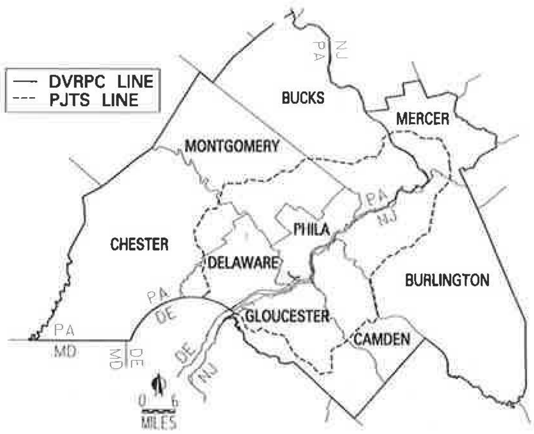

FIGURE 1 Map indicating PJTS and DVRPC regional cordon lines.

Currently, forecasts of through and external trips are estimated by Frater and gravity-type models, respectively. These models were calibrated with 1960 data and updated with 1980 census journey-to-work information. However, nonwork trips, which constitute the major portion of these trips, could not be validated with census data. Thus, new and comprehensive survey data are essential to update the parameters of these models in order to produce accurate travel forecasts for highway planning and design.

Design of Survey Questionnaire

Similar to previous cordon line surveys, the DVRPC survey questionnaire was designed to collect information about traffic patterns and vehicle characteristics (*1–3*). As shown in Figure 2, seven questions were included in the survey form, which was used in the mail-back and the roadside interviews surveys. Drivers were requested to complete the questionnaire and return it to DVRPC by mail, while interviewers were instructed to record the answers to the questions directly on the survey form.

Trip Origins and Destinations

Questions 1 and 2 are perhaps the most important questions in the survey because they produce detailed origin-destination information needed to define traffic patterns inside and outside the region. Frequency of trip destination and trip length are needed for validating trip distribution models and estimating VMTs. Street address or nearest street intersection, as well as town, city, county, state, and zip code were specified to code the survey information to DVRPC traffic analysis zones (TAZs).

Trip Purpose

Question 3 was intended to collect information on trip purpose, including work, school, home, shopping, and social or

The Delaware Valley Regional Planning Commission, in cooperation with the Pennsylvania, New Jersey, and Delaware Departments of Transportation and the counties of Bucks, Chester, Delaware, Montgomery, Burlington, Camden, Gloucester, and Mercer, is conducting this survey to assess your transportation needs. Please complete this questionnaire and return it to us.

1. Where did you begin this trip?

   Street address or nearest intersection

   Town or City　County　State　ZIP Code

2. Where will this trip end?

   Street address or nearest intersection

   Town or City　County　State　ZIP Code

3. What is the purpose of this trip? (Check one)

   1[ ] Work　4[ ] Shopping
   2[ ] School　5[ ] Social/Recreational
   3[ ] Home　6[ ] Other (Specify)________

4. What type of vehicle are you using for this trip? (Check One)

   1[ ] Car　4[ ] Truck - Single Unit...........(2, 3, or 4 axles)
   2[ ] Pick-up, Panel, Van　5[ ] Truck - Single Trailer...(3, 4, 5, or 6 axles)
   3[ ] Bus　6[ ] Truck - Double Trailer......(5, 6, or 7 axles)
   7[ ] Other (Specify) ________

5. How many persons are in your vehicle (include driver)? ________

6. Where is this vehicle registered? (Check one)

   1[ ] Pennsylvania　4[ ] Maryland　7[ ] Virginia
   2[ ] New Jersey　5[ ] New York　8[ ] Other (Specify)
   3[ ] Delaware　6[ ] Ohio

7. From this survey point, what is/are the major highway(s) that you will take to reach your destination?

   1st highway________

   2nd highway________

   3rd highway________

THANK YOU

FIGURE 2 DVRPC traffic survey.

recreational. All other trip purposes were grouped in one category, under "other."

Vehicle Type, Occupancy, and Registration

Question 4 identified the type of vehicle surveyed, including cars, vans, trucks, and buses. Trucks were further classified by type of unit and number of axles.

Vehicle occupancy information was obtained from Question 5, which was needed to determine the average vehicle occupancy. Question 6 identified the state of vehicle registration. Seven states were specifically listed in the questionnaire, including Maryland and Delaware, which have contiguous borders with the DVRPC region.

Highways Used

Question 7 is not usually included in traditional cordon line surveys. Under this question, drivers were asked about the major highways that they would use to reach their destinations from the survey stations. This information is especially useful for comparison of actual paths with those obtained from the traffic assignment model.

The survey information is also essential for the planning and evaluation of alternative transportation strategies and programs to relieve highway congestion, such as transit options, alternative route selection, high-occupancy vehicle lanes (HOV), and park-and-ride lots.

Sample Size and Selection of Survey Stations

In the past, large sums of money were spent on cordon line surveys. Most vehicles crossing the cordon line were interviewed on major as well as on local roads. Sometimes surveys were conducted for 24 hr a day to account for day as well as night trips. For example, PJTS conducted more than 310,000 interviews, about 61 percent of the total number of vehicles that crossed the cordon line on a typical weekday (*4*). In the early 1970s, the FHWA recommended a sample size of 25 percent of the traffic during off-peak hours on highways with volumes of 10,000 vehicles per day or less, and 10 percent during peak hours on highways with daily volumes over 10,000 vehicles (*5*).

Recently, however, almost all regional cordon line surveys have been based on small samples because costs have increased significantly. In 1980, the Georgia Department of Transportation chose a sample of about 13 percent of the total traffic volume crossing the cordon line of the Atlanta metropolitan area. About 57,000 vehicles were selected for interview on 82 roads crossing the Atlanta cordon line (*2*). The 1986 external trip survey for the Phoenix metropolitan area was based on a sampling technique that reduces the number of interviewers and uses effective bypass procedures to minimize traffic delay (*6*).

Design of Sample Size

Statistical theory indicates that the sample size or number of interviews required for the survey is a function of the following five variables (*7–9*):

- Tolerable sample error,
- Desirable level of statistical confidence,
- Data variation around the mean,
- Level of data aggregation and cross classification, and
- Type of variable being estimated.

The sampling error is usually expressed as the percent discrepancy of sample data from the real or true value of the population. Because the sampling error is inversely dependent on the sample size, the accuracy obtained can be improved by increasing the size of the sample, but this incurs greater costs. Basically, accuracy is a trade-off between what is desired and what can be afforded.

The confidence coefficient specifies the desired level of statistical confidence in the sample data that fall within the specified error. It can also be represented as a percent indicating the number of standard errors required to provide the desired level of confidence.

The coefficient of variation is the ratio of the standard deviation of the measured variable to its mean. It is not usually determined until the survey has been completed. However, previous travel surveys have shown that the coefficient is close to 1 (*10–13*).

The sampling error increases with the increase in the disaggregation of survey data and cross classification of the results. For example, the sample size needed to make statistical inference at the regional level (for all highways) is smaller than that needed to estimate the same variable by route type or area type.

Finally, the sample size varies significantly depending on the type of survey variable being estimated. Previous research efforts have shown that accurate trip distribution at the level of TAZ would sometimes require a large sample, close to 100 percent (*10*). There are 1,335 TAZ aggregated into 71 county planning areas in the region. In order to reduce the sample size, county planning areas were substituted for TAZ. On the basis of 1987 simulated data, the highest trip interchanges between cordon stations and county planning areas ranged between 60 and 16,000 trips per day with a mean value of about 3,000 trips per day. This range was assumed in the estimation of the sample size.

On the basis of these statistical principles and assumptions, and experience gained in previous DVRPC surveys containing similar questions to this survey, alternative sample sizes were estimated (*11–13*). Table 1 presents the assumptions used to determine the minimum sample size needed for two groups

TABLE 1 ALTERNATIVE MINIMUM SAMPLE SIZE FOR DVRPC CORDON LINE SURVEY

Survey Question	Sampling Assumptions: Confidence Coefficient (%)	Sampling Error (%)	Minimum Sample Size: Percent	Interview
Questions 1 and 2 (Trip Origin and Destination)	90	20	3.0	33,000
	90	15	4.1	45,000
	90	10	9.6	106,000
Questions 3, 4, 5, 6 and 7 (Trip Purpose, Vehicle Type, Occupancy, Registration, and Highways Used)	90	10	0.04	400
	90	5	0.10	1,100
	95	5	0.10	1,500

of survey questions: (a) origin and destination, and (b) the remaining survey questions. The sampling error was assumed to range from 5 to 20 percent, and the confidence coefficient from 90 to 95 percent. As mentioned previously, the coefficient of variation and average daily trip interchange between cordon stations and county planning areas were assumed to be equal to 1 and 3,000, respectively.

In transporation planning surveys, it is desirable to design a sample that provides 5 percent accuracy at 95 percent confidence coefficient. However, these desired values cannot be proposed for trip origin and destination because they result in a very large sample size (see Table 1). For most trip interchanges between county planning areas and a cordon station, the required sampling rate may exceed 60 percent, six times the highest rate in Table 1.

Because of budget constraints, the sample size finally chosen was 33,000 interviews, which were distributed among the sample cordon stations. The margin of error in the survey results is expected to range from ±1 to ±20 percent, depending on the variable being estimated.

Selection of Cordon Stations

The simplest procedure for conducting the survey is to maintain a uniform sampling rate (3.0 percent) among the 128 cordon stations, but this would have been costly and provided an inadequate sample size for local roads with small traffic volumes. Accordingly, it was decided to sample the principal highways at a lower percentage than secondary roads. A sampling rate ranging from 3 percent for heavily traveled highways to 16 percent for local roads was selected.

Cordon Station Traffic Volume (AADT)	*Required Sample Size*	
	Percent of AADT	*Number of Interviews*
≤ 2,500	≥16	400
2,500– 5,000	16–12	400– 600
5,000–10,000	12– 8	600– 800
10,000–20,000	8– 5	800–1,000
20,000–40,000	5– 4	1,000–1,600
40,000–80,000	4– 3	1,600–2,400
≥80,000	≤ 4	3,200

The interviews on each highway were then divided into four groups for the purpose of sampling traffic patterns and characteristics during peak and off-peak hours. On the basis of actual traffic counts, the required minimum and maximum sample sizes were divided as follows:

Interview Time	*Station Sample Size (Interviews)*	
	Minimum	*Maximum*
7:00 a.m. to 9:30 a.m.	110	900
10:30 a.m. to 1:00 p.m.	90	700
Subtotal	200	1,600
1:00 p.m. to 3:30 p.m.	90	700
4:30 p.m. to 7:00 p.m.	110	900
Subtotal	200	1,600
Total	400	3,200

The final step in the sampling design was the selection of cordon stations that represent the traffic patterns crossing the cordon line. Analysis of the 128 roads that cross the cordon line resulted in the selection of the following sampling stations:

- Turnpike, freeway, and expressway cordon stations (10) were all selected for the survey because they are heavily traveled by different users throughout the region;
- All local roads (*14*) carrying less than 700 vehicles per day were excluded from the survey; and
- A sample of the remaining arterials and local roads (20 out of 104) was selected at random on the basis of highway traffic volume, physical characteristics, and geographic location.

Thus, 30 out of a total of 128 cordon stations were finally selected for the survey, in which 33,000 interviews were apportioned (see map shown in Figure 3).

Preparation and Conduct of the Survey

The survey questionnaire was printed on 5.5 × 8.5-in. cardboard stock in two different colors for inbound and outbound traffic. To maintain control, the survey forms required for each station were packaged in eight envelopes, four for inbound traffic and four for outbound traffic. (Traffic was surveyed during the morning and afternoon peak and off-peak periods.)

The DVRPC staff requested and received manpower assistance from the Pennsylvania and New Jersey departments of transportation, the planning departments of DVRPC counties, and state and local police departments. Survey signs and equipment, such as Traffic Survey Ahead, Stop, Arrow, Cone, Red Flag, Night Reflector Light, Left Lane Closed, Right Lane Closed, 25 MPH, Hard Hats, and Slow, were borrowed from state departments of transportation for the conduct of the survey.

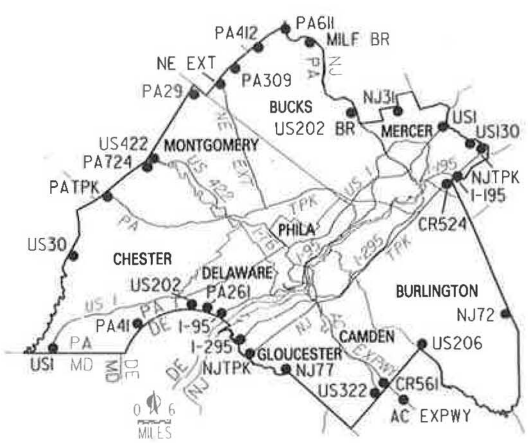

FIGURE 3 Map indicating cordon line stations selected for the DVRPC traffic survey.

Training Program for Surveyors

The DVRPC staff held several training sessions for interviewers and survey supervisors. The training program covered the following major items:

- Discussion of the survey goals and objectives, including accuracy required in the answers to the survey questions.
- Description of the cordon stations, including location, area, and highway physical characteristics.
- Review of the survey questionnaire, including possible answers to the questions.
- Description of the survey signs and equipment and how they should be set up in the field.
- Definition of role and responsibility of each member of the survey crew, including reporting time, transportation, equipment, and survey conduct.
- Clarification of any ambiguous questions or statements.

Conduct of the Survey

Safety was the most important consideration in locating the survey sites on highways. Station layouts were devised in cooperation with traffic engineers from PennDOT and NJDOT according to their safety manuals (*15*). A traffic control plan for each station was developed on the basis of the highway traffic volume and physical characteristics. Generally, straight and level sections of roads with unrestricted sight distances and wide shoulders with parking areas were selected. Two policemen were assigned to each survey station and requested to arrive 30 min before the start of the survey to allow time to inspect the site layout and survey signs. During the survey, police directed drivers selected at random to the survey sites, where they were interviewed by field personnel. Other drivers were allowed to bypass the station when interviewers were occupied. This platooning method was used at all stations, including those designed for mail-back survey. The number of interviewers needed at cordon stations varied depending on the number of surveys and ranged from 5 to 11 persons per station per day.

The survey was conducted in the fall of 1988 and spring of 1989. Interviews were conducted at 21 stations and a mail-back survey approach was used at five stations, including four surveyed by the Delaware Department of Transportation (*3*). In the Delaware survey, all stations were operated during daylight hours, from 7:00 a.m. to 6:00 p.m. These hours allowed surveys to be conducted in both the morning and evening peak and off-peak hours, but they may have introduced some bias in the results. Although different from DVRPC's survey questionnaire, the Delaware survey cards were processed and used by DVRPC for these stations.

On the Pennsylvania and New Jersey turnpikes, motorists were handed the survey form at all interchanges as they entered the turnpike (*16, 17*). These two surveys were conducted in 1985 and 1986 to determine trip purpose, trip frequency, vehicle class and occupancy, trip origin before entering the turnpike, and trip destination after leaving the turnpike. This information was also used by DVRPC for four cordon stations.

The response to the DVRPC survey was excellent. There were no accidents, traffic delay was minimal, and only a few persons complained. The completed interviews and mail-back questionnaires were then packaged for coding, keypunching, and processing.

SURVEY RESPONSE AND PROCESSING

The response rate to the mail-back survey at five cordon stations ranged from 14 to 28 percent. For the remaining 21 stations, the number of completed interviews was in most cases equal to that estimated in the sample design. However, weather or daylight conditions sometimes resulted in a smaller sample than that specified in the design.

More than 27,000 survey interviews and mail-back questionnaires were received for the 26 stations, not including the surveys returned by the users of the Pennsylvania and New Jersey turnpikes, which were processed and evaluated in 1986 by a consulting firm. Table 2 presents the number and type of stations surveyed and the valid forms prepared for coding and processing. All turnpike, freeway, and expressway cordon stations were included in the survey, but a sample ranging from 10 to 33 percent of local roads and arterial highways was surveyed.

About 6 percent of the motorists entering or leaving the region at the sampled stations were surveyed. As designed, the sample size ranged from 3.9 percent on freeways and expressways to 12.2 percent on local roads. The sample rate on the Pennsylvania and New Jersey turnpikes was about 10 percent (*16,17*).

Coding and Keypunching

The completed survey forms (interview and mail-back surveys) were screened and those with apparent mistakes were discarded. The remaining forms were than geocoded manually and keypunched according to a specific record layout for computer processing.

Manual coding of trip origin (Question 1), trip destination (Question 2), and highways used (Question 7) was performed (see Figure 2). If the trip origin or destination was inside the region, the coding was done at the TAZ level; otherwise it was performed at the minor civil division, county, or state

TABLE 2 CORDON STATIONS AND VALID SURVEY FORMS SAMPLED BY HIGHWAY TYPE

	Cordon Stations			Sampled Cordon Stations		
Highway Type	Total	Sampled	% of Total	Volume AADT (000)	Traffic Survey Forms (000)	Valid % of AADT
Turnpike*	4	4	100	-	-	-
Freeway & Expy.	6	6	100	201	7.7	3.9
Arterial	43	14	33	248	15.3	6.2
Local	61	6	10	32	3.9	12.2
TOTAL	114	30	26	481	26.9	5.6

*Turnpike surveys were processed in 1986 by Wilbur Smith Associates, Consultants to the Turnpike Commission level. The number of cordon station for through trip was also coded manually on the basis of the responses to Questions 2 and 7, which defined the place of destination and highways used to reach the destination, respectively.

Data Processing and Survey Tabulation

After the completion of punching of survey information, the responses were processed and tabulated for

- Each cordon station,
- Freeway and expressway stations,
- Arterial stations,
- Local road stations, and
- All stations.

Previous DVRPC FORTRAN and UTPS programs were used to process the survey information and produce tabulation for the following:

- External and through trips, frequency of trip distribution, and average trip length inside the region.
- Trip purpose, vehicle type and occupancy, and state of registration. This information was tabulated by traffic direction (inbound and outbound) and time of interview (a.m. and p.m. peak and off-peak).
- Frequency of highways used to reach the destination by motorists interviewed at each station.
- Cross tabulation of information on vehicle type and occupancy, and state of registration by trip purpose.

SURVEY RESULTS

Examination of the survey results indicated some bias in the mail-back surveys conducted at five of the cordon stations. Only a few commercial truckers completed and returned the survey form; conversely, the response of commuters to the survey was overwhelming. In addition, some questions were misunderstood, and others were not completed by respondents. The use of a mailback survey has increased the percentage of work trips at a few stations. At the US-1 station, for example, 66 percent of the surveys covered work trips, about 20 points higher than the average of all surveys.

Most of the survey results, including traffic pattern and characteristics, were computed on the basis of the sample. In the future, the survey information will be factored to estimate total travel, including the number and type of trips and vehicle miles of travel. It will also be used to calibrate and validate DVRPC trip generation and distribution models, which produce regional travel forecasts for external and through trips.

Daily and Hourly Traffic Volumes

Directional and total daily and hourly traffic volumes on each of the 26 highways sampled were counted by portable traffic recorders for a minimum 48-hr weekday period. The counts were then factored to convert the shorter term counts to annual average daily traffic (AADT), which account for daily and seasonal variation in traffic. Figure 4 shows the distribution of total AADT crossing the cordon line at the sampled stations. About 7.5 percent of the 24-hr traffic was recorded in the morning peak hour (7:00 to 8:00 a.m.), while 8.0 percent was observed in the evening peak hour (4:00 to 5:00 p.m.). The figure also shows that traffic volume between 5:00 and 6:00 p.m. was nearly as heavy as the previous hour. The traffic peak in the morning period was sharper than in the evening peak, mainly because of the presence of many nonwork trips in late afternoon and early evening. Approximately 54 percent of the vehicles during the morning peak hour were outbound, while 52 percent of the vehicles in the evening peak hour were inbound. This pattern indicates that the number of workers who live in the DVRPC region and work in the neighboring regions is higher than the number of those who commute to the Delaware Valley from other regions.

Trip Origins and Destinations

As stated before, trip origins and destinations inside the DVRPC region were coded to TAZs. For the purpose of DVRPC traffic simulation, external-internal trips were assumed to be produced at cordon stations and attracted to TAZs. Conversely internal-external trips were assumed to be produced at TAZs and attracted to cordon stations. The places of origins and destinations, or production and attraction, were aggregated to minor civil division, county, and state levels. For example, the map in Figure 5 shows the places of destinations of external and through trips entering the region at the Atlantic City Expressway station. Most of these trips had destinations close to the cordon station. About 61 percent of the trips were destined for Camden, Gloucester, and Philadelphia counties. No more than 10 percent of the vehicles traveled through the region from this station (*18*).

In general, the distribution of destinations matched trip origins. Trips entering the region at a cordon station had similar traffic patterns to those which left the region. However, the distribution of origin and destination may differ slightly because evening return trips were not captured and some drivers may not have used the same highway for their return trips.

Of the 627,800 vehicles that crossed the cordon line at the sampled stations, 12.5 percent completed their journeys through

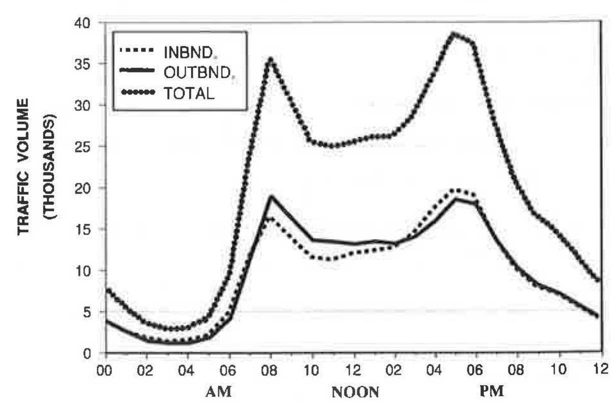

FIGURE 4 Distribution of total daily traffic volume.

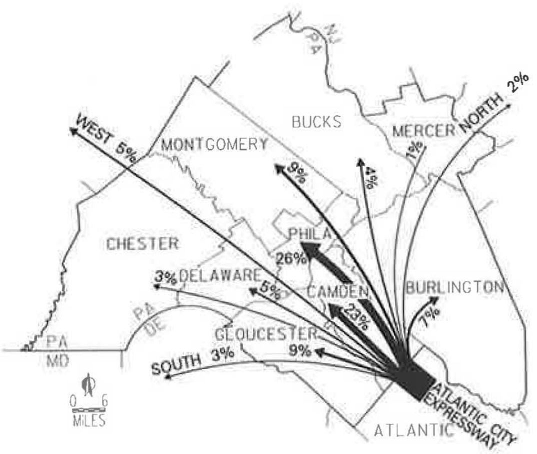

FIGURE 5 Map indicating Atlantic City Expressway cordon station and distribution of inbound trips by place of destination.

the region without major stops. A large portion of through trips was accommodated on the Pennsylvania and New Jersey turnpikes, on which almost 43 percent of the trips had both their origins and destinations outside the region. Most of these were on the New Jersey Turnpike, which extends from the Delaware Memorial Bridge to US-46 in northern New Jersey.

On the basis of previous travel time and speed run surveys, trip length and time were estimated. Excluding turnpike travel, the average trip length of through trips inside the region was 37.2 mi. The average driver crossed the region in 57 min at a speed of 39.2 mph.

Figure 6 shows the trip length frequency distribution for all external trips by travel time and distance. As shown in the figure, a major portion of external trip origins and destinations was clustered within 6 mi of the cordon line. The average trip length and variance were estimated to be 18.7 and 237.6 mi, respectively. Almost 34 percent of the origins and destinations were within a drive of 15 min from the cordon line. The average trip length and speed of external trips inside the region varied significantly by highway type as follows:

	External Trips		
Highway Type	*Distance (mi)*	*Time (min)*	*Speed (mph)*
Freeways and expressways	24.9	43.7	34.2
Arterial highways	17.7	33.6	31.6
Local roads	10.7	20.7	31.0
All highways	18.7	34.5	32.5

Trip Purpose

Trip purpose is defined by the motorist's next major stop after leaving the cordon station. For example, a home-to-work commute in the morning is a work trip, and the return trip in the evening is a home trip, provided no major stops are made en route. If a stop is made at a mall, then the first leg is a shopping trip and the second is a home trip. Figure 7 shows that 46 and 24 percent of the trips sampled were work and home trips, respectively. Home and social or recreational trips may have been underestimated because no surveys were taken after 7:00 p.m. when many of these trips occurred.

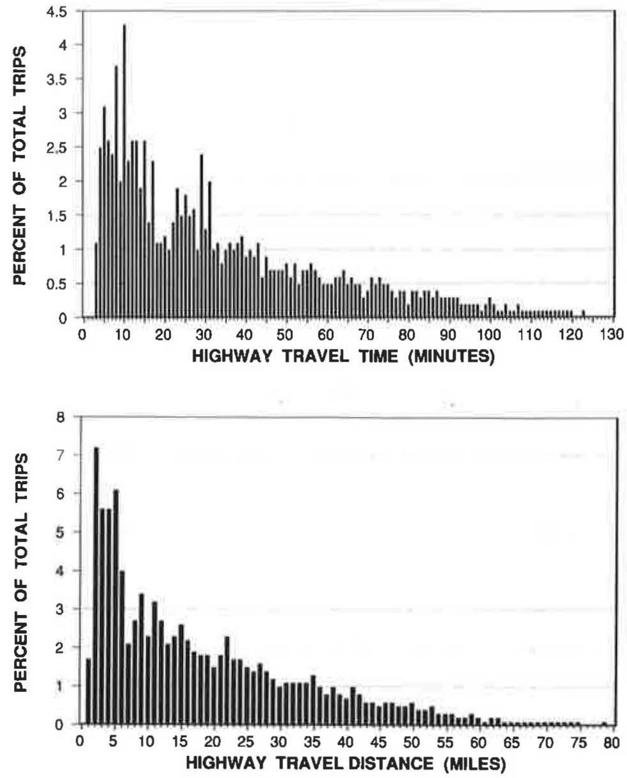

FIGURE 6 Trip length frequency distribution for external-internal and internal-external trips.

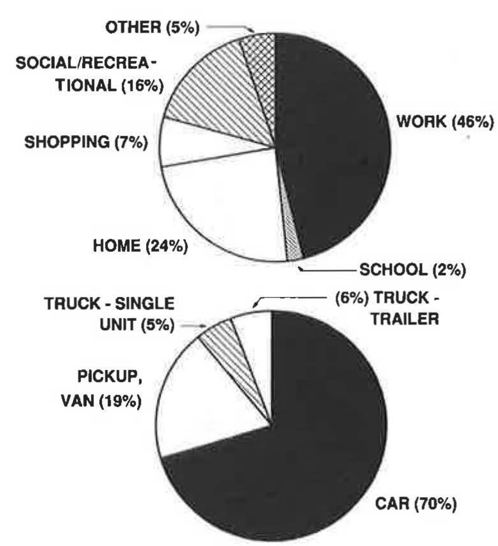

FIGURE 7 Trip purpose and vehicle type.

Social or recreational trips constituted approximately 16 percent of the total. This relatively high proportion of cordon line trips is not surprising because the survey was conducted on some highways serving entertainment, recreational, and resort centers, including the Pennsylvania Dutch Country, Pocono Mountains, New Jersey shore resorts, and Atlantic City. Shopping trips amounted to almost 7 percent of the total.

Vehicle Type

Vehicle type was estimated from the survey as well as from data collected by a field recorder for 24 hr. In some cases, 8-hr manual classification was performed in the peak and off-peak hours. Figure 4 also shows that automobiles were the predominant vehicle type on all highways, accounting for more than 70 percent of total traffic. Pick-ups, panels, and vans made up the second largest portion of traffic with almost 19 percent of the total. Because these vehicles are used primarily for the movement of people, approximately 11 percent of the vehicles entering or leaving the region were used for the movement of goods. If turnpike traffic was included, the percent of medium and heavy trucks would have increased to 12.6 percent of total cordon line traffic. Buses accounted for 0.4 percent.

Vehicle Occupancy

The number of vehicle occupants, including the driver, was checked on the survey questionnaire. The driver was the sole occupant in about 71 percent of the vehicles surveyed. In contrast, 1 percent of the vehicles had five or more, and about 8 percent had three or more persons (see Figure 8). The average vehicle occupancy of all trips was 1.5 persons per vehicle. Trip purpose was the greatest determinant of vehicle occupancy, which ranged from 1.25 for work trips to 2.15 for social or recreational trips. The average vehicle carried 1.45 and 1.73 persons for home and shopping trips, respectively.

Vehicle Registration

The state of registration was taken from the vehicle license plate at the time of the interview, or was checked by the driver on the mail-back survey. In general, the state of registration indicates where the vehicle is garaged. As shown in Figure 7, almost 85 percent of the vehicles were registered in Pennsylvania and New Jersey, in which the DVRPC region is located. About 8 percent were registered in Delaware and 2 percent in Maryland. These two states have contiguous borders with Pennsylvania to the south. The remaining vehicles were registered in other distant states, including New York (1.1 percent), Ohio (0.6 percent), and Virginia (0.5 percent).

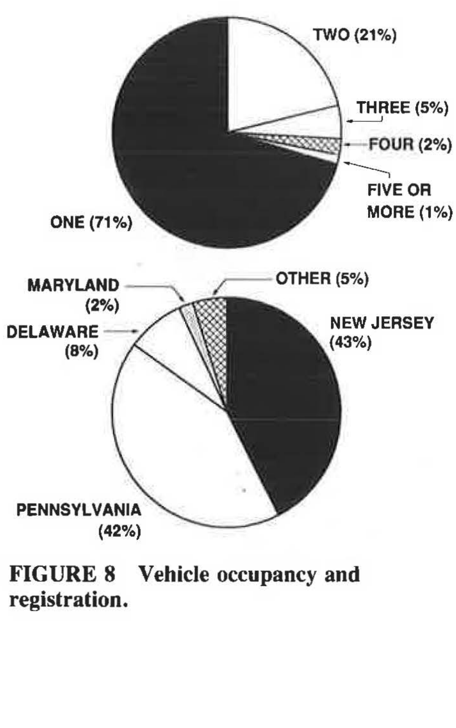

FIGURE 8 Vehicle occupancy and registration.

Major Highways Used

Drivers were asked to list the major highways they would be using to reach their destinations after leaving the survey point. Many drivers did not list any additional highways, either because none were used, or because they did not wish to answer the question. However, the highways listed were useful to identify exit stations of through trips and to define traffic flow within the DVRPC region. For each station, the highways used and frequency of use were tabulated. Analyses of the survey results indicate that the highways used constitute a natural extension of the highways surveyed. In other words, traffic flow between a cordon station and a community within the region is generally accommodated on the highway with the shortest travel time. Most of the traffic remains in the highway corridor. The traffic pattern is consistent with the concept of the gravity model in which trip interchange between two TAZs is directly proportional to the relative attraction of each of the zones and inversely proportional to some function of the spatial separation between zones.

Comparison of Survey Results with 1987 Simulation

In 1987, DVRPC conducted a major travel simulation for the Delaware Valley Region, including cordon-line-through and external trips. The simulation process resulted in extensive tabulations of socioeconomic data, external and through-trip generation, internal-trip generation, trip distribution, modal split, and highway and transit assignments. Comparison between counted and simulated highway screenline volumes indicated that the simulation models produced acceptable levels of accuracy both in highway and in transit assignments (*14*).

In Table 3, the survey results are compared with those produced by the simulation models. The table indicates that the difference between traffic counts and simulated volumes is small (4.8 percent). Also, survey and simulated data on percent of trucks do not show a significant difference (7.9 percent). However, the models resulted in 92 percent overestimation of through trips. On freeways and expressways, through trips were overestimated by 125 percent. The overestimation of through trips was offset by a 13 percent underestimation of external trips.

As presented in Table 3, the average trip length of external trips inside the region on all highways computed from the survey data is very close to that simulated by the model (18.7 versus 17.5 mi). However, the model underestimated trip length on expressways and freeways by about 33 percent. Conversely, trip length on local roads was overestimated in the simulation by 54 percent. These findings are significant and should be incorporated in the next validation of simulation models of external and through trips.

TABLE 3 COMPARISON OF SURVEY RESULTS WITH 1987 TRAFFIC SIMULATION

Variable	Survey	Simulation	Percent Difference (%)
1987 Total Traffic Volume (AADT in thousands)	1,071	1,122	4.8
Percent of Trucks (%)	12.6	13.6	7.9
Percent of Through Trips (%)			
Turnpikes	42.5	74.3	74.8
Expressways	11.6	26.1	125.0
Arterials	8.9	14.8	66.3
All Highways	12.5	24.0	92.0
Percent of External Trips (%)	87.5	76.0	(13.1)
Average Trip Length of External Trips (miles)			
Expressways	24.9	16.8	(32.5)
Arterials	17.7	18.1	2.3
Local	10.7	16.5	54.2
All Highways	18.7	17.5	(6.4)

Survey Cost

The DVRPC cordon line survey project was divided into three phases completed in two calender years at a total cost of $186,000, or about $9,000 per cordon station. Phase I of the study covered the survey design, preliminary planning, and discussion of survey procedures. Phase II included field preparation, conduct of the survey, coding, keypunching, and tabulation of some survey results. The third phase covered the completion of fields surveys, tabulation and analysis of total survey results, and preparation of the final report for each station.

If the cost of services received from member governments, such as the assistance provided by PennDOT and NJDOT, was included, the total survey cost would have increased to $250,000, or about $12,000 per cordon station. The total cost of each interview or mail-back survey questionnaire was about $12.00, which included the cost of collecting sample data, coding, punching, tabulating and analyzing survey results, and preparing the final reports. This is the minimum cost required for conducting such a survey for the purposes of regional planning and travel forecasting of through and external trips.

CONCLUSIONS

The 1989 DVRPC cordon line survey provided essential information on trip origin, destination, and purpose; vehicle type, occupancy, and registration; travel time, distance, and speed; and highways used by motorists entering and leaving the Delaware Valley region. Such data are required for the evaluation of alternative transportation strategies and programs to relieve highway congestion, particularly in the growing suburban areas near the perimeter of the region, and to update information collected in 1960 by the PJTS for travel forecasting and transportation planning.

In order to avoid major traffic delay and reduce costs, a sample of automobile and truck drivers was surveyed at 26 out of a total of 114 highways and roads. More than 27,000 survey forms were processed and evaluated, and information on traffic patterns at four turnpike cordon stations was obtained from previous mailback surveys. Strict safety procedures were followed in setting up the interviewing stations. Stations layouts were devised according to the state safety manual, and no accidents occurred. While some minor traffic delay occurred on high-volume roads, only a few persons complained and traffic delay was minimal during the peak hours. The mail-back survey forms had some incomplete answers or bias in the results, primarily because of the low response rate of commercial truckers; conversely, the response of commuters to the survey was overwhelming. Despite these problems, the margin of error both in interview and in mail-back surveys was acceptable for all planning purposes.

Analysis of the survey results indicates that the volumes and traffic patterns of through and external trips crossing the cordon line have changed significantly in the past three decades. Comparison of the survey results with those already produced by simulation models indicates that the models should be recalibrated to reflect the new survey information. For example, simulated through trips should be decreased 92 percent and external trips increased by about 13 percent. Also, the average trip length of simulated external trips on expressways and freeways should be increased by 33 percent. On local roads, however, the trip length should be decreased by 54 percent.

The assistance received from the Pennsylvania and New Jersey departments of transportation, the nine county planning departments, and the bridge and turnpike commissions was invaluable. Without such cooperation, the survey cost would have increased by about 33 percent. The total cost of each completed interview or mail-back survey was about $12.00, or $12,000 per cordon station. This included the cost of collecting sample data, coding, punching, tabulating, analyzing survey results, and preparing the final reports.

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History of Estimating and Evaluating Annual Traffic Volume Statistics

DAVID ALBRIGHT

Traffic volume summary statistics are foundational to the transportation profession. A historical perspective to estimation and evaluation of annual traffic volume statistics in the United States is provided. During the 1930s there were extensive manual count activities. In the 1940s the transition to mechanical measurement of traffic changed the approach to data integrity. In the 1950s and 1960s dominant personalities gave theoretical direction to calculating annual traffic summary statistics. The procedures developed during this period were at times questionable but became the unchallenged basis for traffic reports over the next three decades. At the end of the 1980s earlier traffic data assumptions began to be challenged. Among the historical assumptions and procedures being reexamined are the normal distribution of traffic, traffic variability, and data imputation and smoothing. In part it was awareness of problems in historical traffic volume procedures that influenced the development of national traffic monitoring standards. The history of traffic volume summary statistics provides a helpful lesson in designing the future of traffic monitoring.

Annual average traffic summary statistics are used to estimate the central tendency of vehicle demand on individual roads and road systems. The precision and bias of annual summary statistics have wide-reaching implications for the transportation profession. Traffic summary statistics affect road geometry and pavement thickness (*1,2*). When expressed as vehicle miles traveled, summaries of traffic volume influence calculations of accident exposure and mobile sources of air pollution (*3,4*). Traffic summary statistics are also used for purposes as diverse as fund allocation, benefit/cost analysis, signalization warrants, alternative route alignment, and transportation research.

The applications and impact of traffic estimates require ongoing review of the assumptions and practices that have been used to produce traffic statistics. The history leading to current procedures for estimating and evaluating annual traffic volume summary statistics are thus examined.

The study began with a comprehensive literature search. Documents relating to traffic volume were reviewed dating from 1930 to 1990. After reviewing the literature, several themes were identified that influenced current practice. Themes were also selected to help inform a more intentional future of traffic monitoring.

HISTORICAL DEVELOPMENT OF TRAFFIC MONITORING

Seminal work was undertaken in statistical analysis traffic data during the 1930s. Some of the initial work was based on manual traffic counts taken in 5-min intervals. The objective was to quantify highway capacity analysis and volume/speed relationships. For example, in 1932 Johnson (*5*) published an article on capacity analysis. Kinzer (*6*) presented a related paper in 1934 on the relationship of probability theory to highway traffic data. Kinzer's paper influenced subsequent national and international discussion of the assumption that traffic is a random series. In 1936 Adams (*7*,p.122) analyzed manually collected hourly traffic flows to demonstrate that, under free-flowing conditions, traffic generally corresponds to a random series of events.

An early statistical analysis concerned with the adequacy of base data for estimation of traffic summary statistics was presented by Shelton (*8*,p.347) in 1938. Shelton designed his study on the basis of concern for complete data sets:

> Most studies of time periods of highway traffic volume have been devoted largely to averages in the form of trends, or patterns, and have been confined to incomplete data.

Shelton (*8*) examined the grouping of traffic volume by hour, day, and month at two sites in Iowa. For the two sites, hourly manual traffic volume observation was conducted for 1 year. The analysis of variability at these sites specified that "there are no additional hours of wider variation not included." Shelton sought to identify the optimal number of manual count hours at a site. Within 3 years there was widespread development and implementation of mechanical traffic-recording devices, and the urgency of Shelton's findings diminished. What did not diminish was the concern for unadjusted data sets for statistical analysis. The value of Shelton's work is not so much in his findings as in his approach to ensuring the integrity of base data.

In 1939 Shelton (*9*) prepared a followup analysis concerned with the variability of traffic volumes. He analyzed observations of traffic volume at nine locations in Michigan. The traffic volume summary statistics were based on hourly manual volume counts for every hour of the day, for 366 consecutive days. Shelton found that some sites were more variable than others and that there tended to be "greater constancy" during work hours than at other hours of the day. He calculated that one of the nine Michigan sites would require seasonal counts, rather than a count in any single month, to estimate annual traffic accurately. Shelton's commitment to unadjusted and complete data for analysis and his observation that at some sites traffic was more variable and would therefore require more than one count annually were important contributions to traffic monitoring.

In 1940 the national traffic volume emphasis shifted from intensive manual counts to mechanical traffic recorders. Rather

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than short-term manual counts adjusted to represent an annual traffic summary statistic, 48-, 72-, and 96-hr continuous mechanical traffic counts were taken. These short-term mechanical counts were, in time, adjusted to represent annual summary statistics from permanently operating traffic-recording devices. From 1940 to the mid-1950s, the traffic monitoring emphasis was on short-term mechanical counts and the use of geographically based, permanent counter adjustment factors to adjust these counts to mean annual statistics (10).

In 1954 Petroff (*11*) first published an article concerned with estimating the error of short-term counts compared with permanent count data. Petroff continued this emphasis and in 1956 wrote what was to become a pivotal traffic monitoring article (*12*,p.110). As in his previous traffic analysis, Petroff was concerned with estimating the error of traffic counts. The data for Petroff's analyses were from permanent counters in New Mexico, Florida, Colorado, Idaho, and West Virginia.

An important contribution of Petroff's 1956 work (*12*) was to identify the deficiency in the approach of geographically proximate sites for adjustment of short-term counts. Two years later, Burggraf et al. (*13*) used Minnesota data to confirm Petroff's observation that adjustment factors based on similar road use were more accurate than those based on similar geographic location. The result of Petroff's work was that, typically, short-term count adjustment factors were based on one permanent counter on a same-use facility. The subsequent development of mean traffic adjustment factors by functional classification of roadway described in the FHWA *Traffic Monitoring Guide* (*14*,p.3-3-4) can be traced back to Petroff's work.

There were other consequences of the 1956 article that had as important, but not as positive, an impact on traffic monitoring. Petroff (*12*) defined the task in traffic summary analysis in one sentence:

> Then the task is to find ways of measuring the errors in the estimates of ADT (average daily traffic) when the estimates are derived by different methods of sampling traffic volumes.

The task definition assumes that the variability in ADT is the result of different sampling techniques.

Petroff (*12*) did not address the issue as one of both the inherent temporal variability of traffic at a site over the period of a year and the additional variability introduced by alternative sampling and estimation methods. Concerning permanent counter data collection he noted:

> The error of estimate of ADT due to a specific method of sampling can be determined only at a few stations where there are permanent machine installations because only there is the true ADT known. Even at permanent installations, the ADT is not absolutely true because of machine failures; the error is comparatively small, however, and is ignored.

The observations of a so-called "true ADT" states clearly the search for a single number rather than the question of whether and to what extent the mean statistic is indicative of the central tendency of traffic volume when summarized over the period of a year. The assumption of a true ADT led Petroff (*12*) to use purely descriptive statistics in determining an approach to the problem of estimating ADT.

In Petroff's quote there is an assumption concerning the impact of machine failure at permanent count stations. This assumption would lead in Petroff's work, and in subsequent state highway agency practice, to techniques for completing or filling in missing data measurements. This practice of completing missing data is termed "imputation." Because the assumption was made that the error would be small and could be ignored, no assessment was made in subsequent work of the impact of imputation and mixed data sets between measurements and imputed values. Or, as Petroff (*12*) wrote,

> At the continuous count stations the true ADT is always known. The difference between the estimated and true ADT value is termed the error.

Some of Petroff's writing concerning traffic estimate accuracy and precision may have been influenced by the interest of the data users. In one section of his 1956 article, Petroff (*12*) wrote the following:

> Experience shows that the estimates of ADT with errors measured by standard deviation of about 10-12% for high-volume (over 500 vehicles per day) roads are satisfactory to the users of the data.

There is a concern with emphasizing the users' interest in precision. What might be satisfactory variation to users in fact may be less than the inherent within-year variation of the traffic on the road. For example, in the data analysis of the 1956 article, Petroff (*12*) calculated the coefficient of variation (the standard deviation divided by the mean and multiplied by 100) for New Mexico short-term-count ADT and true ADT. The calculations were for primary rural road systems and were based on a sample of 172 counts of 7 days' duration. The coefficient of variation was calculated as 8.0 percent. The New Mexico data comprised one of the largest samples in Petroff's study and had one of the lowest coefficients of variation. This calculation was used to support the conclusion that the ADT estimate would be accurate with a coefficient of variation of no more than ±10 percent.

In 1961 Petroff (*15*,p.45) wrote a response to a traffic sampling paper by Thomas Muranyi of West Germany. In the response Petroff noted the following:

> In this country the prevailing number of states base their ADT estimates on single samples. In 16 states so far, rural traffic counting procedures have built-in statistical controls. These procedures were designed to produce the ADT estimates with standard deviation 5 = ±10%. Actually, after the "smoothing out" process whereby small adjustments are made in the ADT estimates when they are examined for reasonableness in relation to the data at the adjacent stations on the map and compared with the records of previous years, the final resulting errors are probably smaller than those indicated by the "raw score" measure 5 = ±10 percent.

As this quote illustrates, by the early 1960s the process of data smoothing to reduce the variability of the estimate was accepted as common practice. Shelton's (*8,9*) concern in the 1930s for the integrity of base data was, for the time, not addressed. It would be over 30 years before analysis of data at permanently installed traffic devices in New Mexico determined that the inherent variability of traffic volume at a site produced a coefficient of variation greater than concluded in Petroff's analysis (*16*).

Petroff's observation that raw data from 1 day's sample traffic monitoring could result in an estimate of ADT that could be characterized at a 95 percent confidence level as having a confidence interval of ±10 percent was based on the experience of 16 states. One of the states that implemented the Bureau of Public Roads approach to traffic data was Georgia. In 1967 Parrish et al. (*17*,p.43) published a paper describing Georgia's automated traffic data collection and analysis program. The authors noted the implementation of the Bureau of Public Roads procedures:

> Methods for using statistical techniques to objectively design traffic-counting programs had, by 1964, progressed to the point where the U.S. Bureau of Public Roads could draw from previous research to develop firm procedural outlines.

As Parrish et al. (*17*) explain, the procedures implemented to collect and summarize traffic data were similar to those identified by Petroff:

> Accessory computer programs are being implemented to tabulate and update the hourly volumes collected from any counting station by the telemetry process. The tabulation can be scanned by a traffic analyst to insure the acceptability of all data. Based on the educated discretion of the analyst, any unacceptable recorded hourly volume may subsequently be discounted and a substitute volume mechanically estimated by the computer, or as an alternative, a volume could be estimated by the analyst.

This approach became common practice among state transportation agencies. The result was the obscuring of the difference between traffic measurements and substituted values in state traffic data bases.

In 1963 the Bureau of Public Roads (*18*) published the *Guide for Traffic Volume Counting Manual*. The method of grouping permanent counters by function of roadway to derive adjustment factors was presented for state evaluation and implementation.

In 1966 Bodle (*19*) analyzed traffic data from five states to determine if Petroff's work was still applicable. The methodology Bodle employed was based on Petroff's work. The percent error for any estimate of ADT from a short-term count was expressed as the relationship between short-term counts and an assumed absolute ADT. The variability of the traffic summary statistic was expressed in terms of the coefficient of variation of the sampling from coverage count periods within a month and the coefficient of variation of the monthly adjustment factors.

Bodle (*19*) noted that his findings were essentially the same as those of Petroff:

> One striking observation that can be made is that the coefficient of variation for 24-hour counts taken Monday through Friday is nearly always greater than ±10%. . . By taking 48-hour weekday counts, it appears that the coefficient of variation of the count can be reduced below the ±10% level to a point where ADT estimates will more closely approach the desired accuracy.

Bodle's work reinforced the importance of 48-hr coverage counts and the presumed variability of traffic based on this estimate. It also demonstrated that, by following Petroff's methodology, similar conclusions would be reached a decade later.

The 1966 comparison of reduction in error among 24-, 48-, and 72-hr counts computed by Bodle (*19*) was reprinted in the 1970 *Traffic Volume Counting Manual*. Then, with a citation to the 1970 document rather than Bodle's work, the same graphic comparison was published almost 20 years later in the 1985 *Traffic Monitoring Guide* (*14*).

The acceptance of Petroff and Bodle estimates of traffic variability was not limited to governmental agencies. In 1975 ITE Technical Council Committee 6U (*20*,p.35) published Data Collection Guidelines and Analysis Techniques, Part I, as an informational report. The report included the following comment:

> In large urban areas, the 24-hour volumes taken on typical weekdays may be considered to represent the annual average daily traffic within an accuracy range of ±10%.

No specific reference is provided for this observation. The *Guide for Traffic Counting Manual*, published by the Bureau of Public Roads (*21*) in 1965, is cited among other titles as a general reference. This guide was based on Petroff's work. The related finding of Petroff was based on a limited number of data observations during 1953 and 1954 and was published in Petroff's 1956 article (*12*).

The ITE report (*20*) recommends that, to improve the statistical significance of before-and-after studies, two short-term counts may be taken before and after the improvement. Then the two counts may be averaged as a "close approximation of the mean" (20). The ITE report, as the work preceding it, assumes that the mean is the appropriate indicator of data's central tendency.

Petroff's work continued to influence traffic monitoring in the 1980s. It was referenced in a 1983 article on traffic count statistics by Hartgen and Lemmerman (*22*,p.11). Citing the Bureau of Public Roads 1965 manual for traffic counting, and Petroff's contribution to the manual, Hartgen and Lemmerman wrote,

> For high-volume roads (AADT > 1,500), the method produces AADT estimates that have a standard deviation of estimate of ±10%.

A limited number of observations of data by Petroff, with associated assumptions that were open to question, became the common reference for traffic variability. Although not challenging Petroff's assumption of traffic variability, a contribution of Hartgen and Lemmerman (*22*) did challenge Petroff's assumption of the insignificance of measurement error. The experimental basis for Hartgen and Lemmerman's concern with measurement error was limited, but the authors did identify that mechanical measurement error could "cloud the reliability of any count."

In the 1970s there was an effort in California to quantify traffic summary statistic variability more accurately. In 1979 the California Department of Transportation (Caltrans) completed an analysis of permanent traffic counter data. The purpose of the analysis was to estimate the confidence interval given a 90 percent confidence level. The Caltrans work concluded that the mean statistic annual average daily traffic (AADT) was highly correlated with the variability around the mean. The work completed in 1979 is still used by the agency and is published in the Caltrans annual survey of traffic volumes (*23*). The California approach to calculating the accuracy and precision of traffic volume summary statistics assumes the normal distribution of traffic volume data and homoscedasticity of the joint distribution of the means and variances. The California finding that the means and variances are correlated suggests that these assumptions are inappropriate. The assumption of the normal distribution of traffic data may similarly be questioned.

Although derived from permanent counter data, in the Caltrans presentation no distinction is made as to the basis for the AADT estimate. The estimate could have been based alternatively on a permanent traffic device; on a short-term count by length of count and by days and season, with adjustment factors applied; or on uncounted sites adjusted for annual growth. The Caltrans (*23*) report states,

> If the estimated ADT was compared to an average based on a 365-day count, it probably would be different, but for 90 out of 100 times the percent variation would not be larger than that shown above.

The approach did not identify the difference between inherent variability of traffic volume over the period of a year and the variability introduced by alternative methods of estimating the mean.

California, as other states, has an extensive procedure for imputing missing data points. If there are a few months of missing data, the data are estimated on the basis of other counts at the same site. If more than 3 months of data are missing, the previous years' data are used to impute the missing values (*24*). The California observations, as those of other states, were based on earlier assumptions concerning the importance of permanent device equipment failure and the validity of data smoothing.

The Caltrans work did not have the constructive impact it might on subsequent work in the field. Subsequent writing by authors such as Ritchie (*25,26*) did not reflect the interest in using permanent counter data to estimate same-site daily traffic variability. Subsequent work was more characteristically interested in refining the work of Petroff on estimating the variability of short-term count adjustment factors.

Such a model for estimating the variability of AADT from short-term counts was developed by Ritchie (*25*,p.14) in the mid-1980s. He began with the following equation for estimating AADT from a short-term traffic count:

$$\text{AADT} = \text{VOL}\,(F_S)(F_A)(F_G) \quad (1)$$

where

AADT = annual average daily traffic,
F_S = seasonal adjustment factor for the count month,
F_A = weekday axle correction factor, and
F_G = annual growth factor if no count was taken in the current year.

Ritchie then proposed that the coefficient of variation (cv) of AADT could be derived from the following expression:

$$\text{cv}^2(\text{AADT}) = \text{cv}^2(F_S) + \text{cv}^2(F_A) + \text{cv}^2(F_G) \quad (2)$$

The work by Ritchie (*25*) addressed the critical question of accuracy and precision of traffic volume estimates. It did not, however, address the question of the inherent variability of the traffic volume at the site. For example, omitting the variability of the traffic summary statistic can result in the computation of the variability of a summary statistic at an uncounted site being measured by only the variability introduced by the annual growth factor employed. The result can be, as in Petroff's and Bodle's work, that the calculated precision of an estimated summary statistic reflects less variability than the inherent variation in traffic at the site.

Ritchie's paper (*25*) was based on Washington State Department of Transportation data. The Washington traffic data procedures were detailed during the same time period in a Washington State study by Ritchie and Hallenbeck (*26*). Their study did not address the issue of permanent traffic recorder mechanical failure and data imputation. Washington state traffic summary statistics included imputed data to complete a 365-day data set at permanent counter sites (*27*). Neither Ritchie's paper (*25*) nor Ritchie and Hallenbeck's study (*26*) addressed inherent site variability and the variability introduced by data imputation. Their findings, as those of Caltrans in 1979, reflect data variability under the condition of the imputation techniques employed in the traffic data base.

In 1985 FHWA (*14*) published the *Traffic Monitoring Guide*. This document presented an efficient procedure for states to use in providing system-level traffic information for federal reporting purposes. The document addressed neither the question of inherent temporal variability nor the question of base data integrity. It did, however, provide an overview of the state-of-the-art in traffic monitoring. It was this document that first provided the incentive and direction for the refinement of traffic monitoring procedures.

In 1988 the first statewide standards for traffic monitoring practice were implemented (*28*). The standards specified data integrity and prohibited data imputation. After the first 2 years of standard data, the underlying distribution of traffic volume characteristics was examined.

In 1990 two events took place that have the potential of positively changing the history of traffic monitoring practice. In June 1990, ASTM initiated the first draft of traffic monitoring standards. The intention of the ASTM standards was to provide a common traffic monitoring specification for public agencies and private firms. Then in December 1990 the AASHTO Standing Committee on Planning established a Traffic Monitoring Task Force. The task force was charged with the responsibility of preparing a guidance for state transportation agencies. The purpose of the guidance was to provide a common traffic monitoring practice, and it was to be developed in concert with ASTM standards.

From the outset, both the ASTM and AASHTO activities were based on clearly defined traffic monitoring principles. Among the initially proposed principles was assurance of base data integrity. If endorsed and implemented, base data integrity will permit analysis of the underlying distribution of the data. This analysis will, in turn, refine the understanding of traffic volume summary statistics. The unfolding ASTM standards and AASHTO guidance have the potential to return traffic monitoring to the careful attention to and regard for data as expressed by Shelton in the 1930s.

SUMMARY: ATTEMPTING TO LEARN FROM THE PAST

It seems remarkable that as common and important a statistic as annual traffic volume would be so subject to modification and estimation. The benefit of tracing the errors in traffic volume summary statistics is more than reforming current practice under standards. This task alone will be a challenge to develop and implement, but it is not enough. There is a broader sense in which future practice is structured to avoid similar problems.

When standards of and guidance for traffic monitoring practice are completed, they will be subject to the same limitation as the mid-twentieth century work of Petroff and Bodle. The errors will be different, but there will be errors. They will not be intentional; rather, they will be the result of persons attempting to use available tools in a responsible manner.

If the profession is to learn from the past, what must change is the growing distance of the analyst from the measurements being analyzed. The profession could retain the illusion that traffic volume summary statistics were equivalent and comparable only because examination of base measurements was rare. Simple questions were unasked, such as, On what measurements are these summary statistics based? Although such questions were unasked, vast traffic data sets were computer processed, analyzed, and reported erroneously with ever-increasing speed.

By learning from the past, the ability to master quantity and speed of data has been demonstrated. Through deliberate concern with relatively simple questions about base data, the challenge is to demonstrate the ability to master quality.

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Traffic Volume Summary Statistics

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Standardized traffic volume data provide a basis for preliminary examination of the underlying distribution of the data. In this study, traffic volume data from permanently installed devices were examined on a daily basis throughout (Federal) fiscal year 1989. The examination included computer-based edits and analyst data review. If the edited data were accepted, the data were stored in a computer file for later use. Missing or incomplete days of data were not included. Data were not adjusted on the basis of professional judgment. The reviewed and accepted data were maintained in a file specifically designed to prohibit intentional or unintentional operator modification of the measurements. These steps were taken to help ensure base data integrity. At the end of the year, all accepted data were analyzed using Statistical Analysis System software. The traffic volume data from the permanent sites indicate that traffic on many roads is not normally distributed and that site-specific traffic data collected over the period of 1 year may be more variable than previously estimated.

The purpose of this study is to examine the underlying distribution of traffic volume data using 1 year of standardized traffic volume data. Data from permanently installed traffic volume recorders in New Mexico were used in the analysis. The importance of ensuring base data integrity, the distribution of traffic volume data over the period of 1 year, and the variance associated with annual traffic volume summary statistics are described.

BACKGROUND

During 1987 and 1988, the New Mexico Highway and Transportation Department conducted a survey of traffic monitoring practice within the state and nationally. This survey led to the awareness of needed reform through establishing of mandatory traffic data standards (*1*). In May 1988, the secretary of the department signed the first set of statewide traffic monitoring standards, designed to go into effect October 1, 1988 (*2*). The standards were required for both the public and private sectors for all traffic counts on roads that received, or were proposed to receive, state or federal funding.

The state requirements were designed to ensure the integrity of base data. A computer system, written in Statistical Analysis System (SAS) language, was developed and implemented to help ensure that all public and private sector data complied with the traffic standards. This program was termed the "Traffic Monitoring System" (TMS).

Of the several principal TMS design elements, the most important was base data integrity (*3*). Daily electronic edits were implemented for all data from permanent traffic recording devices. Each day, all permanently installed devices were polled using a telecommunications system. Hourly records of traffic volume were uploaded to a VAX 8550 computer. These data were edited by computer to check for compliance with standards. Following electronic edits, an analyst reviewed site-specific, hourly volume records that were flagged as having questionable directional distribution or variance.

For all questionable data, an analyst was given the responsibility to review the hourly traffic records. The analyst also had the authority to accept or delete questionable days' data. If deleted from the active file, TMS automatically stored the data for further analysis in a research file.

No procedures were permitted for individual analysts to exercise professional judgment in modifying measurements. Similarly, individual analysts were not allowed to complete missing or incomplete days of data. Any missing or erroneous mechanical measurements resulted in nonacceptance of the day's data, and data storage in the research file.

All edited, reviewed, and accepted daily data were defined as "standard" or "edit-accepted" data days. Traffic summary statistics were calculated solely from this edit-accepted data.

On October 1, 1989, the first complete year of standard traffic data had been collected, edited, summarized, and was available for analysis. This provided an opportunity to examine standard data files from traffic counts in a computer software environment suited for statistical analysis.

(Federal) fiscal year (FFY) 1989 traffic volume data are appropriate to the purpose of this study because the data were collected and maintained with an emphasis on base data integrity. On the basis of what was observed from the first year of standard data, additional modifications were made to the standards and TMS (*4*). Both the standards and TMS were designed for refinement on the basis of what was learned from implementation.

STANDARD PERMANENT COUNTER DATA

During FFY 1989, there were 66 permanent devices statewide. Of these, 62 sites were used in this study to examine the data distribution. Among the 62 sites considered appropriate for the purpose of this study, the range of standard data days during the year was from 107 to 310 days.

The sites not used in this analysis had 3, 4, 31, and 44 days of standard data. The low standard days were related to new device installation and construction on the roadway.

The 62 sites with data analyzed in this study were predominantly rural. There were 44 counters on rural roads, and 18 counters from urban roads. The included sites are presented by functional classification in Table 1.

For all permanent counter sites included in the study, there was an average of 247 days of standard data. Because traffic

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TABLE 1 NEW MEXICO PERMANENT COUNTER SITE DATA BY FUNCTIONAL CLASSIFICATION FOR FFY 1989

Functional Classification	Number of Sites
Interstate Rural	14
Principal Arterial Rural	7
Minor Arterial Rural	23
Interstate Urban	4
Principal Arterial Urban	12
Minor Arterial Urban	2
Total	62

data have been historically and are conventionally grouped by functional classification of roadway, it is appropriate to examine standard data days by these categories. Six functional classifications are represented by the permanent counter sites in this study. The average days of standard data by functional classification of roadway are presented in Table 2.

Among functional classifications, the Interstate urban had the lowest number of average standard data days for analysis. During the first year of standard operations, the edits for standard compliance resulted in rejection of more days of data on Interstate urban roads than for other road classifications. Approximately 45 percent of the data were accepted as standard. The data collection edits resulted in rejecting daily data less frequently among the other five roadway functional classifications. For the functional classifications excluding Interstate urban, between 65 and 81 percent of the data were accepted as standard. At each of the 62 counter sites included in the study, there is an adequate sample of days of the year to examine daily data variability.

The annual average daily traffic (AADT) was calculated from standard data days of data at each site, with the data weighted by day of week (*5*). The AADT varied among the sites. The range of AADT was from 500 to 127,000. The distribution of AADT by volume group is provided in Table 3.

TABLE 2 PERMANENT COUNTER STANDARD DATA DAYS BY FUNCTIONAL CLASSIFICATION FOR FFY 1989

Functional Classification	Standard Data Days
Interstate Rural	238
Principal Arterial Rural	278
Minor Arterial Rural	251
Interstate Urban	165
Principal Arterial Urban	254
Minor Arterial Urban	294

TABLE 3 PERMANENT COUNTER SITES AND VOLUME GROUPS BY AADT FOR FFY 1989

AADT	Number of Included Sites
<1,000	3
1,000 - 5,999	22
5,000 - 9,999	11
10,000 - 19,999	11
20,000 - 29,999	5
30,000 - 39,999	7
40,000 - 49,999	1
50,000 +	2
Total	62

IMPACT OF DATA STANDARDS

The establishment and enforcement of traffic data standards resulted in significant changes in traffic summary statistics. The impact of standardizing data collection and summarization practice is in part reflected by the change in permanent counter summary statistics from FFY 1988 to FFY 1989.

The FFY 1988 data for the permanent counter sites were the last year of nonstandard data practice. The practice used was similar to that of most states in the nation. Missing values were imputed from current data when there were few missing hours in the dataset, and were estimated from previous years' data when there were many missing hours or days of data. Professional judgment was used to complete and smooth the data.

FFY 1989 was the first year of statewide data standards. The FFY 1989 data summarization standards prohibited any imputation or completion of missing data, and rejected any day's data not both complete and conforming to other data integrity edits.

Of the 62 permanent counters accepted for analysis in this study, 57 can be used for comparing the 1988 and 1989 summary statistics. At five remaining sites, the counters were not installed throughout FFY 1988.

Comparing the impact of change in methodology is problematic when the change involves two different years of data. This noted, some rules of comparison may be reasonably established. First, none of the sites exhibited a year-to-year traffic decrease over the past two decades, and no land use change occurred at the sites in the 2-year study period to suggest a decrease would be expected. A decrease in AADT from FFY 1988 to FFY 1989 could be expected to be identified as a site at which the change was a result of implementing traffic standards.

Second, the fuel consumption in the state increased by approximately 3.5 percent between the two years. Although this figure may be biased because of reporting problems, and the change would be expected to vary by functional classification, any increase in volume between 0 and 5 percent between FFY

1988 and FFY 1989 may be considered reasonable. The increase may or may not be correct, but there is not an appropriate basis for rejecting the increase. Volume increase greater than 5 percent would appear to be a combination of change in traffic and method, unless there was a traffic generation change known to the data analysts. These sites with traffic generation changes that would indicate a greater than 5 percent increase were among those five newer installation sites already deleted from the comparison.

Of the 57 sites that can be used to compare the impact of traffic standards prohibiting professional judgment, smoothing, and imputation procedures, 30 sites had a decrease in AADT from 1988 to 1989, whereas 27 sites had an increase. The relatively equal distribution between the number of increasing and decreasing values would be expected if the two methods were neither inherently nor intentionally biased to produce higher or lower traffic volumes. If there were a methodological impact, the incidence of increase and decrease would be expected to be, and is, almost equally distributed.

Of the 27 sites with an increase in traffic, 9 had increases greater than 5 percent. Combining these permanent counter sites with the 30 that experienced a decrease, nearly 70 percent of the sites were characterized by non-traffic-related change in summary statistic through the data standards.

The range of percent change in AADT from 1988 to 1989 also indicates the impact of the change in method. The high and low values in the change are significantly different than would be expected if the change were caused by unobserved and unaccountable changes in traffic flow. The range of AADT change from FFY 1988 to FFY 1989, by functional classification, is presented in Table 4.

In Table 4, the low change column is not applicable in one case because there was only one minor arterial urban site included in this comparison.

The changes identified at permanent counter sites may be associated to some degree with the establishment of data standards that preclude certain common practices. This observation is important, because the extent of the change suggests not only that standard practice has an impact, but also that nonstandard traffic bases that permit professional judgment in smoothing and imputing missing data points may be limited in their ability to support analyses of traffic variability. The comparisons also suggest that traffic volume summary statistics may be distorted by previous assumptions of mechanical failure insignificance, data imputation, and data smoothing.

TABLE 4 RANGE OF PERCENT CHANGE IN PERMANENT COUNTER AADT BY FUNCTIONAL CLASSIFICATION OF ROADWAY, FFY 1988 TO FFY 1989

Functional Classification	High	Low
Interstate Rural	10%	- 7%
Principal Arterial Rural	9%	- 6%
Minor Arterial Rural	8%	-10%
Interstate Urban	12%	-21%
Principal Arterial Urban	7%	- 5%
Minor Arterial Urban	2%	--

SITE-SPECIFIC TRAFFIC VOLUME VARIABILITY

The standard data measurements from 62 permanent counters were used to calculate site-specific information about traffic daily variation over the period of 1 year. The variability was examined by site, by functional classification, and rural and urban roads.

There is an inherent annual variability in traffic at any site. This annual variability is intuitively known, on the basis of the common experience of driving the same road at the same time on different days and noting that traffic differs. However, the variability of traffic has been commonly underestimated in the literature (*6*).

The distribution of the coefficients of variation, which ranged from 8.3 to 42.1 percent, is presented in Table 5.

The results reflect inherent traffic variability that is higher than commonly considered. The principle is fundamental to traffic monitoring truth-in-data: estimates of variability should be based on actual measurements of traffic, unaffected by either the judgment of the data collector or interest of the data user.

NORMAL DISTRIBUTION OF THE DATA

Some applications of mean summary statistics such as AADT assume normal distribution of data. It may be helpful to consider the effect of skew on the distribution of the mean. Skew is an indication that the mean may not indicate the central tendency of the data.

The data from permanent counter sites were tested to determine whether or not they are normally distributed. Using

TABLE 5 PERMANENT COUNTER SITES INHERENT VARIABILITY BY AADT COEFFICIENTS OF VARIATION FOR FFY 1989

CV	Number of Sites
8 - 9.9	2
10 - 11.9	6
12 - 13.9	5
14 - 15.9	13
16 - 17.9	12
18 - 19.9	8
20 - 21.9	6
22 - 23.9	1
24 - 25.9	2
26 - 27.9	2
28 - 29.9	3
30 +	2
Total	62

the SAS structure of TMS, the moments of the distribution were calculated for edit-accepted data from each permanent counter. The Kolmogorov D test was used to test for departure from normal form, to accept or reject the null hypothesis that the data are a random sample from a normal distribution. The Kolmogorov test measures the discrepancy in location, scale, and shape between a normal distribution and an observed distribution. Data at a permanent counter site for which the null hypothesis was rejected were then examined for skew and kurtosis.

Many of the permanent counters have data that are not normally distributed. An example of a distribution that is positively skewed is from a permanent counter on Interstate 10, milepoint 445. The null hypothesis was rejected. There were 249 standard days of data, and skewness of 1.47711.

An example of standard permanent counter data that are negatively skewed was the permanent counter on Federal-Aid Local Road 4797, milepoint 1. This counter had 310 standard days of data, rejection of the null hypothesis of normal distribution, and skewness of −0.887133.

Data from some of the counters more closely approximate a bimodal distribution. A permanent counter on Federal-Aid Local Road 5096, milepoint 2, had 218 standard data days, with a mean of 38,750, and failed the Kolmogorov D test. There is a skewness of −0.959344. All permanent counter data distributions that appear bimodal were also negatively skewed.

Of the 62 permanent counters in this study, 20 had data that were found to be normally distributed. Positively skewed data were measured at 20 of the sites. Negatively skewed data were observed at 22 sites. Bimodal distributions with negative skew were observed at 8 sites.

There is a difference in distributions by functional classification of roadways. Table 6 presents the incidence of distribution types for rural and urban permanent counter sites.

Rural roads had a higher incidence of normal distribution than urban roads. Rural roads with traffic not normally distributed tended to be positively skewed. Urban roads tended to be more dominantly nonnormal, and negatively skewed. Although in the sample of 62 sites exceptions were found to strict associations of skew and roadway classification, the typically negative skew of the urban sites may be associated with the capacity constraint on these roads. The positive skew of the rural roads may be observed as resulting when the lower values of a distribution are bounded by zero, and the upper values are bounded only by capacity constraints that are not reached by the measured traffic volume.

The difference in data distributions by rural and urban is further reflected in functional classification data distributions. Table 7 presents the incidence of permanent counters by functional classification for normal and positively and negatively skewed distributions.

An assumption of the normal distribution of the traffic data would have been correct approximately 64 percent of the time

TABLE 6 PERMANENT COUNTER TRAFFIC DATA DISTRIBUTIONS IN NEW MEXICO FOR FFY 1989

Distribution	Rural Roads	Urban Roads	Total
Normal	19	1	20
Positive Skew	18	2	20
Negative Skew, Not Bimodal	5	9	14
Negative Skew, Bimodal	2	6	8
Total	44	18	62

Shown in Number of Permanent Counters

TABLE 7 PERMANENT COUNTER TRAFFIC DATA DISTRIBUTIONS BY FUNCTIONAL CLASSIFICATION OF ROADWAY IN NEW MEXICO FOR FFY 1989

Distribution	IR	PAR	MAR	IU	PAU	MAU	Total
Normal	9	2	8	1	0	0	20
Positive Skew	5	5	8	1	1	0	20
Negative Skew, Not Bimodal	0	0	5	1	7	1	14
Negative Skew, Bimodal	0	0	2	1	4	1	8
Total	14	7	23	4	12	2	62

Shown in Number of Permanent Counters

on the Interstate rural roads where daily traffic was monitored. For this functional classification, actual distributions most often satisfied the hypothesis of normality, but the assumption was still inappropriate about one-third of the time. On all other functional classifications of roadway, the assumption of normality was inappropriate in more cases than not. On urban arterials, no sites were found with normally distributed traffic data.

The skew of the traffic data was found to be more significant than kurtosis. Twelve of the sites were evaluated as leptokurtic, and one of the sites as platykurtic.

Over the course of a year, there is inherent variation in traffic at any site. The inherent variability should be assessed before evaluating the error introduced by alternative sampling procedures and adjustment factors. Traffic summaries at permanent counters may be more appropriately understood as a range of values at given probabilities, not as specific or "true" values.

As noted earlier, the observed variability of traffic is higher than previously estimated in the literature. This difference, in part, may be associated with the historical practice of smoothing base data. It suggests but does not define the extent of the traffic summarization errors introduced by the practice of altering base data.

The assumption of normal distribution of traffic data is not appropriate on most roadways. Mean traffic summary statistics should not necessarily be considered as indicating the central tendency of the data. Statistical analyses that assume normal distribution and homogeneity of variance may be inappropriate for traffic volume data.

FURTHER RESEARCH

The process has just begun in learning from the traffic data collected and summarized under standard practice. At present, there are active efforts underway to define standards of practice by the ASTM, and to define a guidance for common practice by AASHTO. Through these efforts, in the coming years the number of standard data bases can be expected to increase substantially. A larger sample will facilitate further analyses, particularly in urban areas.

Several issues addressed in this study may be further examined. Mean statistics are considered robust in that departures from normality may not diminish the helpfulness of the mean in indicating the central tendency of the data. Thus, further work in defining the appropriate limits of accepting the mean statistic is recommended for future research.

The indication that traffic data frequently are not normally distributed leads to further questions. Alternative summary statistics, perhaps based on percentiles, may be examined for use in traffic analyses.

The difference in distributions of traffic data within the same functional classifications of roadway indicates the need for continued research concerning operational classification of roadway data. The principle of operational classification is that the data should be grouped on the basis of observed variations in traffic measurements, rather than marginally political and a priori categories such as functional classification. The potential for reexamining how base measurements are grouped suggests that base data integrity involves not only saving unmodified measurements, but also retaining the measurements for future hypothesis testing.

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Applying Geographic Information Systems to Transportation Planning

LARRY D. ANDERSON

A technology crucial to better coupling of land use and transportation planning is that of the Geographic Information System (GIS). Because few documented practical applications of this technology have been developed, the Planning Support Branch of FHWA's Office of Environment and Planning, with the Transportation Planning Division of the Maryland-National Capital Park and Planning Commission (M–NCPPC) in Montgomery County, Maryland, conducted a 3-month case study examining M–NCPPC's application of the GIS Spatial Analysis System (SPANS) software to its transportation planning activities. This case study comprises one module within FHWA's GIS/Video Imagery Demonstration Project 85. SPANS was used to disaggregate the county's traffic analysis zones (TAZs) into smaller subzone components to produce finer-grained modeling data. The primary goal was to compare current and planned housing and employment with prescribed development ceilings. This activity permits creation of future scenarios based on the amount of remaining legally developable land, as well as the future demand for transportation by mode (automobile, bus, rail, walking, bicycle, etc.). The results indicate that using GIS-produced disaggregate socioeconomic data with travel demand modeling techniques improves the planner's ability to model both trip generation and modal choice. Further work by planners and GIS software developers alike will expand the application of the GIS well into the future.

Montgomery County, Maryland, is an urbanizing county located to the immediate north of Washington, D.C. Now encompassing 350,000 jobs and 700,000 inhabitants in 270,000 households, the county was once composed of bedroom suburban communities, self-sufficient towns, and fertile agricultural areas. However, in the past several decades, Montgomery County has witnessed rapid growth both in employment and in housing as the Washington, D.C., area has developed a more multinucleated metropolitan form. Like many other urban and suburban areas, the county recognizes traffic congestion and regulation of land development as its top local political issues (*1*).

In response to this rapid growth and development, the county council passed the Adequate Public Facilities Ordinance (APFO) in 1973. The APFO mandates that the county planning board cannot approve a preliminary plan or subdivision if the existing public facilities (or those programmed in the local and state capital improvements programs) will not adequately serve the applicant subdivision and all previously approved projects. Under the county's annual growth policy (AGP), the county council establishes criteria and standards for administering the APFO and approves staging ceilings for each of the county's 17 policy areas (districts) on the basis of the adequacy of transportation and public school facilities. The staging ceiling for a given policy area is the maximum amount of land development accommodated by the existing and programmed public facilities serving the area without exceeding policy standards for adequacy of public facilities (*2*).

Once the policy area ceilings are established, the remaining capacity for development in the respective policy areas is calculated by subtracting the pipeline (approved but unbuilt developments) from the ceiling. When the pipeline has risen to meet the ceiling, the planning board cannot approve additional subdivisions in that policy area, except under certain circumstances. Therefore, development potential is a measurable entity with definite limits.

Faced with these policy restrictions, the transportation planning modeling staff of the Maryland-National Capital Park and Planning Commission (M–NCPPC) in Montgomery County needed both a tool and a procedure to manage and process large amounts of data in monitoring current development patterns, as well as to construct future development scenarios quickly yet accurately.

Like many other urbanized (and urbanizing) areas, Montgomery County possesses vast amounts of usable data in one form or another. However, in the past, the actual use of these data was typically limited to specific software formats (*3*). Recent advances in computer hardware and software have improved this situation. Moreover, because transportation-related data contain spatial components, the best way to associate elements from different datasets is through a consistent spatial referencing system. A technology capable both of georeferencing and of data base management is that of the Geographic Information Systems (GIS). By definition, a GIS is "a computer-based system for the storage and retrieval (and usually the analysis and display, as well) of two- and three-dimensional geographic data" (*4*).

Performing travel demand modeling ranging from master plan models at one extreme to the Baltimore-Washington super network at the other, M–NCPPC's transportation planning modeling staff was concerned that their traditional four-step, zone-based regional transportation models ignored the varying socioeconomic compositions of these aggregate zones by applying single zonal values representing average characteristics (*5*).

Wanting to take advantage of these intrazonal data variations, M–NCPPC believed using a GIS could assist in disaggregating the county's existing 246 traffic analysis zones (TAZs) into 945 component subzones, allowing for the creation of more flexible zonal systems for varying levels of analysis.

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Therefore, using data such as the county tax assessor land parcel file records within a GIS to allocate zone-level land use data to the disaggregated subzone components better estimates the subzonal share of TAZ land uses. Representing a bottom-up approach, disaggregation of zonal socioeconomic data better accentuates the relative housing and employment allocation and variation between and within the respective analysis area configurations. TAZ disaggregation also creates smaller, more homogeneous analysis zones, permitting finer network detail. From a travel demand modeling perspective, improved trip assignments subsequently result from smoother loadings onto the network.

Once M–NCPPC made the commitment to GIS, the next step involved selecting a particular microcomputer-based software package. After some deliberation, M–NCPPC chose the Spatial Analysis System (SPANS), developed by TYDAC Technologies Corporation.

SPANS (version 4.302) is like other GIS software in that it imports, manipulates, and exports data from raster and vector structures. However, unlike most other GISs, SPANS uses a quadtree data structure. For example, a given map's geographic information is divided into four equal areas (the first level in the quadtree). If any of these areas are homogeneous, then the quadding of that area stops. All of the areas that are not homogeneous are further subdivided by four (the second quad). This partition process continues until all of the areas are homogeneous, or until a user-specified level of quadding is reached. The quadtree structure then is like a raster structure, but with variable-sized grid cells. Where a map is uniform, the grid cells are large to save memory space; however, where a map is complex, the grid cells are small to preserve resolution (*6*).

M–NCPPC uses the following hardware and software to run SPANS: Compaq Deskpro 386/20 microcomputer with a 300-Mb hard disk, 1-Mb RAM, 80386 math coprocessors, DOS version 3.3, parallel ports for SPANS hardware key and printers, serial ports for the digitizing table, color VGA monitor, monochrome monitor, and Tektronix 4696 color ink-jet printer.

MONTGOMERY COUNTY CASE STUDY

Data Requirements

Like other GIS software packages, the power and flexibility of SPANS allow the user to specify the type and amount of data input into the system, as well as that of the information output from the specified analyses. One advantage of GIS is its ability to use existing spatial data bases residing in various formats. Thus, the initial existence of the necessary datasets is the only data-oriented restriction facing agencies interested in establishing GIS applications.

However, data conversion remains a somewhat time-consuming and less-than-perfect procedure. With no prior proven method, M–NCPPC initially developed a prototype procedure to convert the datasets, then perform the TAZ and subzone calculations and projections. Most of this data sorting and calculating was performed in Lotus spreadsheets, exported as ASCII files, then imported as SPANS attribute data files. Processing over 14,000 records in this manner consumes more than 100 person-hr. However, M–NCPPC is currently developing more automated methods, such as writing small programs in-house, which should eventually reduce the processing time by over one-half.

Once the data are processed and formatted into SPANS, the creation of maps and accompanying analyses proceeds at a less cumbersome pace. Assuming staff adequately trained in the GIS in general and SPANS in particular, this operation consumes significantly less effort than the initial data preparation. The planner's preferred level of specificity influences the amount of time devoted to performing the spatial analysis. Therefore, the key for transportation planning agencies interested in using the GIS is identifying its available resources (data, staff, time, computer hardware, software, etc.) from the outset, and later determining the amount and type of work to follow.

Montgomery County's Input Data

Among the input data included in the Montgomery County case study are the following:

- The 255,000-record county tax assessor parcel file (of which north Bethesda's 14,013 records were used), containing data on all registered land parcels in the county (including acreage, zoning category, land use codes, assessed value of land and buildings, traffic zone number, and census tracts and blocks).
- A data attribute (pipeline) file containing all approved subdivisions in the county, including size of approved subdivisions. The status of these projects was also included.
- Existing Geographic Information Manipulation and Mapping System/Geographic Area Data Structure (GIMMS/GADS) vector line graph files of parcel boundaries for approved subdivisions that were later polygonized.
- Existing GIMMS/GADS vector line graph files of TAZ boundaries, as well as subzone boundaries digitized into SPANS. Both files were then polygonized.
- MetroRail and commuter rail station points digitized by M–NCPPC into SPANS.
- The county's Topographically Integrated Geographic Encoding and Referencing (TIGER)/Line street vector file.
- Montgomery County's Road Maintenance File containing sidewalk and street mileages. From this file, M–NCPPC calculated subzone level ratios of sidewalk mileage per street mileage.

Case Study Methodology

Focusing on the north Bethesda policy area (one of the county's 17 aggregate policy planning areas), a household and employment forecasting model was used to allocate the aggregate zone-level forecast data from north Bethesda's 14 TAZs directly to the policy area's 59 more disaggregated subzones. The model's primary goal was to map the policy area's current household and employment compositions on both TAZ and subzone levels in relation to the county's prescribed development ceilings. The results provide the planner an indication of the amount of developable land remaining for formulating future development scenarios.

Setting these subzone housing and employment levels to full buildout of the current zoning required using predetermined zoning yields. For each commercial zoning category, the assumed floor area ratio (FAR), assumed number of square feet per employee, and employment type were necessary to estimate maximum employment. On the other hand, the residential zoning yield factors defining the maximum number of dwelling units per acre of land for each zoning category were used to project housing per land parcel. The model's variables and relationships are as follows (M. Replogle, unpublished data):

For Zones $i = 1, \ldots n$ in policy Area p:

B_i = base-year parcel file containing number of dwelling units and jobs,
C_i = parcel development completions,
U_i = approved but unbuilt (pipeline) developments,
F_i = development floor $(B_i + C_i + U_i)$,
R_i = zoning capacity (the allocation potential) for vacant and redevelopable parcels not in the pipeline,
Z_i = anticipated zoning ceiling $(F_i + R_i)$,
Q = policy-based decision variable ranging between 0 and 1 applied uniformly to all Zones i in policy Area p that allocates a fraction of R_i,
S_i = staging ceiling value for Zone i, such that $S_i = F_i + (R_i * Q)$, and
S_p = staging ceiling for policy Area p, such that $S_p = \Sigma S_i$.

R_i, therefore, represents the maximum potential of residential or employment development that may occur in a given TAZ or subzone. Uniformly allocating a specified portion of R_i for all zones in policy Area p, the variable Q can then be adjusted by the planner to construct various development scenarios based on different possible policy orientations. This procedure allows the planner to play multiple what-if games with the model's data in developing planning alternatives.

Uses of the Model and Data

Once the zones and subzones are established and the various residential and employment totals are converted, calculated, and projected, data analysis and display follow. The planner can then construct SPANS modeling equations and algorithms to produce output maps. Because M–NCPPC is more concerned with pattern than pace of development, housing and employment densities are closely examined. With SPANS, selected attribute data can be aggregated or disaggregated, as well as calculated with itself, yielding output such as density analyses at either the parcel, subzone, or TAZ levels.

Depending on the desired analysis, several data manipulation and display strategies may be used. In order to examine development densities, the M–NCPPC uses three such methods. First, in simple choropleth maps, spatial information is assumed to be homogeneously distributed within a TAZ or subzone and represented by different class values. Because spatial distribution of particular data items is not considered within every subzone or TAZ, class-specific colors or shading patterns are assigned zonally. The primary objective of these maps is to symbolize the magnitudes of the data as they occur within the TAZ or subzone boundaries. In other words, these maps provide only the spatial organization of the statistical data (7).

An add-on module in SPANS developed by TYDAC for M–NCPPC entitled "pointquad" groups parcel-specific data points into aggregate quads, and derives as a value the mean "average" of the grouped points. Relying on more point-specific data (over 14,000 data points), pointquad maps provide a less aggregate view of the distribution of the data among subzones.

In addition, SPANS produces isarithmic maps, which use point data to build maps resembling traditional topographic maps. This method, in contrast to choropleth and pointquad mapping, better displays the contours in the differences between adjacent map attribute values. Smooth and continuous peaks and valleys, not simplistic and sudden breaks between data attribute values, are differentiated with this mapping strategy. Isarithmic mapping requires the following three components: (a) The location of the control points, (b) the assumed gradient, and (c) the number of control points (7).

In addition, potential maps, computed by allocating several data values at dispersed locations to a single location and summing the values, may be produced. For example, concentric rings emanating at specified distances from each of the digitized MetroRail Station points are input into SPANS, allowing for subsequent overlays with any of the existing housing or employment maps to provide output maps or reports specifying the number of dwelling units or jobs at certain distances from transit stations at either the TAZ or subzone level. Table 1 provides examples of this overlay and analysis technique.

This SPANS-generated output then serves as input into the A-Logit model, reestimating M–NCPPC's logit mode choice model. Previously considering only travel times (both in- and out-of-vehicle) and travel cost, the model did not accurately estimate walk access to transit in the county's suburban centers, where typically fewer pedestrian facilities (sidewalks, for example) are provided. For M–NCPPC to better estimate walk access in the new mode choice model, transit serviceability (also known as "pedestrian friendliness") is examined. Using the concentric ring overlay maps and reports created in SPANS, and the county's sidewalk-to-street mileage ratios, M–NCPPC can examine additional factors previously overlooked by the A-Logit model.

INTERACTIVE USES OF SPANS

Because data files from various sources (not to mention other GIS packages) are pulled into SPANS, first-hand data collection is not necessary. Instead, M–NCPPC's transportation planning modeling staff converts and imports data residing in other digital formats into SPANS. For example, the existing GIMMS/GADS polygon data relieved M–NCPPC's modeling staff of a great amount of data input and digitizing. As a result, significant data sharing exists between individual agencies and departments within Montgomery County owning other GIS software, such as ArcInfo.

Moreover, there seems to be numerous opportunities for interaction not only between SPANS and other GIS packages, but with the various transportation planning modeling software as well. The main requirement is some form of georeferencing (such as points, lines and vectors, and polygons). However, one difficulty associated with this cross sharing of

TABLE 1 SPANS-GENERATED (AND TEXT EDITOR-ENHANCED) REPORT OF EXPECTED EMPLOYMENT IN NORTH BETHESDA APPROVED COMMERCIAL PIPELINE BY 0.10-mi INTERVALS FROM METRORAIL STATIONS

Class	Distance to Metro	No. of Jobs	%
1	Less Than .10 Miles	0.00	0.00
2	.10 - .20 Miles	97.94	1.03
3	.21 - .30 Miles	1235.86	13.03
4	.31 - .40 Miles	719.62	7.58
5	.41 - .50 Miles	683.57	7.20
6	.51 - .60 Miles	1871.92	19.73
7	.61 - .70 Miles	238.19	2.51
8	.71 - .80 Miles	16.89	0.18
9	.81 - .90 Miles	0.00	0.00
10	.91 - 1.00 Miles	0.00	0.00
11	More Than 1.00 Miles	4624.00	48.74
Total		9488.00	100.00

information is the use of different locational referencing schemes among individual data bases. For example, EMME/2 network nodes are represented as cartesian matrix coordinates, not as state plane or latitude-longitude coordinates as is the case in SPANS.

Even though SPANS version 4.302 does not contain standard transportation network modeling capabilities, future versions will permit internal travel demand modeling. Until then, SPANS will continue to be used primarily for disaggregating model data input to EMME/2, and for using the various existing data bases to better estimate model variables used in trip generation and mode choice. In addition, these disaggregate data are visually displayed in SPANS to provide an immediate presentation of the values of the various map layer attributes for local officials.

CONCLUSIONS

Although the GIS has existed for several years, its fullest potential has yet to be realized. With many innovative applications to explore, the M-NCPPC's early application of GIS to its traditional transportation planning activities represents only a first step in better integrating land use and transportation planning issues and variables within the overall modeling context.

Using the GIS to create smaller network subzones not only exploits the intrazonal disparities often submerged in more aggregate zone-based models, but also improves trip assignment onto this finer-grained network. With GIS, planners (either for the sake of convenience or inadequate computing capability) need no longer ignore the varying socioeconomic compositions of aggregate zones by applying single zonal values representing average characteristics.

M-NCPPC can now perform a finer-grained analysis of origin and destination characteristics related to both trip generation and mode choice modeling. Therefore, greater attention can be given to the pattern of county growth than to the pace (magnitude) of development. For example, current, approved, and maximum potential residential and commercial development are now mapped at either parcel, subzone, or TAZ levels in SPANS to monitor the amount of development near the county's transit stations.

However, some issues remain. Although possible GIS applications to transportation planning and modeling seem limitless, interested agencies should not assume the existence of adequate data in one form or another guarantees immediate subsequent outputs. To the contrary, a significant amount of work is required to retrofit existing data bases into a GIS. Like other large-scale, data-intensive computer models, the GIS is relatively easy to maintain once established. However, long-term commitment to the GIS is essential. Thorough analysis of the agency's needs and available resources must be conducted before initiating the GIS. After the decision to use the GIS is made, a secondary decision-making process concerning which particular software to select must follow.

The GIS possesses vast potential in urban transportation planning and modeling, although the current applications developed by M-NCPPC mark only the beginning. In the future, planners and GIS software developers alike need to better adapt current GIS software and develop new software that addresses specific transportation planning needs.

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Geographic Information System for the Pennsylvania Department of Transportation

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Given the potentially enormous impact of a geographic information system (GIS) and the myriad management and technical issues to be assessed in developing one, the Pennsylvania Department of Transportation (PennDOT) has undertaken research to develop a strategic plan for the development of a GIS for transportation. The planning process and the results of the research to date are described. In addition to PennDOT management and staff, the planning process included other commonwealth agencies that would likely be users or benefactors of PennDOT's GIS. The process involved (a) identifying and setting priorities for potential transportation GIS applications, (b) assessing existing computer systems and identifying data linkage options, and (c) developing a modular strategic plan that addressed priorities and incrementally enhanced PennDOT's GIS technology.

Sound decision making, and the systems and information needed to support it, has always been quintessential to the successful operation of any size and type of organization. In the public sector, the need for decision support systems has grown substantially as government agencies are being asked to "do more with less." As a result, the collective attention of the nation's public agencies has recently focused on such decision support systems as the geographic information system (GIS). The Pennsylvania GIS Interagency Work Group has defined the GIS as, "an automated system designed to allow users to more easily filter, manage, analyze, display, and share location-oriented data and associated explanatory information." A GIS combines nongraphic data (raw or calculated) and graphic data (computer maps) for the purpose of displaying and analyzing information, thus supporting the decision-making process.

There is general consensus that using a GIS can allow state agencies to improve their traditional missions of data collection and input, research and analysis, and information delivery more efficiently, while also providing an opportunity to expand their scope of operations in a cost-effective manner.

Transportation agencies must make maximum use of decision support systems because of diminishing resources, increasing demand, the need for public involvement, and the impact the transportation system can have on economic, environmental, and social conditions. The GIS is ideally suited for the transportation field because of the geographic nature of transportation features and because large amounts of data are already collected and stored.

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Within any department of transportation, probable GIS applications include roadway and bridge construction, planning and programming, safety analysis, pavement management, and maintenance planning. Recognizing the benefits offered by this new technological decision support system, PennDOT has taken a proactive and determined approach to establishing a GIS and helping the transportation industry take full advantage of it.

Because of the potential benefits that can be realized in virtually all state government agencies, PennDOT has taken a definite, cooperative interagency approach toward the development of a GIS. PennDOT is working closely with the Pennsylvania Department of Agriculture, the Department of Environmental Resources, the Governor's Office of Administration, the Governor's Policy Office, the State Data Center, and several other commonwealth agencies through the GIS Interagency Work Group.

Currently, the responsibility within PennDOT for the GIS is shared primarily between the Bureau of Transportation Systems Performance of the Office of Planning and the Bureau of Information Systems of the Office of Administration.

The Bureau of Transportation Systems Performance houses the cartographic services of the department, and therefore maintains all of the graphic data bases of computerized map files.

The Bureau of Information Systems, which is the custodian of the nongraphic data bases that the department will use in the GIS, is responsible for all electronic data processing planning and acquisitions.

PennDOT's GIS is in its planning and early development stages. The ongoing research includes (a) identifying priority applications, (b) assessing existing computer systems in relation to GIS development, and (c) developing a flexible, modular strategic plan.

INTERAGENCY COOPERATION

In the mid-1980s, many Pennsylvania commonwealth agencies began to exhibit an aggressive interest in the decision support capabilities of a GIS. PennDOT began to take the first recognizable steps in this direction through the extension of computer-assisted drafting and design (CADD) applications in the development of area-wide evacuation plans.

In 1987, an extraordinary multiagency effort to secure cooperation as well as to disburse information was initiated by the state Department of Agriculture. A special presentation on GISs—about what they are and what they can do—was made before the state General Assembly.

As an outgrowth of this presentation and to ensure that the commonwealth moved toward increased computer integration, interagency coordination, technology acquisition, and data sharing, the GIS Interagency Work Group was formed. The work group's mission is to

1. Formulate a statewide GIS implementation methodology,
2. Foster cooperation among state agency GIS activities,
3. Eliminate duplication of effort in digitizing information among state agencies, and
4. Enhance data sharing between state agencies by identifying and adopting standards for use in digitizing information.

The work group, which is chaired by the Governor's Policy Office, consists of the following members:

- Department of Transportation,
- Department of Agriculture,
- Department of Commerce,
- Department of Community Affairs,
- Governor's Office of Administration,
- Department of Environmental Resources,
- State Data Center, and
- State Library.

The work group has been involved in disseminating educational information about the GIS to state agencies on request and scheduling educational seminars for state agency personnel interested in learning more about this technology in a hands-on environment.

HISTORICAL PERSPECTIVE

Computer-Assisted Mapping Program

The Pennsylvania approach to GIS development is to build a strong computer-assisted mapping program. This approach is solid because a GIS will be built around the core of an automated map, referred to as the "base" map.

Pennsylvania is well established as a leader in computer-assisted mapping. Its commitment to graphic systems in hardware, software, development costs, and consultant fees totals approximately $2 million. PennDOT's computer-assisted mapping program (CAMP), housed on the Intergraph computer system, began operations in 1984.

The two major efforts required to develop PennDOT's GIS are digitizing and segmenting. A highway must be digitized before it can be segmented.

Digitizing

Digitizing is the computerized drawing of roads and features. Because of time and resource considerations, and in the interest of producing useful DOT products as soon as possible, digitizing was separated into two phases: (a) state highways and major drainage features, and (b) local highways and minor drainage features.

The first phase of digitizing included

- Over 41,000 mi of state-maintained highways;
- Civil boundaries of state, district, county, township, borough, and city;
- Major waterways;
- Railroads;
- Airports; and
- Selected cultural features (e.g., parks and educational facilities).

The 7½-min topographic quadrangle sheet of the U.S. Geological Survey (USGS) is the source input document. The pieces of roads and topographical quadrangles are connected to form seamless counties, which are connected to form the state.

These map features have been manually digitized over a period of more than 2 years. The first phase, state highways, has been completed for the entire state. The second phase, local highways, will be completed in June 1991. (As of this writing, 58 of 67 counties have been completely digitized.)

Georeferencing is accomplished through the use of latitude and longitudinal coordinates in the polyconic projection. Positional accuracy is held to 30 ft of ground position. A more precise accuracy that would proportionally compound costs is not considered necessary.

Segmenting

In order to link spatial data to specific points, lines, or polygons on the digitized map, PennDOT has divided all state highways into segments. This segmenting establishes the linkages between existing data and computerized maps. For example, roadway management system (RMS) data such as network, federal aid system, local name, pavement type and condition, and state route are linked to highway segments.

The department began the state highway segmenting effort in December 1988; segmenting was completed in June 1990.

Data Transfer

Presently, the department is manually transporting a computer tape of extracted data from selected IBM mainframe computer data bases and loading it into the mapping data base file. Hardware and software requirements are being studied to enable direct networking with an IBM computer to provide real time data extracts.

CURRENT PENNDOT APPLICATIONS

Many opportunities exist for using a GIS to support transportation initiatives and enhance decision making capabilities. With the arrival of GIS technology, limitations based on data availability and information analysis time will begin to diminish and the creativity of the user will gradually govern the GIS applications.

These applications can be expected to follow the traditional areas of agency responsibility, namely pavement management, traffic engineering, safety, planning and programming, bridge rehabilitation, etc.

In general, transportation applications of GISs chronologically follow three phases:

- Data retrieval,
- Data integration, and
- Data analysis.

As the system matures, an agency's use of a GIS will progress from data retrieval to data integration and finally to the more sophisticated application of data analysis.

Currently, the department is developing "smart maps" through data retrieval and integration of accident and project data bases to produce accident analysis maps and Twelve-Year Program project display maps. The accident analysis maps are being distributed to state police and local municipalities to enhance safety-related law enforcement efforts. The Twelve-Year Program maps will be used for regional public hearings to acquire public testimony for the biannual update of the Twelve-Year Program.

Although these current applications relate to highway systems, initial efforts are underway to integrate the rail, airport, and port data with the graphics as well. All transportation modes will become part of the GIS.

PENNDOT'S GIS STRATEGIC PLAN

The GIS concept introduces many opportunities for Pennsylvania. However, GISs are costly in resources and commitment. They require the cooperation of many organizations; they require technical expertise and planning; and they must have the support of decision makers. Therefore, a strategic plan is necessary.

With the cooperation of the GIS Interagency Work Group, the Department of Transportation is initiating the development of a GIS strategic plan for transportation. Informed decisions must be made as to how fast to proceed, how long will it take, how much it will cost, and how to get there from here.

Because of the unique opportunities afforded by a GIS, the strategic plan will be guided by an executive steering committee of top officials in the Department of Transportation as well as the Interagency Work Group and other departments. The steering committee contains a cross section of the potential users of a GIS. It has the necessary expertise and wide perspective to ensure that the strategic plan is technically sound and designed to meet user needs. The executive committee will be in direct communication with the department's top decision-making forums, specifically the Strategic Management Committee (SMC) and the Automated Technology Steering Committee (ATSC). The SMC is responsible for department-wide policy level decisions. The ATSC is responsible for decisions related to technology and electronic data processing. The tasks that the department has identified as necessary for the strategic plan are as follows:

- Task 1. Define the scope and focus of a GIS.
- Task 2. Review existing computer capacities.
- Task 3. Develop a modular strategic plan.
- Task 4. Present plan to top management.
- Task 5. Complete GIS Strategic Plan.

Tasks 1 and 2 are completed; Task 3 is underway.

Task 1 Findings

The specific objective of Task 1 was to "develop a categorized list of potential applications and recommended priorities."

After interviewing PennDOT managers and staff and other state agency representatives and reviewing the literature, the following categories of transportation applications were recommended as top priorities:

1. Safety Management. Provides decision support to ensure that safety aspects of transportation decisions are timely and appropriate and that safety enhancements are routinely included and fully integrated into the state's highway project development process.
2. Congestion Management. Provides decision support to monitor changes in congestion and develop strategies for dealing with congestion both by operational improvements and by demand reduction. These activities require system design, development, and implementation; data collection and analysis; and the development of short- and long-term plans.
3. Project Management. Provides decision support for the cost and schedule management of the department's priority projects.
4. Roadway Management. Provides decision support on the inventory of the existing roadway network and current condition data. It is used in making performance predictions that lead to needs and resource predictions.
5. Bridge Management. Provides decision support to establish formal procedures for selecting projects and strategies for bridge maintenance, repair, rehabilitation, and replacement. Considered in making selections are network needs as well as funding constraints.

In addition to these top priorities, the following transportation applications were identified as high priorities:

- Environmental impacts and design management,
- Routing management,
- Administrative management,
- Maintenance management,
- Photogrammetry management, and
- Geological management.

Task 2 Findings

The specific objective of Task 2 was to "assess and maximize the utility of existing computer systems for a GIS, identify linkage options among the various systems, and assess the immediate need to enhance existing computer components."

An agency must take full advantage of its existing resources when planning for a new technology. For a GIS, this necessity is especially true for data resources, as well as hardware and software. For PennDOT, which has massive amounts of data and has digitized the state graphically, using existing data resources (both graphic and nongraphic) is perhaps the most important consideration in cost savings.

Task 2 findings follow:

- PennDOT possesses a modern, robust, well-thought-out hardware and software suite. The IBM 3090–based configuration and the Intergraph CAMP–CADD configurations provide the department an array of capabilities. Therefore, a strong computer foundation already exists. However, the current load placed on these systems is already high and increasing.
- The CAMP–CADD system has reached its maximum processing capacity. It is used by the department for developing special public relations graphics for various commonwealth agencies. Because of the high quality of these products, demand for them continues to increase. In its current production mode, the CAMP–CADD system has no excess capacity, but with enhancements it could play a significant role in any future GIS. Even if the department does not implement the GIS, the CAMP–CADD system will require additional hardware and software upgrades.
- Although both the IBM 3090 and the Intergraph CAMP–CADD systems are highly capable, the current data transfer method between them is inefficient.
- The CAMP–CADD and the commonwealth networks are adequate to meet current connectivity needs. However, the 9,600-baud transfer rate may not be adequate for GIS scenarios.
- Most of the data that would be required by the GIS currently exist within department systems. These data reside on a variety of platforms and formats. No additional data collection initiatives are foreseen exclusively for the GIS.
- Current demands placed on personnel with the needed knowledge and skills render difficult the development, support, and maintenance of a GIS without a decision by the department on the locus for GIS expertise.

In order to move toward GIS implementation, the department should

- Continue integration of nongraphic data. This process would be driven by user needs and administered by a centralized data administration. The integration would improve the quality of the data and provide decision makers with the ability to analyze relationships among data.
- Improve integration of graphic and nongraphic data. Linking the IBM and Intergraph systems would provide real time access for the increasing demand for quick-response displays and future GIS queries.
- Establish hardware and software environments to use the integrated data.
- Maximize and upgrade as necessary existing computer hardware and software on the basis of capacity and connectivity needs.
- Further assess the organizational impact of the GIS. Issues such as the structure of the organization, data sharing and security, maintenance, etc., should be addressed as part of the implementation.

Specific Task 2 recommendations were as follows:

Hardware and Software

- Structure the GIS to exploit the foundation of the existing IBM and Intergraph investments. Select GIS software that can manipulate the department's existing data resources.
- Optimize existing hardware resources by use of CPU capacity available in the Intergraph workstations that the department already possesses.
- Even if the department does not implement the GIS, the CAMP–CADD system will require additional hardware and software upgrades to accommodate increasing production demands.
- Determine what role personal computers (PCs) will play in the GIS so that existing PC investments can be used in the GIS. This survey could include stand-alone PCs, PC networks, and direct links to the IBM, Intergraph, and other GIS platforms.

Data Organization and Structure

- Make the necessary data in existing nonrelational data bases available in a relational format, which is a structure with a particular access method that is required by existing GIS software packages.
- Investigate use of software that allows the translation and updating of hierarchical data required in the GIS (e.g., the Roadway Management System and the Project Management System) to a relational image of the data set.
- Use relational data base formats for all future data base application development.

Organizational Issues

- Decide on an organizational structure and the locus of GIS expertise that best suit the department's GIS needs. Fundamental options are (a) centralized support for decentralized applications; (b) centralized support for centralized applications; or (c) decentralized support for decentralized applications.

Operations and Procedures

- Evolve beyond the use of tape transfer between the IBM and Intergraph systems by establishing a direct link between the two.

Linkages

- Establish a linkage between the IBM and Intergraph systems as a necessary step toward a fully functional GIS and as a help in providing better and more efficient solutions to the department's information management requirements.

- Take full advantage of relational interface system (RIS) technology.

Task 3 Findings

The strategic plan (Task 3) will incorporate the Task 1 priorities and the Task 2 recommendations when defining a modular, flexible approach to developing a GIS. Requirements for hardware, software, manpower, training, and consulting will be specified. The final strategic plan will be completed by June 1991.

An important and unique aspect of the strategic plan will be the development of the plan in modular form. Each module will be a unit of effort in the overall development of a transportation GIS and fully useable for a commonwealth GIS.

By dividing the myriad tasks necessary to achieve a multifunctional and multimodal GIS into small and affordable modules, much greater flexibility will be realized. Adjustments for changing management priorities can be made by changing the sequence of implementing the modules. In addition, progression options will be produced for each module, allowing options for how rapidly or slowly each module will proceed.

SUMMARY

Although PennDOT has already made significant investments in and taken strides in developing a GIS, the challenge is just beginning.

The efforts to develop a GIS continue at a steady pace while PennDOT investigates and plans for this new and exciting technology. As with many departments of transportation, the technology began with CAMP–CADD. As the potential for the GIS became evident, PennDOT played a major role in initiating a cooperative interagency work group to coordinate the state government's efforts. Simultaneously, PennDOT continued to advance toward a GIS by integrating some of the nongraphic data with computerized map files to produce some useful "smart maps." PennDOT is currently in the process of developing a strategic plan for the implementation of a GIS.

In Pennsylvania, as with many other states, the department of transportation has taken center stage in developing this highly useful and tremendously flexible technology—the GIS.

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Integrating GIS Technology in Urban Transportation Planning and Modeling

Poulicos Prastacos

The integration of Geographic Information System (GIS) technology in urban transportation planning and modeling is discussed. The problems faced today and the solution GIS systems could provide are identified. The design considerations and data needs for implementing a GIS-based urban transportation analysis system are analyzed and some of the commercially available GIS software is evaluated. Emphasis is placed on the use of a GIS in model-based transportation applications rather than on other potential uses of GIS. Several applications of GIS methodology for urban transportation analysis are described.

Traffic congestion has become one of the most pressing problems in urbanized areas around the world. The dominance of the automobile as the mode of choice, the continuing separation between jobs and housing, and the flight from the central business district (CBD) to the suburbs have contributed to unprecedented levels of traffic congestion and adversely affected air quality. Advances in technology can assist transportation organizations in their efforts to continuously develop elaborate new procedures for traffic management. One new technology that appears particularly promising is the evolving technology of the geographical information system (GIS).

The GIS is a computerized data base management system that can be used for storing, displaying, and analyzing spatial data. In the last 4 years, there has been a revolution in this field. Lower hardware costs coupled with the availability of powerful computer software has resulted in the widespread use of GIS methodologies for the solution of spatial problems. Traditionally, most GIS applications have been in the field of natural resources management (*1,2*). Only recently, transportation planners and researchers have started to explore the benefits that arise by implementing GIS-based systems for analyzing the transportation infrastructure and demand (*3–5*).

Both transportation and GIS systems use locational data. GIS data bases in addition to the attribute data that can be found in all data bases contain geographic information. All elements in the data base are referenced to the same geographic coordinate system that permits the spatial analysis of the data. In transportation, all information have a locational component; however, the lack of any common georeferencing system makes it difficult to analyze this information. GIS technology could enhance transportation analysis by providing an environment for integrated data bases closely linked to models for decision support.

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GIS technology is being integrated into transportation planning at the urban level. Problems faced today have solutions that GIS systems could provide. Design considerations, data, and commercially available GIS software are needed for implementing a GIS-based urban transportation analysis system. Emphasis is placed on the use of the GIS in model-based transportation applications rather than on other potential uses for the GIS. Experience has been obtained with several applications of GIS methodology for urban transportation analysis and the integrating of GIS and transportation models.

TRANSPORTATION MODELS AND DATA INPUTS

Urban Transportation Planning and Forecasting

Urban transportation planning as practiced today in most of the western developed countries is based on aggregate modeling. The traditional urban transportation planning system (UTPS) for travel analysis and forecasting—containing features of trip generation, distribution, modal split, and assignment—relies heavily on aggregation of spatial networks and data. Land use and demographic information such as population, income, and car ownership are available at disaggregate geography levels; however, for transportation analysis purposes they are aggregated to traffic analysis zones (TAZs). TAZs are assumed to be homogeneous; the socioeconomic and land use variations that exist within the zone are collapsed to an average zonal number without any reference to the variance of these attributes.

Transportation infrastructure is represented as a graph consisting of nodes and links. Links stand for road segments, whereas nodes represent street intersections. The network used for modeling purposes is an aggregation and simplification of the actual physical network. For example, in the San Francisco metropolitan region the street network contains more than 300,000 segments, whereas the network used for region-wide transportation analysis includes less than 20,000 links. The links are often coded without any reference to any kind of geographic reference system; as a result, it is cumbersome to relate network information to other areal attribute data. The models, therefore, are not sensitive to changes occurring at lower spatial levels.

This procedure, forced on planners because of computer limitations in the past, has several significant implications. Because depending on the level of disaggregation, TAZs can represent a population of as many as 10,000 people—in the San Francisco region for a population of 5,600,000 there are 770 zones—all intra-TAZ variations in attributes and networks are lost. This assumption is not overly restrictive for traditional high-density urban environments with TAZ zones occupying a relatively small area. However, most of the urban growth today occurs in the suburbs (*6*), where housing and employment densities are substantially lower. In this case, a TAZ zone can cover a wide area and the assumption of homogeneity of travel and socioeconomic characteristics might be invalid.

Forecasts of future transit usage can be adversely affected by the aggregation of intra-TAZ networks and characteristics. Modal choice is heavily influenced by the time it takes trip makers to get to the transit station. Zonal averages for this variable, particularly in suburban TAZs, often show large access times, thus biasing model results (*7*). The zonal average is estimated without explicit consideration of the actual location of residents, although this information is available down to the block group level. With a common geographic reference system, zonal averages can be estimated as a the sum of the access time of the various subzonal areas weighted by the number of households.

Another problem with the modeling mechanism used today is the lack of any readily available library of models that can be easily applied. UTPS and PLANPACK are two of the most widely used modeling systems. Both are mainframe-based systems that implement the traditional four-stage modeling process. The difficulty with implementing new algorithms and models within this environment stifles any attempt to experiment with new procedures. Data input has to obey a rigid structure, whereas the model output is provided in lengthy tables that make it difficult to quickly visualize the implications of the results. It is only recently that new modeling packages have been introduced for the PC that interact with the user in a graphic way.

Transportation Logistics

Transportation logistics is a critical component of the overall physical distribution management system of a company. It provides the link between production facilities and markets. It is concerned with decisions related to distribution planning, vehicle routing and scheduling, assigning customers to warehouses, designing optimal delivery patterns, etc. The emphasis in the field has been traditionally placed on analyzing logistical problems at the intercity, rather than the intracity, urban level (*8*).

One of the most important problems in the field is the vehicle routing problem (VRP)—assigning deliveries to trucks on the basis of demand and truck capacity, and determining the order in which deliveries should be made. The computerized procedures used are from the field of operations research (*9,10*) with several commercial implementations currently available (*11,12*). A key input variable in VRP software is the transportation cost matrix, the distances and travel times between various locations in the system such as production facilities, warehouses, and final destinations.

The assumed travel cost matrix has to be accurate because travel cost minimization is usually the objective of most logistical problems. The lack of digital information on network structure has forced in the past the estimation of travel distance using paper maps, a labor-intensive procedure prone to several human errors. In an urban environment, it can be difficult to estimate with accuracy on a map the distance between various location points. There is a multitude of paths or routes between any two points, and identifying the shortest path without the use of a computer can be a lengthy process.

Another problem with VRP software is the lack of mapping capabilities. Ease of use and understanding of the results would be greatly enhanced if the delivery routes were shown on the screen over the actual map of the area. Although most of the VRP software has some graphics capability, only a few programs can display maps. Those that have this capability (for example, RoadShow) display the map as a background video without giving users the capability to interact with the map.

BENEFITS FROM INTEGRATING GIS TECHNOLOGY IN TRANSPORTATION PLANNING

A GIS is a data base management system (DBMS) capable of storing, retrieving, analyzing, and displaying locational data. It differs from traditional DBMS systems because, in addition to attribute data, it contains information on the geographic location of all elements in the data base. This feature is accomplished by referencing all elements to a common geographic coordinate system. Longitude and latitude, state plane, Universal Transverse Mercator (UTM) and others are some of the coordinate systems used most often. By referencing all data to the same coordinate system, a GIS can relate and analyze different sets of spatial data bases.

Integrated Spatial Data Bases

The storage of all information in a GIS will result in the development of an integrated spatial data base that can be used for a variety of transportation and urban planning purposes. The data base would consist of several independent layers of data, all linked to the same coordinate system. Data should be maintained at the lowest possible level of disaggregation and then readily aggregated as the need arises.

Figure 1 shows the layers of a representative data base for urban transportation planning purposes. There are separate layers for the

- Major arterial and highway network,
- Secondary and local streets network,
- Rapid transit network,
- Bus routes and stations,
- TAZ boundaries, and
- More disaggregate zonal system boundaries (census tracts and blocks).

Additional nontransportation-related layers such as elevations and hydrology tables could be added. Or some of the layers could be merged if the additional level of detail is not needed. For example, the four layers of networks could be collapsed into one layer without any loss of information by specifying an appropriate set of attributes for each link such as lanes, street type, and whether it is part of a bus route or not.

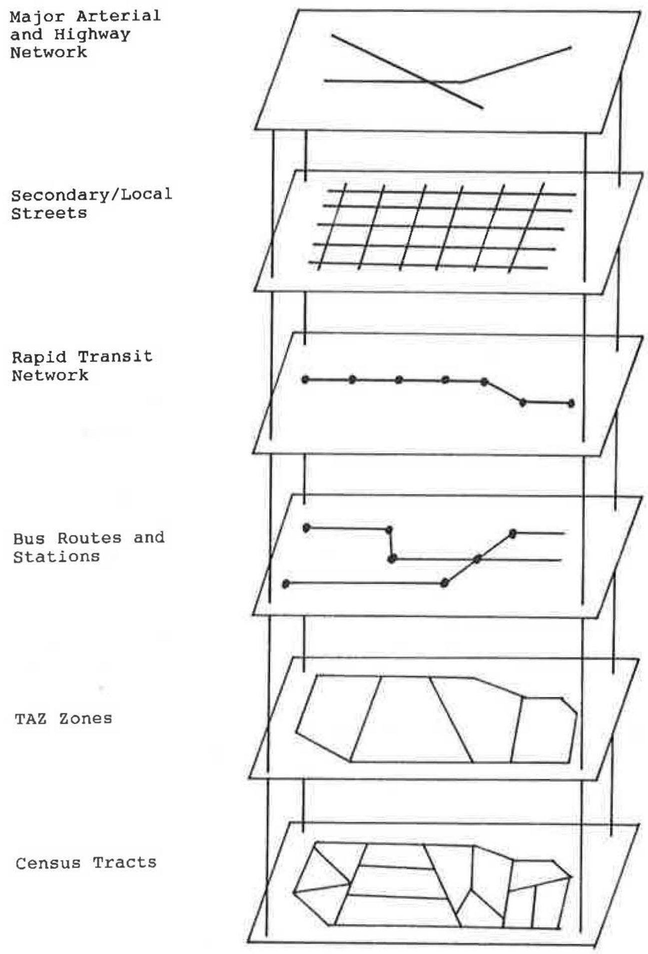

FIGURE 1 Layers of a GIS data base for transportation planning.

An integrated spatial data base would facilitate the respecification of the TAZ and networks used for policy simulation and forecasting. Currently, the redesign of the TAZ or the coded network systems is a major, labor-intensive project in its own right, often relying on imprecise algorithms and guesswork. Having all the data in a GIS, the design of a new zonal system could be easily done interactively or in an automated way if the GIS has the appropriate operators to aggregate spatial data.

Graphic Representation of the Model Results

GIS systems could also be used to graphically exhibit transportation model results. It is recognized that a "picture may be worth a thousand words." This saying is particularly true when transportation data are viewed for which the large number of zones and network links makes imperative the extensive postprocessing of results before conclusions can be drawn. With a GIS system in place, the results of an equilibrium assignment or a routing algorithm could be immediately exhibited on the screen, superimposed on the network.

Geocoding or Address Matching

Geocoding is the process of determining the geographic coordinates of a point in space on the basis of information about its location. It can be performed using street addresses (if data on address ranges are available), TAZ zones, or other boundary information stored in the GIS. Most of the GISs available today have efficient algorithms for locating street addresses in the transportation network and for interpolating longitude and latitude positions. Once a data base has been assigned geographic coordinates, it can be analyzed to estimate spatial relationships.

The applications of geocoding in transportation planning are numerous. A geocoded parcel file can be easily aggregated to any TAZ or other zonal system. In dial-a-ride and carpooling applications, geocoding can indicate on the map the locations of all riders to be picked up or it can match riders to carpools. In travel surveys, the addresses of the trip ends can be translated to geographic locations and assigned to the appropriate TAZs. Transit agencies can use geocoded address lists for marketing purposes and analysis of ridership.

SOFTWARE CHARACTERISTICS

In order to be useful for transportation planning purposes, a GIS system must have certain characteristics. The most significant of these are described in the following paragraphs.

Vector-Based Information

With networks represented as links and nodes, it is of paramount importance for the GIS to be able to handle vector-based information. Raster-based GISs are not of use in transportation planning except for a limited type of applications. Ability to efficiently store, retrieve, and graphically display large linear network data bases, interactive communication with the user, and on-screen editing of the network are a few other features that are deemed necessary.

Topology

Ability to handle network topology is another essential feature. Topological data describe the way spatial objects are connected. The topological structure of a transportation network defines the location and connectivity of the various links. On the basis of this information, paths between nodes can be easily estimated. Topology is the distinguishing factor between the GIS and computer-aided design and drafting (CADD) systems. CADD-based maps and networks can indicate arcs and nodes in a graphic way, but cannot tell where link intersections occur or determine the path between any two points. Additionally, attribute data on a CADD mapping system are stored for display as graphic text and cannot therefore support data analysis.

Integration With Models

Beyond the ability to integrate and efficiently manage spatial data bases, a GIS-based transportation system must also have the capability to support decision making. The objective of transportation planning is to generate and evaluate alternative solutions to the problems of traffic faced in cities. In order to achieve this objective, analytical techniques and models must be incorporated into the GIS framework. There are at least two major different ways for combining transportation models with GIS systems: (a) use the existing urban transportation modeling framework and the GIS independently, and (b) embed a transportation modeling functionality within the GIS.

In the former approach, a set of conversion routines is used to transfer data between the two systems. The GIS generates the necessary input data for the models, which produce solution files to be fed back for display and data base storage to the GIS. The two systems can be tightly or loosely integrated; if tightly integrated, the linkage is transparent to users and the two systems appear as one. An alternative and probably more efficient approach is to embed a transportation modeling functionality within the GIS system. This approach is accomplished by either developing a library of routines that can solve a variety of transportation problems and patching them to the GIS, or implementing in the GIS a set of transportation operators. Users manipulate and combine these operators to design their own models. Although this procedure might be more elegant (*13*), it does not take advantage of the existing computer code for various transportation problems and requires extensive additions to the GIS.

DATA SOURCES

Availability of digital data bases with information on urban street networks is the crucial factor that will influence the acceptability of GIS technology in transportation planning. A digital data base of a street network should contain two types of information, coordinate data and attribute data, the former to indicate the geographic location of nodes or street intersections and the latter to describe characteristics of the links and the system. Coordinate data are usually a pair of x and y coordinates, whereas attribute data can be numeric or alphanumeric. The set of attribute data in the data base can include a multitude of variables needed to support the intended applications. Street name, number of lanes, capacity, and traffic direction are the most common attributes. For geocoding, address ranges must be stored in the data base, whereas, for pavement maintenance applications, pavement type and condition should also be stored as attributes. The length of the link does not have to be explicitly stored in the data base because it can be estimated from the x and y coordinate pairs of the nodes at the two ends of the link.

Of particular significance for the adoption of GIS systems in transportation planning is the release of the topologically integrated geographic encoding and referencing (TIGER) file by the U.S. Bureau of the Census. The TIGER information system was designed to automate the mapping and related geographic activities required to support the 1990 census and the other survey programs of the census bureau (*14,15*). The objective of the TIGER development effort was to provide a digital data base that covers all of the United States and includes information on road networks (both Interstate and urban), railroad tracks, major power lines, pipelines, water features (rivers, lakes, and streams), and administrative or statistical areas (states, metropolitan areas, places, census tracts, census blocks).

Extracts from this file are released to the general public and can form the basis for building the base map in a GIS system. The released data files contain separate records for each street segment with information on

- Longitude and latitude of starting and ending points,
- Street names,
- Address ranges on each side of the street (for urban areas only), and
- Statistical or administrative areas on each side of the street.

This data structure does not explicitly contain data on nodes; however, it provides pointers to easily establish street intersections and identify nodes.

The FHWA sponsored a demonstration project to assess the value of the TIGER data as the base map of a GIS system for traffic management and transportation planning (*16*). The results have been particularly encouraging. With the appropriate software, TIGER data were used for developing digital data bases of a transportation network suitable for travel demand modeling, geocoding and indicating on a map data bases with information on traffic sign and accident locations, relating TAZ zones to census data, and designing a shortest path evacuation route.

Although TIGER files can provide the basis of a digital network data base, improvements and additions in the files are needed to support various transportation applications. For many urban regions, the TIGER files are outdated, and streets in recently developed areas and missing address ranges have to be added in. The route or street classification must be improved to reflect capacity, as well as street type (Interstate highway, state highway, or local street). Other attribute data such as number of lanes and traffic direction have to be added.

Other sources of digital network data include the digital line graphs (DLG) of the U.S. Geological Survey or files available from commercial vendors (e.g., ETAK). If digital data are not available, they must be digitized or scanned from paper maps. Aerial (photogrammetric) and satellite images are other sources for constructing digital networks. Recent advances in technology that integrate raster and vector graphics permit the drawing of the streets on top of the satellite images. Finally, the emerging technology of the global positioning system (GPS) is particularly useful for quickly identifying the longitude and latitude of any point on the street network.

AVAILABLE SOFTWARE

There are currently several commercial GIS packages and many more are expected to be published in the next few years. Although most of these systems can be used for storing geographic information, not all of them are suitable for transportation analysis purposes. The section below briefly reviews some currently available PC DOS-based GIS systems that can be used for transportation planning and modeling.

ARC/INFO

This system is the most widely used GIS system available for a variety of computers (mainframes, minicomputers, workstations, and PCs). It is a powerful, command-driven GIS with extensive capabilities for data storage, editing, display, and geographic analysis. It supports transportation modeling in the NETWORK module. This module contains the following procedures of interest to transportation planners:

- ROUTE to determine the shortest path between any pair of nodes,
- ALLOCATE to assign links in the network to the closest center, and
- Geocoding routines to perform address matching.

ARC/INFO was designed as a general GIS system, it is therefore difficult to connect it to the already developed transportation models and algorithms. All transportation models have to be rewritten in the ARC macro language. Shaw (*13,17*) reported using the ARC macro language for modeling a capacity-restrained traffic assignment. The approach proposed is iterative and becomes prohibitively inefficient when a real-world network with a large number of origin-destination zones is used. Additionally, this procedure cannot handle problems of user equilibrium or stochastic assignment.

MapInfo, Atlas GISs

MapInfo and Atlas GISs are menu-based, user-friendly desktop mapping and GIS systems that can store and display street networks and zone boundaries. Both of these packages have sophisticated routines for geocoding, but only limited capabilities for transportation modeling. The proprietary data structure is not topological, hence paths and routes cannot be defined. However, because of their ability to display networks and zones and their ease of use, they can be used to display graphically the results of transportation models estimated outside of these two packages.

SPANS

SPANS (version 5.00) is a menu-driven, user-friendly GIS system with powerful spatial analysis capabilities. It is available on DOS, OS/2, and UNIX platforms. By using the quadtree method for storing information, SPANS can handle both vector and raster data. It supports a complete topological linear network and is therefore amenable to transportation planning. Networks can be analyzed to model travel distance, travel time, and rate of flow. An optimal routing procedure is included in the system, as well as procedures for gravity modeling. New transportation procedures have to be developed with the SPANS macro language because existing computer code cannot be easily integrated in the system.

TransCAD

TransCAD is a powerful and easy to use GIS-based transportation package. In contrast to the other software packages mentioned that were developed as general GIS systems, TransCAD was specifically designed to serve as a platform for solving transportation, logistics, and operations research problems. The system, which is available only for PCs, consists of two parts; a GIS engine (available also as a separate product called GIS PLUS) and a toolbox of transportation models and procedures. The GIS engine is menu driven and, in addition to the standard GIS functions, can directly support transportation data structures such as nodes, links, networks, paths, and tours.

For transportation planners, a most significant component of the system is the toolbox, which consists of an expandable set of mathematical models and procedures that can be used for a variety of transportation problems. Version 1.2 of the software includes routines for

- Building networks from a set of links and nodes;
- Estimating shortest paths between any pair of nodes (with or without transfer penalties);
- Solving the "traveling saleman" problem (routing and scheduling);
- Performing a traffic assignment (capacity constrained, user equilibrium, incremental, stochastic);
- Spatial interaction modeling (gravity models of the entropy type); and
- Assigning service stations on a network (arc/node partitioning).

TransCAD also provides a platform for users to develop their own transportation-related models. These models can be developed as standalone programs in any DOS-compatible computer language (such as FORTRAN or C) and then linked to TransCAD. This capability is significant because users can easily integrate algorithms they already have without having to recode them in a different language.

Other Modeling Software

There are also other commercial software packages with transportation modeling and graphics capabilities. These packages, which include EMME/2, MINUTP, System II, and others, provide an elaborate implementation of the UTPS models coupled with user-friendly interfaces, graphic editors, and presentation graphics. However, none of these packages is a GIS, that is, possess full geographical and topological capabilities, and therefore none can be used for integrating data from a variety of sources.

SOME APPLICATIONS OF GIS IN URBAN TRANSPORTATION

The use of GIS-based systems for transportation planning is recent and few actual applications have been documented. Simkowitz (*3*), Lewis (*18*), and others discuss the use of GIS systems in FHWA and selected state departments of transportation for maintaining highway data bases at the state level. The following section presents some current applications of GIS systems for urban transportation planning and some results of experience in trying to integrate GIS with transportation models.

Use of a GIS to Generate Inputs to Transportation Models

Montgomery County, Maryland

The Maryland National Capital Park and Planning Commission (M–NCPPC), in Montgomery County, Maryland, is one of the early users of GIS technology for integrating transportation planning data bases (*7*, paper in this Record by Anderson). The SPANS GIS software was acquired in 1988 to aid transportation model development and data management. The initial application of SPANS was to produce thematic (chloropleth) maps of zone level input data to the transportation model used.

The second and more sophisticated application of SPANS was to provide land use data inputs to a series of subarea planning models. The regional TAZ system of 351 zones used in aggregate transportation planning was considered too coarse for subarea master planning, and evaluation of neighborhood level strategies for transportation system management (TSM). In order to model small areas, a new more detailed zone system was developed and coded to operate with the EMME/2 computer transportation modeling software. The land use input data for the transportation model were prepared by SPANS. On the basis of various input data and decision rules, SPANS allocates TAZ forecasts to subzones. The 255,000-record tax assessor parcel file, the digitized file of approved subdivisions, and attribute data for parcels, subzones, and zones are some of the data files maintained and analyzed by SPANS.

Another area in which M–NCPPC anticipates use of SPANS is the analysis of a household travel survey and, more specifically, the time-of-day travel behavior. Thematic and potential mapping techniques will be used to analyze and display the collected data to understand the spatial dimensions of peaking behavior. Potential mapping is a feature of SPANS that allows users to sample large point data sets to produce contours of equal potential, similar to lines of equal elevation.

Los Angeles Metropolitan Area

The Southern California Association of Governments (SCAG), the planning agency for the Los Angeles metropolitan region, is in the process of developing a land use–transportation model to assess long-term growth patterns. The large volume of data and the need to relate information from different spatial levels necessitated the maintenance of all data under a GIS. ARC/INFO was chosen as the GIS environment to provide an integrated data base.

The data base includes a variety of information. In addition to several socioeconomic variables for a variety of spatial levels, it includes the digitized master plans of all communities in the region, an accurate representation of the street network, and the exact location of most employers. Existing land uses will be identified through aerophotography and then digitized and merged with the rest of the data base.

Use of GIS-Based Travel Analysis Models in New York City

The Metropolitan Transportation Authority (MTA) in New York City has used TransCAD since 1989 to support data management, modeling, and decision support for transportation planning. The network data base contains both the highway and subway networks of New York imported into TransCAD with the TCBuild utility. Census tract polygons were also imported into the system together with information on population, income, and other socioeconomic characteristics.

The models in TransCAD are extensively used for a variety of purposes. Transit travel time matrixes are estimated with procedures that consider both link costs and transfer penalties when the links belong to a different line. The transfer penalties represent the expected waiting time for a train or a bus on the target line. Highway travel matrixes are computed with the shortest path algorithms included in TransCAD. Other procedures in TransCAD are used to analyze trip making and forecast future travel patterns.

Integrating a Land Use–Transportation Model With a GIS

The objective of this effort is to combine the POLIS land use–transportation model developed by the Association of Bay Governments (ABAG) with a GIS package. POLIS (*19*) has been used by ABAG since 1985 to estimate future distribution of population and housing in the San Francisco Bay region. Its major difference from Lowry-based land use models is that future forecasts of jobs and housing location are explicitly affected by the transportation system, as well as housing availability, proximity to employment centers, zonal attractiveness, etc. Because the model is cast as a mathematical programming problem, households and employment allocation and trip flow patterns are estimated in a single iteration and are consistent with each other and the land use constraints.

The integration process consists of two major tasks: (a) combining the model with a GIS package to display the results of the allocation on a map, and (b) developing a GIS data base with all relevant planning information that generates the appropriate inputs for POLIS.

POLIS divides the bay area into 114 zones; however, the majority of the data is maintained at other spatial levels. Development potential information is available on a project basis, and has to be aggregated at the census tract and then POLIS zone level. Other economic and demographic information is available at the more than 2,000 census tracts, while travel cost data are maintained by the Metropolitan Transportation Commission at the more than 700 traffic analysis zones in the region. A series of ad hoc designed routines are used today for aggregating the data and developing the necessary input files for POLIS. This procedure has not been satisfactory, and often changes that occur at the lower spatial level are not reflected in the inputs for POLIS.

At this point, the focus is on the former task, integrating POLIS with a GIS package. The TransCAD software was selected because it can accommodate the existing model without extensive modifications and rewrites. Presently, the two systems are connected in a loose way through the exchange of files. DOS memory limitations do not permit the operation of POLIS on personal computers. POLIS runs on VAX computers and creates various output files with the results, which are then downloaded to the PC and imported in TransCAD.

POLIS will soon be installed on PCs using 386-specific compilers and a transparent connection will be developed between the two systems.

A GIS-Based Decision Support System for Routing and Scheduling

A study in Athens, Greece, is involved in designing a GIS-based decision support system for routing (*20*). The objective of this pilot project is to demonstrate the use of digitized networks and mathematical models to support routing and scheduling decisions of distributors and, more specifically, soft drink distributors. As in the United States, distributors maintain inventories at one or more centralized warehouse locations (depots) and use trucks to deliver the products to their customers. The customer locations are typically retail outlets such as supermarkets, liquor stores, bars, or restaurants.

The need for implementing computerized vehicle routing systems and the associated cost savings are well documented in the literature (*11*). The approach followed in this study is different than the standard VRP approach in that it integrates geographic data bases with the traditional models used in VRP. The system uses commercially available software (TransCAD and MapInfo) together with the TourenPlanung (TP) software for routing developed at the Institute of Operations Research of the University of Hamburg.

The system consists of three key geographic data bases:

1. A digital road network of the Athens region structured as a TIGER file. In addition to the latitude and longitude of the starting and ending points and the address range of every segment, the data base contains information on the number of lanes, directionality of every segment, and average time distance. The latter is derived by assuming an average speed.
2. A customer database that contains the street address of every customer. The longitude and latitude (x and y coordinates) of each location are derived in an automated way with geocoding. MapInfo is used for estimating coordinates on the basis of a street address or an intersection in the network. The geocoded customer database can be used for routing, as well as marketing and other purposes.
3. A distance matrix between customers and depots with the shortest path from each site to all others. This information is directly obtainable from the street map of Athens and the shortest path algorithms available in TransCAD. The distance matrix can reflect distance or travel time or a generalized cost consisting of distance, travel time, number of lanes, and other characteristics.

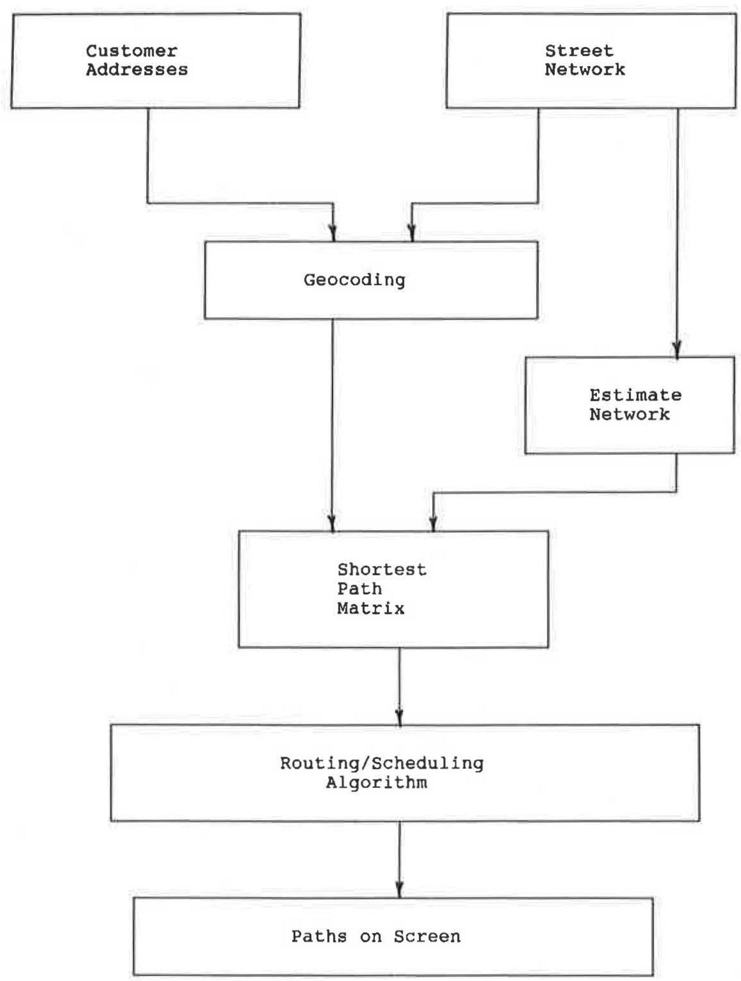

FIGURE 2 GIS-based routing.

In addition to these geographic data bases, there are data bases that contain information on the product demand for every customer (assumed to be known), fleet composition (number and capacity), and time windows for deliveries (that is, time intervals during which customers must be served), etc.

A key aspect of the complete system is the algorithm for assigning customers to delivery vehicles and then computing the sequence of deliveries. The VRP has been studied extensively and several heuristic algorithms have been proposed for its solution (*10*). However, most VRP formulations make simplifying assumptions by ignoring some of the constraints that frequently occur in practice (e.g., different types of vehicle, more than one route per vehicle, and time windows).

The TP software from the University of Hamburg selected for solving the routing problem (*21*) provides a system for simulating real-world routing decisions and its source code was made available to this project. The TP software is the result of an extensive research effort between the Institute of Operations Research and several companies in West Germany to design routing software that addresses most of the constraints encountered in practice.

The TP software can handle constraints related to

- Fleet composition (number, types);
- Fleet capacity (as a function of volume or weight);
- Time window constraints on deliveries;
- Multiple delivery routes per vehicle per day; and
- Constraints on the customers assigned to a particular vehicle.

The TP software was integrated as a special procedure in TransCAD and the two systems work together. The sequence of operations in the complete system is shown in Figure 2. After geocoding the customer data base, the coordinate file is passed to TransCAD. Users specify the customers for whom delivery must be scheduled and TransCAD computes the cost (as distance or generalized cost) matrix and prepares the necessary input files for the routing algorithm. The results of the algorithm are stored in a data base, passed back to TransCAD, and exhibited on the screen.

CONCLUSIONS

The use of GIS technology is starting to be explored in urban transportation planning. This paper has presented some of the difficulties faced today and the benefits arising from the use of GIS systems. The few attempts made to use a GIS for modeling have demonstrated the power of the GIS to integrate data bases and to support decision making. With the emergence of powerful software geared to transportation professionals and the availability of digital network data, GIS systems will be more widely used for transportation analysis.

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Assessing Alternatives for Automating District Office Administration

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The nature of information handling within the Indiana Department of Highways (IDOH) but outside of the central office has developed in response to the needs of dedicated and sincere workers trying to serve Indiana in the best possible way. The breadth of services provided by IDOH is vast and most of these services require a large level of information management and processing. Until relatively recently, information flow and data handling in support of these activities have been accomplished completely manually. The details of the procedure by which the information handling and management activities of that agency were assessed for identification of the appropriate level of office automation of those activities are described.

Introducing automated information management systems to traditional engineering offices can be an arduous task. When the offices are distributed and lack professional office automation or computer administrative personnel, the job becomes even more difficult. Many different philosophical and practical questions must be asked, such as: "Is it cost-effective to automate present information systems?" or "To what degree should potential automated information management systems emulate present nonautomated systems?" Further, information management systems need to be studied and themselves managed. As stated well by Lochovsky (*1*): "In the same way that organizations have come to realize that their data is a very important resource and should be managed as such, it is equally clear that the tasks that operate on that data are also an important organization resource and requires appropriate management."

Alternate strategies were developed for automating remote-office information collection and handling within the Indiana Department of Highways (IDOH), an extremely large state institution having overall responsibility for the maintenance and administration of Indiana's highway system. A general methodology for planning remote-office information system automation is presented in detail, a summary of its use within IDOH is described, and the strengths and weaknesses of the approach are summarized.

Like many large state agencies across the country, the structure and function of information handling within IDOH outside the central office has evolved in response to the needs of dedicated and sincere workers trying to serve Indiana in the best possible way (*2*). Much (if not most) of this evolution occurred before the microcomputer revolution of the past decade. The breadth of services provided by IDOH is vast and most of these services require a large level of information management and processing. Specifically, IDOH maintains six remote district offices each having approximately six subdistrict offices. Until recently, information flow and data handling in support of these activities have been accomplished completely manually.

Because of the concerns of IDOH data services personnel together with IDOH staff throughout the state, office automation technology, which has been used for some time at the central office, is finding its way to the remote offices. In order to promote information management within IDOH, the Data Services Department distributed to each district during 1986 one or more personal computer (PC) systems. Each of these systems was installed as a stand-alone workstation at a fairly central location within each office. Initial training of individuals at each office was initiated and a PC user's group was formed. This distribution of PCs was intended not as a means of completely satisfying the needs for office automation, but rather as a preliminary experiment to see how this technology would be received by IDOH district staff.

Concurrently, a study was undertaken in an effort to help direct this spread of office automation technology to remote sites (a) by identifying the nature and extent of information-handling activities at remote locations, and (b) by attempting to define alternative approaches to automate those systems. The methodology used in and a summary of findings resulting from that study are presented.

OFFICE AUTOMATION NEEDS SPECIFICATION

The process by which remote information system requirements are determined requires careful examination. To develop such a system it is necessary to isolate areas of concern with respect to information handling and to develop a plan to elicit data about each information system (*3*). Although previous researchers (*4–6*) have attempted to define and describe these areas, the major contribution of these efforts has been to provide suggestions rather than an explicit methodology for analysis. For example, Jones and Soares (*3*), when discussing the integration of personal computers within an organization, offered a three-step procedure for determining the appropriate level of automation: (a) identify the integration objectives, (b) determine the functional requirements of the integration, and (c) determine the technical requirements of the integration. These authors argue that by following such a systematic procedure, the design team is actually documenting the information flow requirements of the user, and using these to dictate computer hardware and software requirements. They further recommend that questions be asked such as "Is accessing the mainframe data the important con-

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sideration?" "Is unreliable storage and back-up an issue?" "How important is security?" and "Do users require access to networks within the corporation or to public databases?" Although several suggestions were set forth for conducting a detailed needs assessment, a comprehensive methodology for quantifying the answers to these questions was not offered.

A recurring theme of many of the papers reviewed was the importance, when developing such a methodology, of determining the sources of office expertise and the methods by which information is to be acquired. Most useful, Lederer et al. (7) discussed a five-point plan for implementing office automation. To determine the needs of the office, they suggested that a task force consisting of potential users be formed and that this task force analyze the work profiles of representative users. Although the formation of such a group is acknowledged to be an important and useful mechanism for determining needs, the general lack of experienced in-house personnel together with the diversity of office functions precluded the incorporation of this technique into this research.

Though the methodology proposed through this research does not explicitly follow the guidelines offered by previous investigations, it borrows extensively from those ideas. The following discussion merges many of these hints into a viable working methodology for determining the information requirements of a public-sector service organization.

THE NEEDS SURVEY

Managing the quantity of information collected in organizations the size of the IDOH is complex. What is required is an understanding of what information is being gathered, and why, and a working knowledge of who should be allowed access to this information, and in what form. Although general IDOH district operations are essentially the same throughout Indiana, the importance placed on these tasks and the methods and personnel used vary considerably.

The method used to capture this administrative information at the IDOH was to conduct informal interviews with representatives of all sections in every district office, and at least one subdistrict office in each district. A wide range of personnel was interviewed from top-level managers to clerical staff and skilled workers. This survey provided insights as to the views not only of those responsible for the content of information used at remote locations, but of those who actually collected and handled that information.

Before these field interviews, a series of informal meetings were held with IDOH central office management personnel representing six divisions within the IDOH: Administration, Construction, Development, Maintenance, Material and Testing, and Traffic. The purpose of these discussions was to learn as much as possible about the information handling protocols throughout the state as specified by official departmental policy. In addition, information about past efforts to collect and synthesize information about data management practices was obtained. The central office interviews were followed by individual site visits to each of the six district offices across Indiana. The goal of the visits was to gain an understanding of how information was processed and what type of information was being used at the district and subdistrict offices in administering the overall mission of IDOH.

Each site visit began with a general meeting with the district engineer (the person in charge of each office) and each section head. This meeting served to introduce the reasons for the visit and allow for the planning of the interviewing agenda. The informal interviews in each section were conducted over 1-week periods. District and subdistrict personnel described their individual job functions and were allowed to express a desired list of tools that would make their jobs easier or better. Through these interviews, an overall picture of what information was required to maintain the IDOH, as well as possible procedures for system improvements were obtained.

To evaluate the computer needs of the IDOH it was first necessary to know what information was being collected, and why, and to compare these needs relative to the best modes of operation, both automated or nonautomated, for each information system. A four-step procedure for collecting this information was devised:

STEP 1: Identify Organization Structure and Function. At the outset of each interview, personnel were encouraged to discuss their overall job responsibilities, their place in the organization, and each of their daily tasks. Further, they were asked to describe the relationships between their tasks and those of other district, subdistrict, and central office personnel. From these descriptions a general organizational picture of the IDOH could be formed.

STEP 2: Categorize and Describe Existing Systems. Exhaustive interviews were conducted to obtain a true perspective on the type and quantity of information used to perform daily activities. At the IDOH, some 250 personnel were questioned at virtually all levels of the agency. Careful records of these interviews were synthesized into descriptions by functional area. Each functional area was thus able to be described by a set of information systems. (Throughout this discussion, the term "information system" refers to any systematic procedure of protocol of collecting, synthesizing, sorting, or otherwise managing information used in IDOH operations. The goal of this research was to determine the appropriate level of automation for these systems.)

STEP 3: Identify Information Flow. Once these systems were identified, it was necessary to find where the information was collected, who needed the information, who could use the information to support decisions, and in what form. This was imperative as the information flow within a system will likely influence hardware and software requirements. Therefore, the information flow of each IDOH information system was noted.

STEP 4: Develop Information System Profiles. For each information system identified, a brief report—called a profile—was drafted. Each profile presents a general description of the information system including the purpose, information flow, office interfaces, existing forms, and additional remarks. In all cases, IDOH information profiles were identified through observations made during the site visits; they were not an attempt to explain the current systems outlined in IDOH manuals.

Figure 1 shows a sample of 1 of some 84 information system profiles that were prepared during the course of this research. Preliminary profiles were sent to each district office, reviewed by district personnel, and returned. With additional input

DIVISION: **Maintenance**

SYSTEM: **Maintenance Management System**

PURPOSE:
The purpose of the maintenance management system is to plan and monitor the yearly maintenance activities of all Districts and Subdistricts.

DESCRIPTION:
The maintenance management system plans acceptable levels of work one year in advance. This plan is specific and generally accurate. The plan is sent to the districts and monitored through completed Crew Day Cards.

INFORMATION FLOW:
One year in advance, subdistrict superintendents and district maintenance engineers estimate expected activity time requirements based on the previous year's performance and knowledge of roadway expansion. This is discussed with Central Office engineers and compared with the Crew Day Cards. From these meetings, the Central Office budgets the following year's maintenance and gives guidelines to acceptable levels of work via Crew Day Cards. The Crew Day Cards are filled out daily by the subdistricts and compared with the estimated performance. Large discrepancies are discussed.

EXISTING FORMS: MM-103, MM-109, MAMMs-180, MM-311

REMARKS:

FIGURE 1 Sample information system profile.

from the districts, the final profiles accurately described district and subdistrict activities. Each profile described an information system currently in use within the IDOH, and represented a target for potential automation over a wide range of computer support, from a dedicated microcomputer to remote access on an existing central computer. An important result of this study was this categorization and description of the information systems being used by IDOH.

The interviews took place over a 2-month period. From the outset, several important initial observations were made that were continually reinforced as additional site visits were made. The more important of these impressions are presented to reflect a general perspective on the state of information management at that point in time at the IDOH:

1. Existing hardware and software systems are used (almost) exclusively for data entry. For the most part, personnel in the district and subdistrict offices were open, encouraging, and provided extremely thoughtful comments. In each case, negative comments about the existing computer system resulted because of the feeling that information management did not benefit local operations. Although most district personnel interviewed were not computer educated, they seemed willing to learn new systems; particularly if these systems were shown to save time, or improve decision making. Reluctance and skepticism on the part of some workers was usually traced to some previous negative experience with computers or discouragement at having to do data entry with no perceived purpose. Generally, district personnel view computer work as extra, or duplicate work, as keypunched data are often followed by written verification.

2. Data collected at remote sites have little or no influence on decision making at those sites. Although much of the information routinely collected at the subdistrict and district offices could clearly be used in support of decision making at those sites, in many instances, this information was passed directly to the central office, either in raw form, or through remote data entry. For instance, descriptions of daily maintenance activities were being entered into the central office mainframe at the district offices, yet district personnel had little access to this information, and served only as central office keypunch and check. They could, however, make use of this information in a reasonable monthly or weekly form.

3. The PC equipment placed at the district offices is being used differently across districts. As an introductory experiment, each district received two IBM PC XTs. PC usage in the districts seemed to be proportional to the previous PC experience of the district personnel. The result of these constraints is that some divisions in each district had received adequate computer exposure and had developed many PC applications, whereas others have not.

4. The potential for cost savings through increasing the overall efficiency of information management was large although most of these savings would result from intangibles. The main goal of the IDOH is to provide a high level of service to Indiana residents. Although financial responsibility is important, it is also desirable to increase the level of service to the state. A primary result of efficient automation is large increases in system performance. For instance, a roadway history is currently being kept in each district that includes information on large maintenance and construction contracts. If this system were to be automated, the capacity for storing and retrieving

this information would increase dramatically. The capability for storing information such as daily maintenance activities and accident and signal histories as well as large maintenance and construction contracts could be incorporated. The cost savings become apparent when the applications are explored. One possible use of a central, complete roadway history is as a pavement management tool. By knowing the composition of a stretch of road, as well as it's maintenance history, it would be possible to better study the construction of new roadways. A more durable road would save the state immeasurably. Another application of a complete roadway history could be to answer legal interrogatories. If this system could produce complete roadway reports, time would be saved scouring files for such information and the professional appearance of these reports would be improved. If only one lawsuit is averted or won because of a sophisticated data management and retrieval capability, the system could be financially worthwhile. Interdepartment communications is another possible avenue of improvement. Because of the complexity of maintenance scheduling, the potential exists for roadway paving soon after painting or installing expensive raised pavement markers. Installing a computer calendar, where all projects from each division are entered and updated might prevent such an occurrence and save expensive repainting or reinstallation of the markers. A related benefit of automation would be in public perception. Subdistricts report large time delays in the issuance of oversize or overweight permits caused by inefficient system design. If this system was efficiently automated, and the public served faster, it would have a direct positive impact on the public and departmental view of IDOH efficiency. In most cases, these intangible benefits would result not from automating existing information systems but from the implementation of new ones. For example, there is no present formal mechanism for interdepartment exchange of work scheduling information. This would require a new information system to be designed and implemented, perhaps using some form of automation.

5. There is currently a large amount of redundant paperwork being done throughout IDOH. It is not uncommon to see clerks and office secretarial staff transferring raw data onto summary sheets and forms, or even doing data entry at a terminal connected to the central office computer by reading numbers from a printout that had been computer generated.

6. Information flow between districts is minimal, and probably best served by nonautomated means. It was rare that data collected at one district would be used by another. More commonly, summaries of these data, such as resource utilization levels, might be distributed to district offices from the central office.

SYNTHESIZING SURVEY RESULTS

The methodology described in the previous section resulted in the identification and documentation of some 84 separate information system profiles. In analyzing these profiles, six evaluation parameters were established; (a) mode of use, (b) information backup and recovery requirements, (c) system security requirements, (d) task time requirements, (e) auditability, and (f) data integrity. Evaluating each information system with these six parameters provided invaluable data to the systems engineer. Each evaluation parameter is discussed in the following paragraphs.

Mode of Use

This parameter addresses the way in which a particular user might best interact with a computer-based information system. Mode of use reflects a presupposed level of understanding and experience on the part of the user as well as having implications for the hardware and software required to support that user mode. Five levels or modes of system use have been identified for purposes of this study.

1. No Automation—Some information systems are best left nonautomated either because the expense of any level of automation would not be cost-effective, or because automation would tend to isolate the decision maker from the system. For example, in the IDOH a final construction report is compiled for each completed construction project. This process should not be automated (at least not completely automated); compiling and finalizing this report serve to familiarize the construction engineer with the complete history of the project. In automating this report preparation process, this familiarization might be lost. However, many of the reports included within the final construction report, such as daily, weekly, and monthly status reports, should indeed be automated.
2. Local Stand-Alone Computer—There are many instances where stand-alone computer applications would enhance day-to-day activities without the need to transfer data to or from the computer being used. These activities would best be served by a centrally located stand-alone microcomputer. For example, IDOH materials test analyses could be done by single-purpose programs running on personal computers.
3. Local DBMS—An important consideration in the optimal design of an automated information management system is the location of data. A well-thought-out protocol must be established for who will have overall responsibility for the "true" data set; particularly in cases where the possibility of more than one copy of the data at different locations is possible. For some information systems, it is clear that the best location for the master data set is the remote location. For others, a central location is optimal. For example, on-line inventory data would best be maintained at the remote district offices, whereas budget and accounting data should reside at the central office.
4. Local CPU with Remote Data Access—Even if the actual data reside at the central office, those data may be needed by models and applications at the district offices. When local analyses require remote data, those applications might best be served by a local CPU that can access and download data from a remote host. For example, information on state-wide road closures might be needed by users at a subdistrict office for purposes of issuing an oversized vehicle permit and route.
5. Remote Data Input/Access Only—In many cases, a remote workstation might simply be used to request information from a central computer (either at the central office, or a CPU located in the district office) or for routine data entry. This is the mode of use presently employed at district offices throughout IDOH.

Mode of use is only one parameter that should be considered in determining the appropriate end-of-line hardware best suited to automate a given information system. In many cases, one type of hardware can be used to function in more than one mode. A personal computer, for example, might be configured for any of these modes of operation.

Backup and Recovery Requirements

If information is collected, that information that is considered important should either be protected against loss, or some mechanism should be provided to ensure that if loss occurs, the information can be recovered (*1,6,8*). However, some information is more important than other information. Because information backup (providing multiple and possibly archived copies of data) has a real cost, the importance of data for particular information systems should be considered in any hardware and software specification. Information backup considerations are complicated by the fact that data frequently has a lifetime, and its importance typically changes over that lifetime. Some data might only be important for a short period of time but loss of data during that time might be severe. Other data might not be particularly important, but might potentially be needed for a long period of time. In considering the level of backup required for any particular type of information, one must consider the costs of recovering those data versus the potential costs of not being able to do so. For purposes of this study, three levels of backup importance have been established:

- HIGH: Extremely important data that must be recovered within a short time of being lost.
- MEDIUM: Data are important, but loss would not be catastrophic, or recovery, though expensive, would always be possible.
- LOW: If lost, information would not need to be recovered, or recovery of information would not be expensive.

System Security

Related to the inherent importance of information is the concern that some information might require special access restrictions. For example, personnel data such as wage and salary histories should have access privileges only for those individuals whose jobs required that information. Like backup considerations, data security is specific for each data set used. For example, inventory data may properly be copied and read by a large group of individuals but only changed by a privileged few. Again, three security levels have been identified for this study:

- HIGH: Permission to view the data restricted to a select few. Permission to edit the data restricted to that individual responsible for the integrity of the data.
- MEDIUM: Software or administrative measures are sufficient to control read and copy access to the data or read and copy access are unrestricted. Edit permission restricted to that individual responsible for the integrity of the data or his designate.
- LOW: Read and copy access to data unrestricted. Edit permission not an issue.

Computer Access Time

Careful consideration in the design of an information system should be given to the amount of use that the system should expect. System performance must be viewed relative to the number or frequency of transactions or data and query processes. If a quantitative estimate of system use can be developed, the number of terminals or computers can be determined. Efficient automation will, itself, cause shifts in system use.

Auditability

Some information systems require a high level of auditability—the ability to trace the data to their origins or to the individual responsible for some type of authorization relative to the information. Auditability is particularly important for transactions involving monetary exchange. Although security issues pertain to limits of data access, auditability is concerned with identifying individuals who must be associated with specific data. Three levels of auditability have been defined:

- HIGH: Accountability must be traceable to the individual with responsibility—authorization.
- MEDIUM: Accountability may be traced to working group or division. It can be used to verify or monitor data collection, transfer, or analysis.
- LOW: Not an issue as information is temporary or task specific.

Data Integrity

This refers to the accuracy, completeness, and correctness of the information at the time that information is used in a decision-making activity. This information can range from information that must be accurate, complete, and correct at the time of input, to data where one or more of these factors may not be important or will be caught somewhere down the line. Integrity is particularly complex where multiple copies of a data set must be used at separate locations (*5,8*). Although technologies are available to ensure integrity of information, they are expensive and must be used sparingly. Three categories of information integrity have been specified:

- HIGH: Data must be accurate, complete, and correct before use in all circumstances.
- MEDIUM: Inaccurate, incomplete, or incorrect information will be caught and corrected when failure to do so will cause significant expense.
- LOW: Accuracy and completeness is not important, but incorrect data will be caught and corrected when failure to do so will cause significant expense.

INTERPRETING SURVEY RESULTS

Each information system was evaluated by each of the aforementioned parameters. By representing each information system as the sum of these parameters and recording these data in concise summary tables, automation requirements were clearly defined and readily available. The information system tables serve to summarize the design criteria for automating each information system profile. Included are the following parameters: modes of use, backup and recovery, security, time of use required, auditability, and data integrity for each profile. These parameters are not the only ones to be considered; adequate software design in support of each information system is assumed.

Table 1 presents a sample evaluation for the information systems identified within the maintenance division, including the example information system presented previously—the maintenance management information system (see Figure 1). A description of the evaluation conducted for this typical system will demonstrate the utility of the methodology. A similar summary was prepared for each of the six IDOH divisions, and is provided by Wright et al. (*9*).

The IDOH Maintenance Division in the district office plays an important role in managing many district activities. Included is the responsibility for the maintenance management system, a system to plan, budget, and monitor the yearly maintenance activities of the district and subdistrict offices. This system requires extensive input from each subdistrict in the form of man-hour and work progress reports. Presently, every IDOH maintenance activity is reported to the central office in the form of a type of time card, called a "crew day card." Each crew day card reports the maintenance activity performed, work accomplished, personnel involved, etc. It is estimated that the central office receives 360 crew day cards each day.

However, the central office has little use for such detailed information. Rather, the central office only accumulates the information, and because the district offices do not have the capability to store and retrieve this information, it is not being used in support of decision making in real time. The ideal mode of operation for such a system would be for the district offices to maintain the data base locally and transfer relevant summaries to the central office. This process lends itself well to automation; information gathered by the subdistrict for the central office can easily be stored at the district office and put into meaningful district reports. Hence, the mode of use should be a local DBMS with data transfer.

If the data for the maintenance management system are to be kept in the district, special steps should be taken to ensure these data are not lost. If lost, the sheer volume of data would make data recovery impossible within required time frames. Hence, the system rates as high for backup and recovery. Security of the maintenance management system, however, is not a vital concern as it would be beneficial to allow access to view such data to concerned IDOH employees. However, access to edit the files should be restricted to the individuals accountable for this information. Therefore, it was recommended that the system be rated medium for security and auditability parameters.

The maintenance management system is seen as one of the most computer-intensive systems, in terms of access time. With automation, the maintenance management system would be a powerful tool that could be used by several different maintenance engineers for many different purposes. At least two computer stations would be required to handle the maximum-use day each month in the Maintenance Division and proportionally more high-use days would occur in this division than in most others.

Finally, data integrity is seen as essential for the maintenance management system because these data are used in the development of maintenance strategies, which in turn determine resourcing requirements for the future. Ideally, these data will undergo scrutiny by a variety of division personnel. Hence, the system is rated "high" for the data integrity parameter.

In a similar fashion, all information systems identified as important within the maintenance division were evaluated, and are likewise included in Table 1. In addition to having responsibility for the maintenance management system, the Maintenance Division also administers a preventive maintenance system, a crew day card system, a winter employee transfer system, a building and grounds inventory, a bridge inspection log, a pavement management system, a payroll hours inventory, a vehicle control system, a requisition procedure, and a general equipment and materials inventory. (A separate computer-based maintenance management system has been ongoing in support of the activities of this division for the past several years. The present software for this system resides on the mainframe computer in the IDOH central office. The information systems presented in Table 2 are not connected to the program elements of that system. It is likely that automation of many of the systems presented in that table would duplicate the tasks being designed into the present effort.) Many of these systems require extensive input from each subdistrict in the form of man-hour and work progress reports. This requirement lends itself well to automation; information gathered by the subdistrict for the central office can easily be put into meaningful district reports. Relevant parameters for automation of maintenance division information systems are presented in Table 1.

District maintenance keeps several important inventories. In addition to maintenance equipment inventories, there are the building and grounds inventory and the bridge inspection log. As is the case of most other IDOH inventories, the best

TABLE 1 MAINTENANCE INFORMATION SYSTEMS

Information System	M	B	S	T	A	I
Preventive Maintenance System	3	H	M	4	M	M
Crew Day Cards	4	M	L	1	M	H
Winter Transfer Employee Report	3	M	L	1	M	H
Building & Grounds Inventory	3	M	L	1	L	M
Bridge Inspection Log	3	L	L	2	M	L
Maintenance Management	3	H	M	3	M	H
Pavement Management	3	L	L	1	L	L
Payroll	1*	-	-	-	-	-
Vehicle Control	5	L	L	1/2	L	L
Requisition	5	M	H	1	H	H
Inventory	3	M	H	1/2	H	H

**Major responsibility for this activity resides elsewhere.*

M - Mode of use:
1 = No automation recommended
2 = Local dedicated CPU
3 = Local DBMS with data transfer
4 = Local CPU with data access
5 = Remote data input/access

B - Backup & Recovery: L - Low concern
S - Security: M - Medium concern
T - Time of use: (hours per day) H - High concern
A - Auditability:
I - Integrity of data:

mode of operation for these systems would include local control of the systems with a local DBMS with data transfer.

Maintenance management should become controlled at the district level. Presently, this requirement is passed from the central office to the district in the form of a budget book. An automated maintenance management system would enable the district offices to retrieve data from subdistrict crew day cards and make comparisons of work accomplished versus work planned.

Similarly, it would be feasible to control the preventive maintenance system at the district office. Preventive maintenance would be more timely, and the level of service to district vehicles and equipment would improve. Of course, the information contained in the system might be needed in the central office as well as in each subdistrict office. Therefore, the best mode of operation would be a local DBMS with data transfer.

There are several systems in which backup and recovery are important. As the districts become responsible for these systems, special care must be considered for backup and recovery. If the data for the preventive maintenance system and the maintenance management system is to be kept in the district, special steps should be taken to ensure these data are not lost.

Together with the maintenance management system, the preventive maintenance system is considered to be the most computer-intensive system, in terms of access time. Maintenance systems are not as sensitive to intentional or unintentional abuses, and therefore, auditability is not a major concern. There are several systems in which data integrity becomes significant. The winter transfer report, the maintenance management system, and crew day cards all contain information that must be consistent wherever the data resides.

TOWARD IMPLEMENTATION

One valid approach to the automation of information handling and management at remote office locations would be to develop software for each system consistent with the guidelines provided in the information system tables and with input from those individuals responsible for those areas. However, this approach may have serious drawbacks and should be considered carefully.

It is important that proper thought be given to whether such systems should be automated in their present form; that automated systems would be best designed to mimic information systems designed in a nonautomated environment. Also, as noted before, many benefits would result from the implementation of new systems that draw on information presently gathered. The strategy of automating existing information systems can present some severe problems, both practical and philosophical. Some of these problems are as follows:

1. Existing systems may be difficult or inefficient to automate. Many systems designed out of a nonautomated environment do not lend themselves to efficient automation. For instance, automating many separate inventories would be inefficient and difficult. Similarly, automating each material engineering calculation system individually would be inefficient.

2. Automating existing information systems may result in an overall system that would be difficult to support and maintain. Presently, at the IDOH central office, computer service is frequently overwhelmed by user questions and requests. By increasing the number of diverse systems, the task of maintaining and supporting these systems would be impossible. Several instances of similar applications being supported by different programs and data sets were encountered during the initial interviews for this study.

3. Such an approach may result in distributed data as well as distributed processing. Distributed processing may result in too broad a range in the distribution of data, particularly if different districts or divisions provide specifications for their own program elements.

4. Such a system may be difficult to expand in the future. A concerted upgrade of many diverse IDOH systems would require a much more involved effort. Programmers and engineers would be required to be familiar with several systems, and coordinating these systems might also be difficult.

5. Such a system may be difficult to monitor and control. Data residing within different systems may be difficult to aggregate into simple, clear computer system reports. Decisions that might be clear with a complete system report would be veiled when system data are disjoined. Likewise, it could be difficult to find and fix system security breaches with many different systems.

6. Training of personnel will be difficult and may not be possible in any systematic fashion. Creating many diverse systems would necessitate that personnel learn several unrelated systems. For example, the high turnaround of IDOH district and subdistrict clerks would require frequent retraining classes and create a void in the position as the new employee would be forced to learn and master many systems.

7. The system would require high start-up costs. Designing each information system separately would require duplicate programming as well as data entry. If systems are not combined, much time and effort would be wasted reprogramming basic program modules.

These are but a few of the problems that might be encountered in attempting to use existing nonautomated systems as designs for their automated counterpart. Even choosing a few major systems would require a great deal of effort and input on the part of a few key engineering personnel and it would not be clear how their normal workload might be covered during such an exercise.

The benefits from automating remote-office information management systems can be enormous, but using existing information systems as goals of such an effort could prove futile or, at least extremely expensive. In a more theoretical view, there is no reason to expect that information systems that have evolved over time without automation technology would be even close to optimal in a fully automated environment. Sutherland (*10*) states:

> The answer to improved productivity in the nations white-collar work force is not more technology. The answer is not even applying technology to improve the efficiency and/or effectiveness of today's organizations. The answer is to bite the bullet and admit that: (1) to survive we must change; (2) this change will involve a significant amount of intellectual effort and pain; (3) in order to change we must cast off the shackles

of "conventional wisdom" about how knowledge is organized, marshaled and directed—and the role technology can and should play in this regard; and (4) breaking out of traditional modes of thinking will require redefining the role of OA as an enabler of new forms of organization.

FURTHER OBSERVATIONS

In the case of the IDOH, revolutionary changes in the way that information is managed would result in significant improvements in the level of service offered to the residents of Indiana. Indeed, if all information systems were automated to their appropriate level, the increase in overall efficiency and in quality of service would be dramatic. Just as important, revolutionary changes are needed to bring IDOH remote office information management practices to the point where they can benefit from future advances in office automation technology that are sure to come.

Three more general recommendations were offered: (a) consolidate the separate information systems into a smaller number of more comprehensive information systems with each having a distinct data structure; (b) increase the staff size to include computer systems administrators at remote offices for handling hardware and software issues and conducting user training; and (c) promote a base of user support by offering mechanisms for user input to software design and future system expansion. Each of these recommendations is discussed in the following sections.

Consolidating IDOH Information Systems

The present IDOH information systems should be both automated and also redesigned. This redesigning effort should be directed toward data structures that encompass the present information systems as well as new ambitious systems to ensure that valuable information that could be used to support statewide decisions is not wasted. Nine separate but related data base systems were proposed for the IDOH:

1. Accounting,
2. Communications,
3. Engineering,
4. Equipment management,
5. Maintenance management and planning,
6. Personnel,
7. Project management and planning,
8. Resource management and inventory, and
9. Roadway inventory and history.

Significant systems exist or are being developed in the areas of accounting and maintenance management and planning presently at the IDOH central office but the degree to which these systems (particularly the administration system) incorporate distributed processing or data management is unknown.

The considerations outlined in the information system tables are still relevant, and should be designed into these new systems, as most information from the former systems will still be required. Other design requirements are as follows:

1. The Accounting System. A single accounting system should be created and automated with utility bill management, payroll records and vouchers, petty cash, requisitions, and claim vouchers incorporated. Information should continue to flow as it does now; district and subdistrict requisition requests should be routed to central office by district administration. These requests should be automated with the district administration checking and compiling the requests and forwarding these to the central office. As a result of this effort, the subdistrict office, the district office, and the central office should be able to generate easy-to-read running budget updates and general accounting reports, as well as the ability to perform complex data base queries.

2. The Communications System. The planning and scheduling of highway projects need to be integrated with the many ongoing highway activities. Road paving and repainting need to be coordinated, as an example. What is required is a highway project calendar and an electronic mail and message program. Communications are easily automated, and would be a great benefit of overall office automation. A complete inter- and intraoffice communications network could be designed. Included in this network would be an electronic mail and message and calendar system. A protocol for updating this system should be enforced, because every district and subdistrict activity should be entered in the calendar and consulted regularly. With this system in place and actively used, conflicting projects can be successfully scheduled, and the problem of, say, repaving a road soon after painting, or installing expensive raised pavement markings may be avoided. This would be a sound IDOH investment. A direct application of this system would be in the area of oversized or overweight permits. Road closure announcements could be mailed through the communication system from the central office and stored locally in the subdistrict office. This procedure would speed up the issuance of permits, because verification of safe routes could be made locally.

3. The Engineering Library. A library of engineering software should be available to all personnel in the district offices. There should be an avenue open to request the purchase of new software; and any new software purchased should be globally available to all district personnel. Several engineering systems were requested by district personnel. These include the following:

- A comprehensive roadway and bridge design package, including coordinate geometry (GOGO), surveying, drainage, and structural analysis and design programs;
- Highway capacity and signal timing optimization software;
- A complete material expert system and calculation package;
- Land parcel acquisition optimization software;
- Snowplow routing optimization software;
- Paint vehicle routing software;
- Barrow pit calculation software;
- Software to retrieve traffic counts from electric counting boards;
- Traffic sign upgrade scheduler; and
- General-purpose CAD/CAE software.

4. The Equipment Management System. The preventive management system should be expanded to include all equipment that requires regular maintenance. This system should also be controlled at the district maintenance division, so that system performance is improved and information more timely.

As communication is important to this system, this system should be used as an input to the communications system. Maintenance notices can be sent by electronic mail to the responsible department in the district or subdistrict, and regular system reports can be made to central office.

5. Maintenance Management and Planning. Each of the many maintenance management systems needs to be consolidated into a single comprehensive automated system. Careful attention should be given to the relationships between information required and provided by the crew day card system, the bridge log, the paint record system, the winter transfer reporting system, the highway improvement program, the pavement management system, and the present maintenance management system. The consolidated system would take as input information from all crew day cards, paint records, fatal accident reports, the trouble call log, and pavement management to plan the next year's schedule. Subdistrict planning would be improved by automated reports that would allow the check of scheduled progress versus actual progress for daily activities. As with other systems, complex data base queries could be made on a routine basis, even across data bases.

6. The Personnel System. Presently, the state personnel system limits district and subdistrict administrators to information of primary interest to the central office. All information is carried on a single sheet of computer output. Furthermore, the present system information is updated using a courier and the preprinted computer form. With additional district automation, it would be possible to create a personnel inventory, owned and controlled by each district office. This system could be customized to include payroll information, safety records, affirmative action reports, as well as special training information. Each administrator should be allowed to personalize his system, and perform complex data base queries.

7. Project Management and Planning. A complete project management and planning system should be designed to encompass many of the construction and material and test systems. Included in the project management and planning system would be the daily, weekly, and monthly reports, all contract and subcontract systems, inspector assignment, contract correspondence, material test reports, the Highway Improvement Program (HIP), material sample management, material test reports, aggregate certification, and the contractor performance (and insurance) reports. This system would allow fingertip access to any project information required by the IDOH offices. Ideally, this system would allow a user to retrieve information such as a list of all ongoing projects; monthly, weekly or daily reports for any project; materials and suppliers being used on any project; contract and subcontracts; HIP schedules; contractor insurance and performance reports; expected schedules for any projects; and other more complex queries.

8. Resource Management and Inventory. The resource management and inventory system would serve to manage expendable resources, such as gasoline, spare parts, paint, and other materials.

9. Roadway Inventory and History. A most important addition to IDOH systems would be the roadway inventory and history system. Properly automated, this system would allow maintenance personnel keystroke access to information on all aspects of present and past roadway conditions. This capability would provide a quantitative basis for the planning and managing of maintenance activities and would contribute to future pavement management programs. Included in the inventory would be the description and the locations of all state highways, bridges, billboards, driveways, signals, overpasses, road markings, signs, etc. This data would be supplemented with the history of the roadway, including

- Major construction and maintenance contracts,
- Fatal accident reports,
- Road test data,
- Daily traffic signal maintenance, and
- Daily roadway maintenance.

At present all information required for such a system is being collected and stored, in some formats. While automating these systems, it will be important to allow for the extraction of relevant information so that the data can be sent to the roadway inventory and history system. The single greatest source of information into this system will be the crew day card. This source of information is a record of maintenance and traffic activities; they report all maintenance activities as they occur and feed all maintenance planning systems. Similar to the maintenance and traffic crew day cards is the construction and maintenance contract histories, in that all construction activities are being recorded through the daily reports. Included in the present system is the progress of the project as well as materials and equipment used. Channeled properly, this information would be invaluable to the roadway inventory and history system. There does not presently exist any comprehensive means for storing or retrieving this information or tying this information to road segment location. This problem needs to be addressed, as the previously discussed benefits of this system far outweigh any startup or maintenance costs.

Systems Administration

There is a need for a person knowledgeable in computer hardware and software development in each district. This system administrator would be responsible for the following activities:

- Becoming familiar with district and subdistrict hardware and software systems,
- Educating district and subdistrict personnel in the use of these systems,
- Becoming familiar with every district and subdistrict information system,
- Software development of district and subdistrict systems, and
- Monitoring and controlling all district and subdistrict hardware and software systems.

The system administrator should always be available for questions from district and subdistrict personnel. With this source close to the system users, learning a new system would take less time and would be more easily mastered. Similarly, as the system administrator becomes more familiar with how district and subdistrict tasks are performed, new efficient systems can be recommended and developed with more informed district and subdistrict input.

It will be necessary that each system administrator report directly to the district engineer, and not central office or the district administrative manager. The system administrator should be both the district and subdistrict advocate to the central office, and also be above the confines of district politics.

It will also be important to schedule periodic, say biweekly, meetings of all system administrators. These meetings would serve to standardize all new systems, as well as organize possible shared development. Time should be spent discussing upgrades to system hardware configurations, and new developments in computer technologies.

Toward a Computer-Educated Workforce

The IDOH should work toward a goal of having a computer-educated work force. District and subdistrict employees should be encouraged to educate themselves in computer software and hardware, and to learn the capabilities of any system, so that they can suggest or implement improvements to these systems.

The benefits of a computer education program would be great. District personnel could play a vital role in shaping the new systems, as well as the systems of the future. By allowing district and subdistrict input into new system designs, computer hesitancy would be erased and systems would be better designed.

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Guidelines for the Development of a Strategic Information Process for State Departments of Transportation

JAMES P. HALL

Information is a critical component in the decision-making activities of any state department of transportation (DOT); this opinion is especially true for strategic management concepts evolving in state DOTs. Advances in information processing technologies and information availability necessitate that the DOTs incorporate information systems into their strategic thinking. DOT information systems are progressing from traditional operational control systems toward more management-oriented executive information systems and strategically oriented strategic information systems. The development of these systems is complex and difficult. The integration and communication of information is technically troublesome. A priori identification of an organization's ever changing management and strategic information needs is difficult. Management and strategic information system development efforts are costly and if not properly managed can unnecessarily drain personnel and financial resources. The complexities of information systems are examined from strategic and managerial perspectives using examples from the Illinois DOT. Present and future advances in information technologies that affect DOT operations are outlined. Guidelines are provided for the development of a strategic information process for state DOTs, which include defining the role of top management, using a product champion, prototyping, and an information system management committee.

The dramatic changes in the collection, accessibility, and use of information require that information be properly managed in an organization. For state departments of transportation (DOTs), information is a critical component in decision-making activities at all organizational levels. Information is a strategic resource that can be used to improve operational efficiencies, analyze performance success measures, and provide services to the public. Advances in information technologies will increase the public's expectations and force DOTs to reexamine their ways of doing business. Information management is largely a technology issue, proper management being necessary to ensure effective implementation.

Information systems can be classified into three types: operational control, management control, and strategic planning. Operational control information systems have traditionally been developed to automate a basic process or provide information for lower-level decision making. These systems are prevalent in all state DOTs and are primarily controlled at the user level for specific purposes. DOT examples include materials inspection, payroll, and accident data bases.

Management control systems are developed to satisfy the information needs of managers and professionals in planning and control systems. Management control systems include such concepts as pavement, bridge, safety, and project management systems. These systems have been called management information systems (MISs). Executive information systems (EISs) are a type of management control system focusing on the needs of upper management. DOTs have only recently started to develop comprehensive systems of this type.

Fundamental to designing workable MISs and EISs is the identification of the information needs of management. This process is complicated. Executive information desires change with time and may not be defined until the information is actually needed. It is difficult to plan a management information system in a chaotic environment. Planning of information systems can be stifled by this complex requirement of providing structure while maintaining flexibility. Once in operation, management control systems may become huge data-hungry information machines that lose their original management and executive informational context.

Wiseman (*1*) hypothesizes that the strategic information system (SIS) is an additional critical type of information system. An SIS can support or shape the competitive strategy of an organization. The SIS involves using both internal and external information sources to develop realizations of future threats and opportunities in the external environment, and strengths and weaknesses internally.

Existing DOT information systems (with examples from the Illinois DOT), their adequacy from managerial and strategic viewpoints, and the processes involved in promoting implementation of the MIS and SIS concepts within a state DOT will be described. As a public agency, a state DOT has no need for competitive advantage from a strategic standpoint; however, while remaining responsible for serving their basic mission of providing efficient means of transportation for the public, DOTs compete for public funding. A strategic management process is needed to analyze the transportation environment, to evaluate organizational needs, and to strategically align resources. Strategic information systems can play a major role in this process.

In order to evaluate the requirements of strategic information systems for DOTs, a literature search was conducted on MISs, EISs, and SISs in general, and on the efforts pursued by other state and provincial DOTs in this area. Interviews were also conducted with top management within the Illinois DOT to determine some basic informational needs of management. Analyses were done of existing information systems and their applicability from MIS and SIS perspectives within and outside of the Illinois DOT.

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On the basis of recent implementation efforts, the functions in implementing MISs are discussed. Current and future developments in information technologies are presented as they relate to DOTs.

Recommendations are made for implementing MIS and SIS concepts within a DOT. Examples concentrate on the management of the roadway system; however, similar concepts are applicable to other areas within DOTs, e.g., waterways and aeronautics.

IDENTIFICATION OF EXECUTIVE INFORMATION NEEDS

Figure 1 shows the organizational structure of the IDOT for roadway-related information. These areas span the organization with a wide diversity in their information requirements. Upper management often requires the integration of information from these areas across the organization.

On the basis of interviews with managers within the Division of Highways and previous experience with management decision-making efforts, general needs of management from an information system perspective follow.

Internal Issues

1. How well is the highway network serving the traveling public, and the trucking industry?
2. What is the structural condition of the highway network?
3. What money is required to maintain the roadway network in a serviceable condition?
4. What is the adequacy of existing operations, materials, design, construction, and maintenance in providing for the highway network?
5. What is the status of specific highway projects?
6. Are internal operations efficient?
7. What is the best method for aligning manpower and budgetary resources with ongoing activities?

External Issues

1. How much money should be devoted to minimizing gridlock, and developing new highway systems?
2. What is IDOT's role in transporting goods?
3. Will tax revenues be adequate? What proportion of funding will come from federal, state, and local agency, and private sources?
4. What is IDOT's role in promoting new development, e.g., access to new manufacturing facilities?
5. What is IDOT's role in promoting integration of new technologies such as geographic information systems and intelligent vehicle highway systems, both internally and for external users?

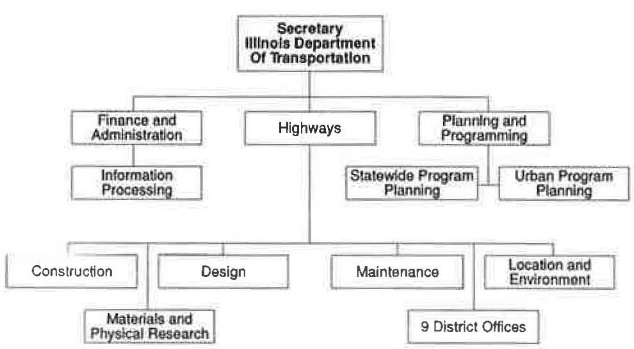

FIGURE 1 IDOT organizational structure dealing with roadway-related information.

Information required for these decision-making purposes is often scattered in various data bases inside and outside the department. The information needs are broad without simple definition. Their characteristics change with changing priorities and operating environments. Although formal management information systems can be developed for specific components, executive information demands are often needed on an ad hoc basis to respond to the changing environment. Flexibility, timeliness, and output style are important.

Traditional management control systems and EIS systems, sometimes developed as prepackaged software programs, can be expensive and difficult for the organization to implement. They may not fit the DOT's information and data base idiosyncracies that have evolved over time. Structured systems may be appropriate for bringing together information when the process is readily defined for common everyday managerial decisions; however, implementation of this type of system must be analyzed carefully because of operating requirements. Three basic questions are as follows: Do they provide the information management really needs? Can the organization support the effort? If they are geared to a particular executive, will they survive his or her exodus?

Once a comprehensive MIS or EIS is initiated, stopping it is difficult even though the system may not meet its intended purpose. The system may sap the organization's resources of money and manpower. Failure of such systems could damage organizational enthusiasm for information system development in future years.

IDOT's internal and external information systems demonstrate the complexity of the information system environment that DOTs must deal with.

EXISTING IDOT INFORMATION SYSTEMS

Computerized information systems developed for roadways within IDOT can be classified into two distinct groups.

1. Project Monitoring Systems—those information systems concerned with determining the scope, cost, and status of a roadway project from conception to final financial closure.
2. Roadway Operations and Inventory Systems—those information systems concerned with the roadway system as a whole, e.g., road inventory, mapping, accident data, and permits.

Figure 2 shows the major roadway-related systems and their classifications within IDOT.

The information systems in these two groupings consist of a wide variety of ages of original data base design features (some pre-1960) with differing data base technologies, data

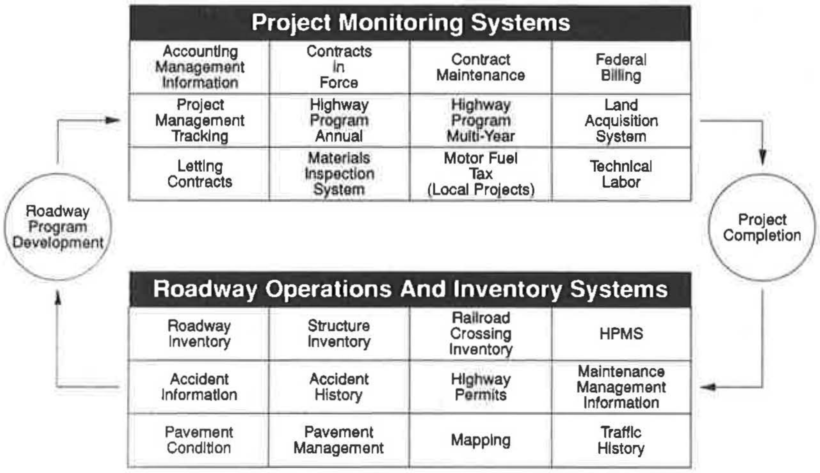

FIGURE 2 IDOT major roadway-related data bases.

storage formats, and key identifiers. As a result, information integration is difficult. Individual systems are primarily controlled by individual bureaus in the lower levels of the organization. The systems have primarily evolved in the conventional manner, that is, operational control, to automate a specific process. Because most systems were developed around user needs at a lower organizational level, system identifiers and information requirements did not evolve in an overall organizational or management context.

Computerized information systems are a substantial portion of IDOT's operating budget. The basic annual cost of computerized information systems in IDOT is approximately $6.5 million spent in contractual, software, and state data processing agency billings and $4.5 million in hardware and lease payments spent in FY 1989.

IDOT MANAGEMENT CONTROL SYSTEMS

With the increasing realization and necessity for management information, upper management has been frustrated in its attempt to obtain summarized information in useful formats for effective decision making. There have been recent attempts to integrate information systems across organizational lines for management purposes. These efforts have included the areas of pavement management, bridge management, safety management, and project management.

IDOT's recent experience in the area of roadway project management is an example of the complexities of implementing a management control system within a state DOT. An effort was undertaken in 1984 to develop a computerized system to address management efforts to obtain summarized information portraying the state and federal fiscal status and project accomplishment for the roadway program. Managing roadway projects from concept to fruition is complicated for several reasons.

Highway project programming spans three major divisions, nine districts, and seven separate computerized information systems with differing identifiers, all involved in different phases of the process. IDOT's highway program encompasses over 1,300 projects annually with a $1.3 billion expenditure of federal, state, and local agency funds. Projects may take years to evolve from the planning stage to final construction with various mutations in between. The Division of Highways addresses the environmental impact analysis and actual highway design with much of the work managed at the district level using outside consulting engineers. The Office of Planning and Programming is involved with the programming aspects of ensuring federal and state monies are properly allocated and distributed and that a proper mix of projects are selected. The Office of Finance and Administration monitors progress against the state appropriations process and also provides computer support through the Bureau of Information Processing.

The development of processes to retrieve summarized management information to support upper-level project management decision making has been extremely difficult. A new computerized project monitoring system was implemented to meet specific information needs of the Division of Highways; however, complexities still arose because of the broad organizational areas directly involved, the continuance of concurrent systems, and the lack of manpower to enter data and develop user outputs.

Until organizational confidence has developed in the new project monitoring system, changes in existing project status information systems, both computerized and manual, have been slow to develop. The system has also met the natural resistance of organizations to change and the perceived usurpation of authority.

This example demonstrates the difficulty in adjusting to new information system design. There must be a balance between user needs and management needs. Systems encompassing several major areas in the organization must address the real organizational issues of communication and implementation. Information is a form of power and there may be unwillingness to share. Existing information systems, no matter how antiquated, have an organizational inertia of their own that inhibits change.

IDOT EXTERNAL INFORMATION SYSTEMS

External information in IDOT is derived in a variety of forms. IDOT subscribes to DIALOG information retrieval services.

IDOT also subscribes to reports on economic indicators and predictions, legislative activities, and media reporting. Technological information is gathered through widespread participation in national roadway-related technical organizations.

External information is transmitted to the organization in a primarily informal manner. Executives obtain external information through outside personal contacts and through participation in external committees. There is no formal external environment scanning process.

STRATEGIC MANAGEMENT

Tyndall (*2*) defines strategic management as "the process of articulating a future vision of accomplishment for an organization and planning, directing, and controlling the organization's entire range of activities toward the desired state or position." Information is a major component for strategic decision-making activities.

IDOT, like most state DOT's, does not have a formal strategic planning process; however, IDOT does perform strategic management activities. Internal strengths and weaknesses and external threats and opportunities are identified in an informal manner by executives through personal and organizational contacts and reports. The dramatic changes in information processing technologies and the increasing availability of external information warrant the evaluation of information in a strategic context.

Given the complexities and choices in the information systems environment, a basic question is whether it is worth the cost and organizational effort to establish comprehensive management information systems that would truly meet management's strategic information needs. Another issue is whether a SIS can be developed within a DOT for strategic advantage.

The answer to both issues is yes. DOTs have existing comprehensive information systems such as the roadway network and computerized mapping of that network that are not present elsewhere. DOTs also have the resources to access, analyze, and display information with state-of-the-art information technologies. Although not crucial to survivability, proper management of these technologies is crucial to performing the organizational mission in an efficient manner.

The service and information relationship between a DOT and the traveling public, legislature, highway contractors, consulting engineering firms, trucking industry, and economic development agencies requires strategic management of information resources. Through widespread use of information, a state DOT sets standards for its use and access by other agencies. Public expectations of information availability and analysis will increase as the technology increases. Future improvements in productivity and decision making will be directly related to information processing technologies. DOT management must be directly involved in this process in a strategic context.

INFORMATION TECHNOLOGY

The advances in information technologies will have a dramatic effect on future operations within DOTs. As primarily a service agency, the transferability and use of information is a key component in a DOT's mission. Some of the major areas of information technology relevant to strategic management analysis include engineering systems, microcomputers and workstations, fourth-generation languages, expert systems, and geographic information systems.

- Engineering Systems. IDOT employs approximately 1,200 engineers. Their functions encompass project design, bridge design, construction inspection, and highway research activities. Information is a key component to engineering tasks and information technologies are redefining the engineer's role. Examples include the application of expert systems for defining complex design and operational tasks, computer-aided design (CAD), computer-aided mapping (CAM), and detailed statistical analysis of performance of highway and bridge design and material components. The development of engineering systems involves a strategic component because of their manpower savings and the use of information within and external to the organization.
- Microcomputers and Workstations. Over the last 10 years, there has been a proliferation of microcomputers throughout DOTs. IDOT currently has a total of 650 microcomputers in place. Uses range from secretarial word processing to complex data base development, financial analysis, and engineering support. Microcomputers provide unprecedented access to information and the detailed analysis of this information at a user level. Microcomputer usage will continue to grow.

However, this movement towards data base development and control at the user level can run counter to the formulation of MIS and EIS for management decision making. Future information system development should categorize information required by lower level users, by management, and by both.

Technically powerful workstations will continue to be acquired for user level CAD, data analysis, and geographic analysis. The processing capabilities of these workstations will greatly enhance information processing at the user level.

- Fourth-Generation Languages. The development of fourth-generation language software has put more of the development of mainframe data bases into the hands of the users. Formalized mainframe and microcomputer-based information systems can be developed more quickly from a user perspective. However, the central data processing area loses some control over development and the creation of resultant management reports. As a result, the overall organizational context may be lost.
- Knowledge-Based Expert Systems. Knowledge-based expert systems are computer programs that use knowledge and inference procedures to solve problems that are difficult enough to require a significant amount of human expertise and reasoning to be solved. These systems have great potential in engineering decision-making activities such as selection of project design alternatives. They also have operational applications in financial, budgetary, and personnel management areas.

Knowledge-based expert systems provide new methods for DOTs to effectively transfer and share knowledge throughout the organization for more effective decision making. They have the potential to increase productivity.

- Geographic Information Systems. Geographic information systems (GISs), integrating data base information with computerized maps of the roadway geography network, have made tremendous strides in recent years. GISs provide the capabilities for displaying information on the highway network in a manner readily understandable by users, management, and the public. There are also opportunities to integrate DOT information with geographic-based information from external sources such as the U.S. Census Bureau and the U.S. Geological Survey for external strategic analysis.

GISs also provide opportunities for developing new concepts in information analysis and decision making. Geographic outputs are more readily understandable and can be directed toward specific user areas, managers, and outside groups.

- General Trends. The growth of information technology has already had, and will continue to have, great impact on state DOT operations. Readily apparent cost savings are in the areas of switching from manual to computerized mapping and development of CAD operations.

Executive information needs will increasingly demand the integration of information from diverse areas and information systems within the organization. This integration will become even more complex as microcomputer and workstation usage increases. Fortunately, data communication and integration technologies are expected to evolve to meet the need. There will also be advances in software, especially with regard to statistical analysis, information summarization, and user-directed outputs. DOTs will need to structure their organization to be able to identify, manage, and fully use these technologies.

GUIDELINES FOR DEVELOPMENT OF A STRATEGIC INFORMATION PROCESS

Although DOTs have comprehensive information systems in place, primarily for operational control, upper management continues to express frustration with obtaining needed management information on a timely basis. Development and implementation of MISs, EISs, and SISs are difficult given the complexities of existing internal and external data bases, the manpower and budgetary requirements for large system design, and organizational issues arising from changes in bureaucratic organizations.

Information technology in DOTs is a fast-growing field with increasing benefits and responsibilities. Information systems and processes will continue to develop to meet organizational needs. This development should be accomplished in a strategic manner within the context of management's future vision after appropriate internal and external analyses.

As with any technology, the implementation of information technology into the organizational culture is a complex issue. There is no easy answer. Organizational resources are limited in pursuing new endeavors. However, there are the internal strengths of existing detailed information systems and personnel with a strong information technology knowledge base. There are also comprehensive external information systems that will be accessible in an unprecedented fashion. A detailed analysis must be made of the options of information technology development and the organizational impacts of cost, personnel time, and available budgets.

Above all, the development of MISs, EISs, and SISs requires effective integration of information processing technologies that account for the needs and idiosyncracies of the organization. Effective integration follows the general requirements for implementing technology and innovation into organizations.

The following recommendations are for guiding the integration of information technology within the strategic thinking of a state DOT—in short, for guiding the development of a strategic information process.

Top Management's Role

Integration of information technology within a state DOT's operation requires a hands-on involvement by upper management. Management's role is to develop a coherent strategy, otherwise development may occur at the lower organization levels without an overall management perspective.

To some degree, upper managers must become information technology–literate, i.e., they must learn the capabilities and limitations of, and put into an organizational strategic context, the emerging information technologies.

There are several ways to do this (e.g., training), but the most important way may be for upper managers to become directly involved with the information areas in the organization. In many organizations, the computer systems group is positioned in the financial division because development of information systems started with cost savings inherent in computerizing accounting systems. Future information system development should retain an overall organizational perspective.

The creation of the position of information management officer in the upper levels of the organization could facilitate information technology communication with upper management. This information officer would become a focal point for new system development and the development of management outputs to meet managerial needs. This concept has been used with success in private industry.

History has indicated that managerial involvement is crucial to the successful implementation of technology. The crafting of strategy involves logical incrementalism as described by Quinn (*3*), in which resources are developed within a managerial vision. This process may not require the trappings of a formal planning process, but the direct involvement of management in key decision-making activities. Keen (*4*) believes that senior managers' have mainly been approvers rather than initiators. Top management, in taking an active role in understanding information technology and its implications, must create the environment needed for promoting change and for leading in a strategically identified direction.

Unless this process occurs, information systems will develop in a piecemeal fashion with absolute systems continuing by inertia. The organizational resources required for MIS and SIS development also require that top management take an active role.

Product Champion

The concept of a product champion is a forceful method to achieve implementation of emerging technologies. A product champion is a person identified with, and actively committed to, pushing an idea to fruition through critical stages. The unique, often egocentric, characteristics of a product champion can provide an impetus to shake up the organizational bureaucracy and to persevere in the pursuit of implementation.

There are examples of agency-wide projects that have languished because of the accompanying complexities and changes required. The assignment of a product champion could take the project out of its doldrums and provide the organizational analysis and communication to achieve success. Top management must determine when and where the assignment of a product champion is needed and to promote it when necessary.

Prototyping

Prototyping is an important component of the integrating of information technology into DOT operations that requires directing the conceptual data base design and potential outputs of the anticipated information system toward different levels and areas in the organization. This result can be accomplished through user level committees, demonstrations with microcomputers, and development of sample-data bases. Above all, feedback must be provided to ensure that the proposed system meet organizational needs and do not unduly drain organizational resources.

The organizational complexities and data requirements of MIS and SIS development can strain the cognitive limits of the responsible individuals. Prototyping is an efficient method for gradually increasing the organization's knowledge base while testing the adequacy of data structures, outputs, and technology applications.

Prototyping also allows management to review an information system project from its own perspective to determine applicability to its needs. Prototyping can anticipate widespread resistance to particular development of the system.

Information Systems Management Committee

Information technology can be viewed as an obstacle as well as an opportunity. Advances in technology create new options for systems development in completely new ways. The resulting complexity may slow information system development.

The application of information system technology to actual systems design requires the oversight of an upper level review committee. The resources needed for developing integrated information systems require that the significant system development and operational costs for personnel, equipment, consultants, and operations be quantified. Analysis of the costs and benefits can then be made from an organizational standpoint by upper management.

Because benefits may be difficult to quantify, the desired management outputs and relative value can best be determined by upper management. These issues may be resolved in phases by means of prototyping of actual developments and go–no go decisions made as the project progresses. The oversight committee would also force upper management to supervise the information system development process. This committee could best judge relative effectiveness of systems, could focus the development process on determining exactly what problems the system is trying to solve, and could determine the benefits of the solutions.

Attempts in the past at initiating this type of committee have degenerated because of the organizational issues involved and have been overwhelmed by the complexity of the task. Also, because managers would not object to system development (fearing hindering of organizational development or offending other managers), realistic system evaluation does not take place. However, if properly managed, the oversight committee should provide the best basis for judging information systems development and to ensure that implementation occurs across the organization.

Information Systems: A Strategic Viewpoint

DOTs should change from classifying information systems development as a data base technology to identifying it as part of the organization's strategic fabric. This process should be based on an external as well as internal orientations that view emerging threats and opportunities in a strategic context.

This process should be implemented in a formal manner as part of an overall strategic management process for analyzing the internal and external environments. Information technology will continue to be a key part of the organizational mix for all DOTs.

The external analysis should provide a basis for defining the strategic role of information in transportation system development, economic growth, and technology transfer. It should look at the macro issues concerned with information technology implementation.

CONCLUSION

The general picture of the management information context in a state DOT has been described because of the nature of the process and the complexity of the organization. Personal experiences with successes and failures of information system design and implementation have portrayed the effect of organizational, management, and budgetary realities on information system development.

For truly effective MIS, EIS, and SIS development, the key criterion is an active, knowledgeable, upper management that develops appropriate communications and prototyping strategies spread throughout the organization. A broad organizational vision of a strategic direction is essential to ensure that these complex, resource-hungry information systems adequately provide information that ultimately benefits the organization. This paper provides the general context necessary in order for strategic information technology implementation to occur.

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Linking Strategic Planning and Budgeting: A Case Study of the New Jersey Department of Transportation

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Strategic approaches to planning and management in the public sector are becoming accepted. Clearly, formal long-range planning that simply projects current trends into the future is wholly inadequate for managing government agencies in an environment with ever-changing political, economic, and legal considerations. Indeed, the benefits of strategic approaches to managing business are well demonstrated in the public sector. The implementation of strategic plans through the annual budget process is discussed. During the past year and a half, the New Jersey Department of Transportation (NJDOT) has developed a strategic planning process under the direction of a strategic planning task force consisting of the commissioner of transportation and other senior management. Over the course of the process, department and division level missions, objectives, and strategies were drafted. On the basis of these, implementation plans were developed that linked planning intentions to the resources needed and available to carry out programs. With the addition of budget-oriented performance measures to the implementation plans, the strategic planning and budgeting processes were joined. A key addition to the implementation plans for future cycles is the inclusion of resources dedicated to resolving critical issues faced by NJDOT.

The New Jersey Department of Transportation (NJDOT) was established by the state legislature in 1966 as the nation's first state department of transportation. In addition to designing, constructing, and operating nearly 2,250 mi of state highways under its jurisdiction, the department also works with counties and municipalities to provide for secondary roads. Because New Jersey is located between two major metropolitan centers, New York and Philadelphia, the department must facilitate the flow of people and goods by coordinating its efforts with a number of independent agencies and authorities, some of which span two states. As a consequence, the department is responsible for a broad range of activities that make it central to most transportation decisions in New Jersey.

Like many departments of transportation, NJDOT must manage a highly complex and varied system. The state's 34,041-mi state and local highway system is the most intensively used in the nation; the number of vehicles using each mile of highway per day is more than 3.4 times the national average. With the exception of two years with gasoline shortages, highway use has increased every year since the 1960s, and it is expected to continue to increase through the 1990s (*1*,p.31). The system involves not only highways, but also extensive bus and rail operations for public transportation, aviation, and bicycle facilities. After a lengthy hiatus, ferry services are reemerging to carry commuters between New Jersey and Manhattan. In addition to moving people, New Jersey's transportation system enables the shipping and receiving of large volumes of goods by highway, water, rail, and air.

Today, the major focus of the department, ensuring the safe and efficient movement of people and commodities throughout the transportation network, presents a number of challenges and important issues. Providing transportation no longer means simply designing and building roads. Rather, transportation managers must be aware of and address a wide range of issues and trends relating to land use, growth and congestion, environmental quality and quality of life, and the economic consequences of transportation decisions. Because of the combination of its large population yet small geographic area, New Jersey feels these forces perhaps more immediately and intensely than do many other states. In recognition of the need to address and respond to these issues, strategic planning and management were initiated at the NJDOT.

Over the past several years, a number of public sector organizations have adopted strategic planning and management techniques. Despite significant barriers to implementing techniques that are more compatible with private sector aims, state departments of transportation and public transportation agencies are finding that strategic planning and management provide an opportunity to improve public planning and managerial effectiveness (*2,3*).

OVERVIEW OF STRATEGIC PLANNING AT NJDOT

Strategic planning at NJDOT was initiated by the commissioner of transportation in January 1987. The reasons for initiating strategic planning were numerous. First, NJDOT recognized the need to anticipate and respond to future demands in a changing transportation environment, that involves increasing demands and more constrained resources. Strategic planning was expected to yield better justifications for state and federal funding requests, as well as a more effective allocation of these resources to high-priority initiatives. Second, the department needed a way to manage the continuing transition from its role as a highway department to a transportation department, with broad responsibility for and participation in statewide transportation planning and policy making. Establishing a department-wide vision of its mission and future would express this transition and serve to unify a large, diverse, and complex organization. Finally, in

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an effort to ensure that the department was well managed and effective, NJDOT management sought to provide the highest degree of accountability. This could be demonstrated by providing useful, measurable performance indicators within the context of an overall strategic planning framework. In early 1988, a consultant presented the department with a reorganization proposal that provided the basis for a plan approved by the governor in April 1988.

An important element of the reorganization was the establishment of a Bureau of Strategic Planning in the Division of Transportation Policy in July 1988. One of the first tasks of the new bureau was to develop a strategic planning work program. After reviewing the experiences of other states, the bureau structured a fairly traditional strategic planning process at NJDOT. As with many public agencies that implement strategic planning, NJDOT established a committee to provide senior management oversight. The committee, called the "strategic scanning task force," comprised the deputy commissioner, the assistant commissioners, the chief of staff, and the executive assistant to the commissioner. Its first task was to draft the department mission, objectives, and strategies (MOS) statement for FY 1990. From little more than a mandate and a department MOS statement, NJDOT has made significant progress toward implementing and institutionalizing strategic planning. Nearly 30 divisions, offices, and other units, assisted by the Bureau of Strategic Planning, drafted their own MOS statements that supported the department-level mission. This process allowed managers and key staff to analyze and describe their overall purpose, clients, and work products. It also was an opportunity to express desired levels of work achievement.

After completing the MOS statements, the divisions and various other units prepared implementation plans (IPs) that translated their MOS statements into detailed, measurable action plans for FY 1990. In May 1989, it was determined that IPs would serve as budget planning documents for FY 1990 and subsequent years.

REASONS FOR LINKING STRATEGIC PLANNING TO BUDGETING

Moving from strategy formulation to implementation is critical to strategic planning efforts. Implementation involves a myriad of skills which involve coordinating, managing, and motivating many individuals (*4*,p.245). However, a strategic planning system achieves its full potential only when it is integrated with other control systems such as budgets (*5*,p.95). Steiner and Miner, who also emphasized the importance of linking planning and budgeting, stated that it is "the most universally used and central basis for translating strategic decisions into current actions" (*3*,p.35). In fact, the most successful implementation of strategic plans in the private sector has been accomplished with linkages to the budget cycle (*6*,p.10).

The NJDOT discovered that integrating strategic planning and budgeting is an important characteristic of successful strategic planning. Originally, the bureau expected only to introduce various strategic planning elements to the department managers during the first cycle. But since the implementation of these elements began to parallel existing budgeting requirements, the commissioner requested that the strategic planning and budgeting processes be immediately integrated. By linking the two processes, the NJDOT has allocated resources to predetermined department and division priorities as expressed in the MOS statement's mission, objectives, and strategies. Although such an unanticipated early fusing of strategic planning and budgeting was not accomplished without difficulties, nevertheless, it was a positive occurrence in the evolution of strategic planning and management at NJDOT.

NJDOT BUDGET CYCLE

The New Jersey budget process involves the governor's office, the Department of the Treasury, the legislature, and the individual agencies. The budget process must meet the internal needs of department managers while fulfilling requirements imposed by the New Jersey Office of Management and Budget (OMB) in the Department of the Treasury. The typical budget process begins well before the beginning of the fiscal year, with the governor's office and OMB analyzing programs and costs before developing planning and budget targets. These targets are incorporated in a planning and budget circular, which is distributed to each department in April, 14 months before the beginning of the fiscal year. At the same time, the various departments of the state prepare long-range plans on the basis of instructions and projections distributed by OMB in February. These long-range plans are submitted to OMB on April 30, and are used as background for the preparation of the planning documents, which are submitted to OMB in mid-July. The planning documents provide OMB with the agency's goals and objectives, a sense of current external impacts, evaluation data, and reallocation and reduction contingency plans. In addition, the planning documents provide for priority requests, which are appeals for funding that constitute substantial increases in funding over the base budget for new or expanded initiatives. OMB uses these two elements to analyze the agency funding request, and the agencies negotiate with OMB in September on a recommended budget. In October, the agencies submit their final budget request, which is reviewed by OMB and the governor, and presented by the governor to the legislature in late January. The legislature holds hearings on the budget in March, so that the budget is in place as required by law before the fiscal year begins on July 1.

For budgetary purposes, the department is organized into 32 budget centers. For the most part, the budget centers are the same as the divisions, although, in some cases, a division and assistant commissioner's office are contained in one budget center. However, in the construction and maintenance area, the budget centers correspond to bureaus rather than divisions. In general, implementation plans are drafted for each budget center.

The internal budget process and its products are, in many ways, driven by outside requirements imposed by OMB. The New Jersey OMB has for several years required agencies to submit budgets and supporting documentation using strategic planning terminology; however, formal agency strategic planning was not a prerequisite to the preparation of such documents. With the introduction and advancement of strategic planning at the NJDOT, the relationship between strategic issues and the resources needed to address these issues will become clearer and help to ensure that external actors in the budget process are aware of the issues that drive the department's budget.

STRATEGIC PLANNING ELEMENTS

As was described earlier, all divisions drafted MOS statements. Once these were in place, the Bureau of Strategic Planning recognized that the statements must be accompanied by detailed, measurable plans for implementation. Because implementation requires the use of resources, budgeting information was expressed in IPs. As shown in Figure 1, the IP consists of a spreadsheet developed in Lotus 1-2-3, with columns of information. The first two columns contain the objectives and strategies developed in the statements. In the third column, managers were required to list the various activities or the specific work that was to be accomplished to implement the strategy. For each activity, managers were asked to provide a performance measure to relate sources to results and to estimate the cost of pursuing particular strategies. This latter requirement was accomplished by allocating their total staff among the activities, expressed as person-years. Because salaries constitute the overwhelming expenditure in the operating budget in all areas except for some construction and maintenance operations, person-years were used as a proxy for all costs, including materials, supplies, and other nonsalary items.

Originally, the bureau asked that the person-years be developed unconstrained by budget considerations. However, when it became clear that the IPs would become the budget document work plans for FY 1990, it was necessary to ask that the divisions use their actual authorized staffing level and allocate their actual staff resources accordingly. Their FY 1990 dollars, derived from the spending plan developed jointly by each budget center manager and the department's Budget Division, were allocated among the strategies proportionally, on the basis of the staff time allocation. Although not a perfect method for estimating the costs of activities, the technique is useful for revealing the relative costs of strategies and activities, and, in many cases, demonstrates both the time and money that is spent on routine tasks.

Integrating strategic planning with budgeting at the NJDOT occurred much more rapidly than had been expected. Because the strategic planning process was put into place and advanced fairly quickly, it started to parallel other existing management and budgeting tools. In particular, the IPs contained most of the information required by the department's Budget Division in the annual budget cycle. By the time it became necessary for budget center managers to provide resource information in the IP, it became clear to senior management that the maintenance of substantially similar budgeting and planning systems was needlessly duplicative and time consuming. In May 1989, the deputy commissioner suggested that the two processes be merged. The processes were combined, as shown in Figure 2, and the Bureau of Strategic Planning and the Budget Division staff briefed budget center managers on their responsibilities in providing budgetary information.

As strategic planning evolved internally, staff examined the budget process administered by OMB and implemented by the Budget Division. The important elements of strategic planning were designed to conform as closely as possible with existing systems, to preserve historical continuity, and to make managers more comfortable with the new process. The transition from the previous budgeting system to the new strategic planning and budgeting system was relatively easy because in most cases there was a one-to-one correspondence between the divisions that prepared the plans and the budget centers. The significant exception was the construction and maintenance units of the department.

STRATEGIC PLANNING AND BUDGETING FOR CONSTRUCTION AND MAINTENANCE

The construction and maintenance (C&M) units are organized, for the most part, according to four geographic regions as shown in Figure 3. Each region performs construction, maintenance, materials, and electrical engineering, and the managers of these units report to a regional C&M director. Central office oversight is provided in Trenton by the Division of Engineering Support and the Office of Operations Engineering. Unlike other divisions, budget center managers do not correspond to division directors, but, instead, to bureaus. For example, the manager of the Bureau of Maintenance Support supervised six budget codes that cut across divisions and regions. The responsibility includes not only maintenance support and maintenance engineering, part of the central office division, but also the maintenance and electrical units of all four regions.

OBJECTIVE	STRATEGY	ACTIVITY	PERFORMANCE TARGET	PERSON YEARS	APPROP.
1. Maintain assigned State highway system at an acceptable quality level to assure the safety of all users.	1. Maintain the highway lighting and signalization system at an acceptable level.	1. Ensure the timely response to and correction of all highway emergencies.	1. Respond to all calls within 8 hours.	1. 25	1. $130.9
		2. Perform all group relamping.	2. Relamp 50% of 2000 traffic signal intersections and 1000 street light units.	2. 30	2. $200.2
		3. Construct and maintain electrical facilities on the local highway system.	3. Inspect and service 172 signals & repair bi-monthly.	3. 50	3. $30.0
	2. Perform routine landscape maintenance in accordance with standards.	1. Implement roadside mowing, spraying program, shrub and tree maintenance, and wildflower and other special planting programs.	1. Achieve 50% of the theoretical workload. Accomplish 2,200 miles of curb and guiderail spraying; 26,000 acres mowed.	1. 20	1. $100.5

FIGURE 1 Example of implementation plan.

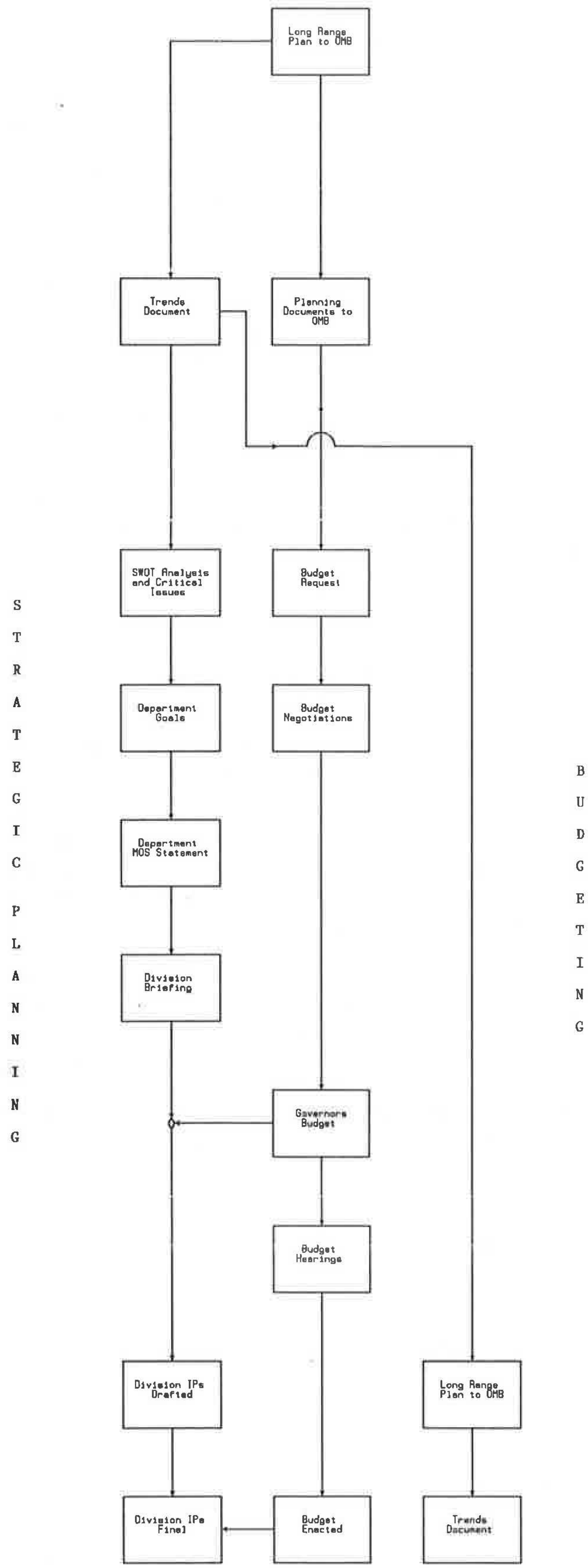

FIGURE 2 Strategic planning and budgeting cycle.

As in other areas of NJDOT, MOS statements were drafted according to function. Recognizing that all four regional offices were functionally similar, the regional directors all met to draft one MOS statement. In Trenton, the Office of Operations Engineering and the Division of Engineering Support drafted separate MOS statements, and strategic planning proceeded in a fashion similar to that of other divisions in the department.

This system worked reasonably well before budgeting was linked to the strategic plans; however, when the linkage occurred, it became clear that implementation planning according to function would be impossible. Originally, it was believed that each strategy would correspond to an individual budget code. Budget managers quickly indicated that there was no such correspondence and that each strategy could be addressed by one, two, or even eight budget centers. This problem was resolved by assembling all three draft IPs—those of the regional offices, operations engineering, and engineering support—and assigning the appropriate budget code or codes to each strategy. The plans were sorted by budget code, and draft IPs were developed for each budget center. These products will provide an excellent basis for future planning.

RESULTS

In general, the first combined strategic planning and budgeting documents were superior to previous work plan budget documents. One of the greatest benefits of the process was the improvement of performance measures. In the past, many measures did not necessarily highlight the most important work of each division. Also, the chosen measures often did not demonstrate the most meaningful aspects of performance. The strategic planning initiative forced managers to rethink measures; improved performance monitoring was the result.

Specifically with regard to the construction and maintenance area of the department, it became clear that there were three functional areas to concentrate on for strategic planning: construction and administration, equipment, and maintenance. In the case of maintenance, there were six separate budget codes; however, because the plans share common objectives and many common strategies, this new process allows managers to compare similar strategies across different functions. For example, maintenance managers will be able to compare training strategies in road, bridge, electrical, and landscape maintenance areas.

COMMON PROBLEMS AND SOLUTIONS

In any new and complex management initiative, problems are inevitable. Many of the problems experienced in the first cycle at NJDOT were caused by the newness of the process, while others were caused by the speed at which strategic planning and budgeting were joined. Whatever the reason, these problems should be of interest to any agency instituting strategic planning. Fortunately, none of these problems appear to be so severe as to be ultimately insurmountable.

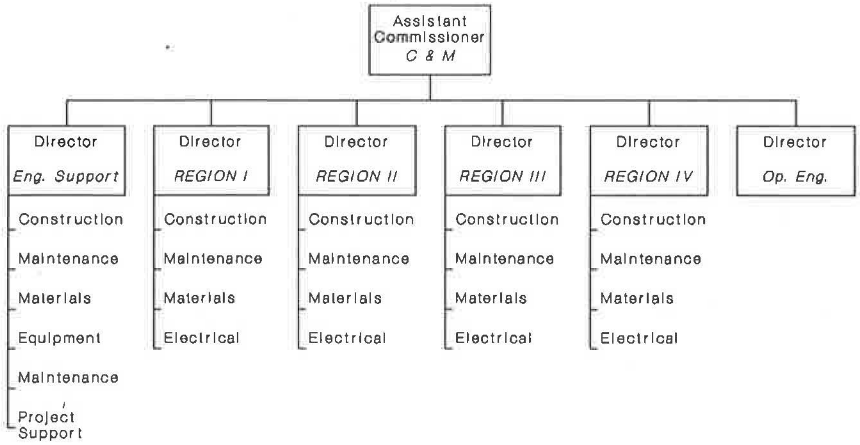

FIGURE 3 NJDOT Construction and Maintenance Division (simplified).

Inadequate Planning

A well-defined process must be in place before strategic planning is presented to managers. In the case of NJDOT, the process evolved as it occurred, which led to ad hoc planning. This was largely caused by a perceived need to institute the planning program as soon as possible, to seize the initiative while widespread enthusiasm still existed, and to gain valuable experience from the first year. While a certain degree of flexibility is important in instituting any new management tool, the unit responsible for developing and monitoring the process must be allowed the time for planning and preparation. The lack of planning caused the direction of the process to change a number of times, much to the annoyance of participants. Obviously, completing future cycles will be easier because the bureau has had a full year to define a process. However, to aid participants even further, a strategic planning handbook has been prepared.

Vague Staff Responsibilities

Because the integration of strategic planning and budgeting required coordinating the Bureau of Strategic Planning with the Division of Budgeting, there was some confusion among the divisions as to roles of budgeting and strategic planning staffs. In general, budgeting was most concerned with performance assessment and actual resource numbers. Strategic planning, on the other hand, worked to ensure that strategic thinking, in the form of MOS statements and IPs, preceded the development of budget documents. Confusion on the part of the divisions ranged from substantive problems, such as not translating performance measures from the old to the new system, to an unclear understanding of where to submit planning materials. In the next cycle, the Bureau of Strategic Planning will be clearly defining roles and responsibilities and working as a team with budget analysts.

Unclear Purpose of Process

When budgeting and planning functions reside in different parts of the organization, it is necessary for the purpose of each process to be clearly delineated. To successfully join strategic planning and budgeting, the individual and combined purposes of each process must be understood by managers. Some divisions at the NJDOT were unclear about whether strategic planning was a new management tool or simply a new twist on the budget process. The MOS statements were perceived as strategic, but the IPs were considered to be little more than detailed budget documents.

One of the major thrusts of the upcoming new cycle is to make the division and the department participation more strategic and therefore, more distinct from budgeting. In the next cycle, submissions being made to OMB will be much more solidly grounded on strategic issues. These issues themselves will be thoroughly analyzed through a more structured environmental scanning process than had existed before. The Bureau of Strategic Planning recently published a document entitled *Trends Affecting the New Jersey Department of Transportation*, which analyzes important social, economic, political and technological currents that will influence the department's policies and operations in the 1990s. Information from this environmental scan was used to conduct a strengths, weaknesses, opportunities, and threats (SWOT) analysis with the assistant commissioners. The product of comparing the department's internal capabilities and shortcomings to external forces is a set of 10 critical issues. These issues, which by their definition must be addressed to ensure that the department's mission and objectives are achieved, include topics from managing congestion and mobility to ensuring management development and employee skills enhancement. Associated with each critical issue are key strategic goals to be attained by the department over the next fiscal year. Revisions of the department and division MOS statements that outline relatively timeless mission and objectives, as well as priorities, will reflect the outcome of these analyses. Likewise, division IPs will incorporate strategies and resources that support the achievement of these goals.

As the strategic direction accommodates shifts in internal policy and external factors, all MOS statements will change to reflect these priorities. Consequently, the IPs express the allocation of resources devoted to achieving priority items. They contain 1-year budget requests and estimated resources needs for the next fiscal year. Managers will be instructed to prepare needs budgets, continuation budgets, or cutback budgets based on OMB projections on the fiscal condition of the state. Any new start items will be funded on the basis of their conformance to priorities outlined in the MOS statements and IPs.

These initiatives and others will demonstrate to managers that the strategic planning process is a tool that enables management to set priorities and that the IPs and the budgeting process are an expression of this work. In an effort to link the two processes, the bureau unintentionally promoted an overemphasis on resources, such as people and dollars, at the expense of addressing strategic issues. A better balance will be struck between these two elements in future cycles.

CONCLUSIONS

Like most organizations, public or private, NJDOT has discovered that strategic planning is a valuable tool for setting overall direction and priorities in a changing environment. In the first year of using strategic planning techniques, NJDOT found that drafting a department-wide MOS statement that articulated the mission, major objectives, and strategies of the department was critical. Using this statement as a framework, the various divisions drafted supporting MOS statements and detailed work programs in the form of IPs. The IPs formed the basis for implementing the MOS statement through the allocation of budget resources and the measurement of performance. Despite its difficulties, the NJDOT adopted the IPs as an internal budget document. Once the strategic planning and budgeting processes are completely synchronized with OMB's budget request timetable, much of the information will be used to develop the annual department long-range plan required by OMB. In addition, the bureau has determined that the documents are used for a variety of management purposes including monitoring manager performance.

While the department is achieving implementation of its strategies using a joint planning and budgeting process, the implementation is, to a certain extent, mechanical. The Bureau of Strategic Planning intends to deemphasize formal process in future cycles and to focus instead on identifying strategic issues and successfully implementing strategies to address them. As the literature discusses, implementation involves a variety of factors aside from linkages to the budget process. New additions to the process, highlighting internal strengths and weaknesses, external trends, and critical issues, will advance this effort.

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Methodology for Estimating Road Damage Cost Resulting from Potential Rail Branch Line Abandonment: The Case of South Central Kansas

VICTOR E. EUSEBIO AND STEPHEN J. RINDOM

A systematic procedure is developed to estimate additional highway costs associated with rail branch line abandonment. The procedure is tested in an area in south-central Kansas where three Missouri Pacific (MP) branch lines were recently placed in the Interstate Commerce Commission's Category I abandonment classification. Results suggest that the procedure can be used to estimate additional damages to county, municipal or city, and state road systems resulting from branch line abandonment. Abandoning the three MP branch lines in south-central Kansas will result in an estimated additional annual truck damage to Kansas rural highways amounting to $138,274 for farm-to-elevator movements of grain. Incremental road damage cost caused by rail abandonment is estimated at $55,961 per year for intercity grain traffic. The procedure also reflects the abilities of intercity and farm-to-elevator road systems to absorb additional grain traffic resulting from branch line abandonments. An additional bushel of grain moved 1 mi by truck is estimated to cause additional damage to roads amounting to 0.90 cent for farm-to-elevator routes while costing only 0.17 cent for intercity routes. A combination of local roads, collectors, and minor arterials generally composes a farm-to-elevator route, whereas a combination of minor and major arterials and Interstates composes an intercity route. The same procedure can be used to estimate incremental road maintenance costs of rail abandonment for other types of traffic.

Loss of rail service is often met with trepidation by residents of rural communities in Kansas despite contentions by rail carriers that many of the so-called "light-density" rail branch lines are highly unprofitable to operate. To farmers, it could mean an increase in trucking costs as they would have to truck their grains farther to remaining rail heads for marketing. To local shippers, it could mean loss of business and cutbacks in elevator profit margins in order to remain competitive with local elevators having rail connections. To the rural community, it could mean loss of jobs, a decline in general farm incomes, and decreases in land values, as well as increased air pollution and potential safety hazards associated with additional truck traffic. At the state level, it could mean hastened deterioration of rural highways and bridges from additional truck tonnage and the accompanying strain on local and state highway budgets.

State and local planners and policymakers have much cause for concern from the trend toward rail abandonments in Kansas. From 1980 to 1988, a total of 39 Kansas abandonments occurred involving 537 mi of track. Another 348 mi has been placed by the major railroads under various abandonment categories (49 CFR 1152). Some 3,000 mi of rail in Kansas are classified as light density. Shifts in freight traffic from rail to trucks as a result of rail branch line abandonment could be substantial. Additional road maintenance expenses associated with increased truck tonnage could reach major proportions.

Cassavant and Lenzi (*1*) developed a methodology to predict and estimate damages on rural roads of potential rail line abandonments. Their conceptual model was applied in a case study involving the abandonment of the Mansfield rail line in Washington state.

A similar issue with a different estimation procedure is addressed. Firstly, rather than relying on shipper surveys, a network model is used to generate grain movement data before and after rail abandonment. Shipper cost minimization is the organizing principle for estimating traffic patterns. Second, the Highway Performance Monitoring System (HPMS) pavement damage functions are used instead of the American Association of State Highway and Transportation Officials (AASHTO) pavement functions to more accurately predict pavement life cycles on low-capacity roads. Third, additional damages to Kansas roads by trucks are estimated for changes in intercity as well as farm movements of grain. Last, damage cost estimates are categorized by (a) road systems (i.e., county, municipal or city, and state), to trace the level of government jurisdiction; and (b) road type (i.e., Interstate, arterial, collector, and local), to reflect differences in structure and design among Kansas roads.

A major change in transportation alternatives, such as one triggered by branch line abandonment, can cause shifts in grain flows at both production and local elevator levels. In competitive grain markets, farmers will sell their produce to elevators with the highest local bid for their grains. With rail branch line abandonment, elevators with rail connections (and cheaper shipping costs) are in a position to offer higher bids to farmers. Also, elevators that lost rail service are forced to truck their grains, often at substantially higher costs, to other elevators with rail service or to terminal elevators. The impacts of these changes on rural roads are two-fold. First, farmers will travel longer distances to get the best bid for their grains. This additional mileage means additional use and

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damage to the state's rural roads. Second, trucks will occupy an increasingly important role in the local elevator-to-terminal elevator (intercity) movement of grain. Such a shift in modal alternatives towards trucks will result in a higher frequency of heavy trucks and greater damage to the state's road system.

The question of how much damage a proposed rail branch line abandonment will do to an existing network of county, city, and state roads is an empirical issue. A methodology is needed that will quantify damage to rural highways as a result of rail abandonment. An empirical tool is presented for estimating incremental highway damage caused by rail branch line abandonment. Damage is estimated for county, municipal or city, and state road systems.

The Union Pacific System (UPS) recently placed three Missouri Pacific (MP) branch lines in south-central Kansas under Category I abandonment classification (see Figure 1). These interconnecting lines (Radium-Conway Springs, Hardtner-Conway Springs, and Turon-Iuka lines) have been chosen for application and illustration of the methodology for estimating incremental highway damage caused by changes in grain traffic flows following rail branch line abandonment.

This study assumes that traffic flows represent minimum cost movements both before and after rail abandonment. Beginning flows are based on the assumption that no unusual deterioration of tracks or service quality had artificially diverted traffic to trucks.

The specific objectives of this study are to

1. Develop a systematic procedure for estimating the incremental highway costs associated with potential rail branch line abandonment,
2. Apply the procedure in a case study area so that its validity and workability can be ascertained, and

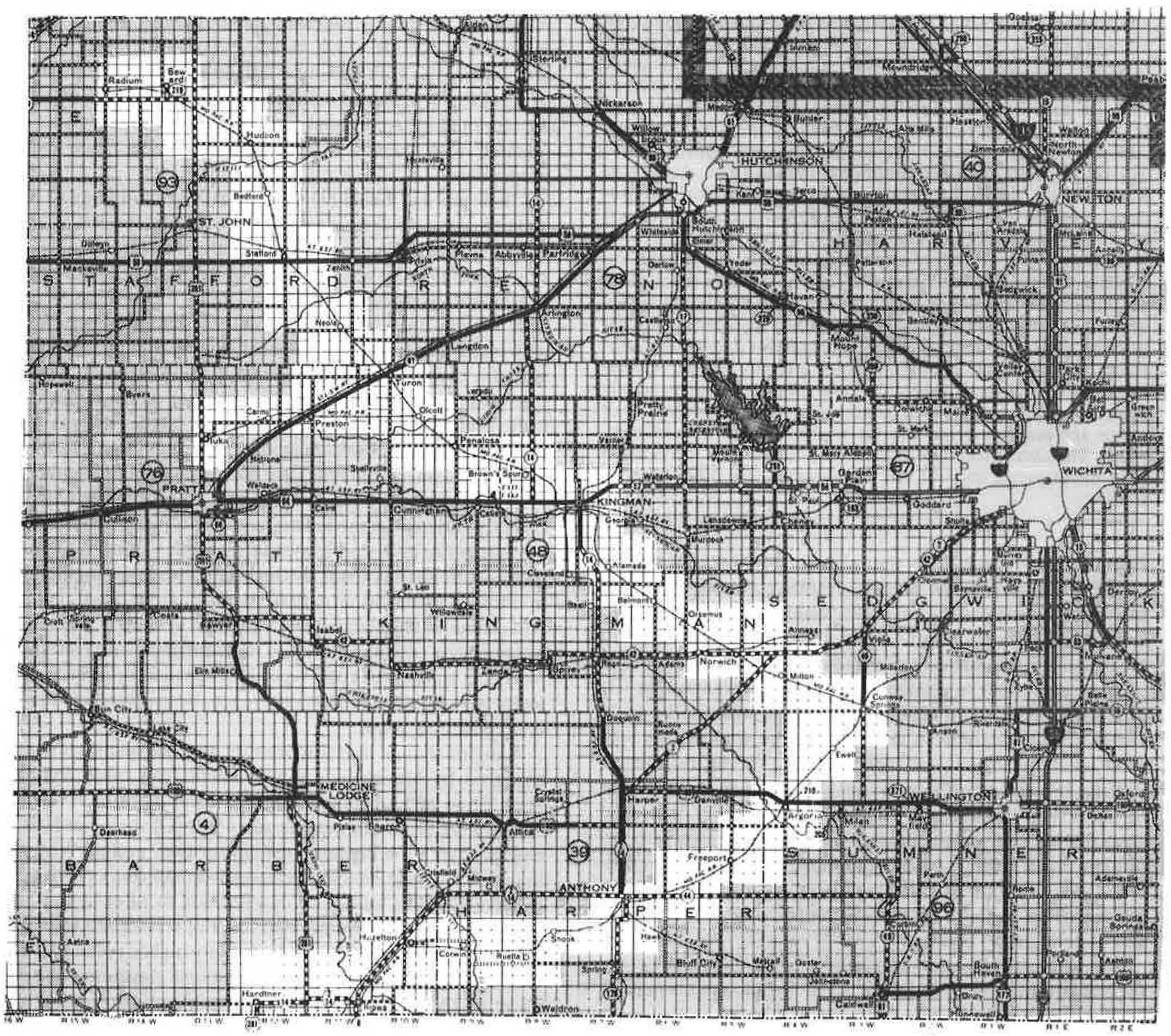

FIGURE 1 Study area.

3. Document the analytical process so that the procedure may be used by other researchers doing similar analyses.

HIGHWAY DETERIORATION PROCESS

There have been many studies (*2–5*) on the cause-and-effect relationship between heavy truck traffic and the degree of highway deterioration. Truck traffic damage to highways varies mostly with truck axle weight and with specific attributes of the highway such as surface thickness, composition of the surfacing materials used, and soil composition. Climatic conditions also affect highway deterioration rates under given traffic and highway conditions. The combined axle damage associated with a particular truck type and commodity hauled over a specific highway section determines the amount of damage attributed to a truck pass. The accumulation of truck passes over time will eventually result in pavement deterioration and the need for rehabilitation of the highway section.

The effective life of a highway section can be seen as a sequence of cycles in which pavements are constructed or restored to some level of condition from which the deterioration process starts all over again. Pavement repair encompasses a range of potential improvement techniques. However, in most cases, resurfacing or rehabilitation entails an overlay of existing pavement with a new asphalt or concrete surface layer. Pavement overlay is assumed in this study when rehabilitation is required. Increased truck traffic resulting from rail branch line abandonment shortens the lifetime of pavements, thereby increasing the need for frequent rehabilitation.

STUDY AREA

The study area located in south-central Kansas comprises parts of six counties (see Figure 1). It is currently being served at most of its shipping points by the MP railroad. Rail service is also provided at a limited number of shipping points by the Atchison, Topeka, and Santa Fe (ATSF) and the Southern Pacific (SP) railroads. All points in the study area are within 100 mi of at least one of three inland grain terminals: Hutchinson and Wichita, Kansas; and Enid, Oklahoma.

Wheat traffic was chosen for analysis in this study for the following reasons. First, wheat is the dominant grain grown in south-central Kansas. Kansas State Board of Agriculture data for 1988 report 74 percent of total grain acreage in the area planted to wheat. Second, Kansas local elevators normally ship 90 percent or more of wheat received from farmers to destinations outside the community in which the grain is produced (*6*). Third, rail transportation dominates the transport of Kansas wheat (*7*). Trucks are readily substitutable for rail on many intrastate movements if rail service is not available or if rail rates are higher than truck rates.

ANALYTICAL PROCEDURES

Transportation Network Model

A network model developed by Chow (*8*) was used to generate traffic flow data for wheat that moved by truck or by rail. This model minimizes shipping costs for a predetermined supply of grain when moved from production origins (simulated farms) to demand centers (domestic and export points) via numerous transhipment points (local and terminal elevators). Both intermodal (rail-truck) and intramodal (rail-rail) competition are generated among the transhipment points.

The model is expressed algebraically as follows:

$$\text{Minimize } Z = \sum_{i=1}^{F}\sum_{j=1}^{C} a_{ij}\text{WF}_{ij} + \sum_{i=1}^{C}\sum_{j=1}^{I} (b_{ij}\text{WC}_{ij} + b'_{ij}\text{WC}'_{ij}) + \sum_{i=1}^{I}\sum_{j=1}^{P+X} (c_{ij}\text{WI}_{ij} + c'_{ij}\text{WI}'_{ij})$$

subject to the following constraints:

1. No stocks will remain at the farm or at transshipment points at the end of 1 year.

$$\sum_{i=1}^{F} \text{WRF}_i - \sum_{i=1}^{F}\sum_{j=1}^{C} \text{WF}_{ij} = 0$$

$$\sum_{i=1}^{C} \text{WRC}_i - \sum_{i=1}^{C}\sum_{j=1}^{I} (\text{WC}_{ij} + \text{WC}'_{ij}) = 0$$

$$\sum_{i=1}^{I} \text{WRI}_i - \sum_{i=1}^{I}\sum_{j=1}^{P+X} (\text{WI}_{ij} + \text{WI}'_{ij}) = 0$$

2. All coefficients a_{ij}, b_{ij}, c_{ij}, . . . > 0.
3. All endogenous variables WF_{ij}, WC_{ij}, WI_{ij}, . . . > 0.

where

Z = total shipment and handling cost;
WF_{ij} = quantity of wheat shipped from Farm i to its next destination j by farm truck;
WC_{ij}, WC'_{ij} = quantities of wheat shipped from country Elevator i to its next destination j by commercial truck and by railroad, respectively;
WI_{ij}, WI'_{ij} = quantities of wheat shipped from inland Terminal i to its next destination j by commercial truck and by railroad, respectively;
a_{ij} = unit shipping cost from Farm i to its next destination j by farm truck;
b_{ij}, b'_{ij} = unit shipping costs from country Elevator i to its next destination j by commercial truck and by railroad, respectively;
c_{ij}, c'_{ij} = unit shipping costs from inland Terminal i to its next destination j by commercial truck and by railroad, respectively;
WRF_i = quantity of wheat received from Farm i;
WRC_i = quantity of wheat received from country Elevator i;
WRI_i = quantity of wheat received from inland Terminal i;
F = number of farms;
C = number of country elevators;
I = number of inland terminal elevators;
P = number of out-of-state processors; and
X = number of export port terminals.

The network model includes 114 simulated farms, 27 country elevators, 3 inland terminals, 1 out-of-state domestic processing point, and 1 export terminal port. The quantity of wheat supplied by the study area was specified from 1987 county production data. The apportioned quantity of wheat from the study area destined for domestic and export markets was estimated from a grain transportation study by the Kansas State Board of Agriculture (*9*). The cost of moving grain by farm truck was obtained from an economic engineering study by Chow (*10*). Commercial truck tariff rates were obtained from the Kansas Motor Carriers Association tariff book (*11*). Railroad tariff rates from the different local elevator points were obtained from published tariff rates by the Kansas City Board of Trade (*12*). Rail contract rates out of terminal elevators were obtained from the 1987 Interstate Commerce Commission Carload Waybill Sample Data. Wheat was assumed to move from farms to final destination points during the July 1987 to June 1988 period.

Two sets of grain movement data, each containing specific origin-destination movements by truck, were generated by the network model. The first set was generated from a network model that simulated traffic flow under the assumption of continued MP operations whereas the second set was generated from a model that simulates traffic flow under the assumption of MP branch line abandonment. For each set of data, two types of truck movements were identified: (a) farm to local elevator movement by single-unit, two-axle (SU–2AX) farm trucks over a combination of county, municipal or city, and state road systems; and (b) local elevator to terminal elevator (intercity) movement by commercial five-axle (CO–5AX) trucks over the same combination of roads. For each origin-destination movement of grain by truck, individual highway sections were identified and combined to form the shortest highway route and the total number of annual truck trips over these routes were calculated by dividing total volume of grain moved by the truck capacity. Route identification and total trips were determined for each of the two sets of traffic data generated.

Measuring Pavement Life

Relating road life with degree of road damage requires the use of a common unit of measurement. Thus, the effective life of a highway section and the pavement damage caused by a particular axle configuration and load over the length of the section are expressed in equivalent single-axle loads (ESALs). The effective ESAL life of a highway section can be estimated by the HPMS pavement function as represented by the following equations:

Flexible Pavement

$$\log_{10}(\text{ESALs}) = 9.36 * \log_{10}[\text{SN} + (6/\text{SN})^{0.5}] - 0.20 + G/\beta$$

$$G = \log_{10}[(5 - \text{PSR}_t)/3.5]$$

$$\beta = 0.40 + 1{,}094/[\text{SN} + (6/\text{SN})^{0.5}]^{5.19}$$

Rigid Pavement

$$\log_{10}(\text{ESALs}) = 7.35 * \log_{10}(D + 1) - 0.06 + G/\beta$$

$$G = \log_{10}[(5 - \text{PSR}_t)/3.5]$$

$$\beta = 1 + 16{,}240{,}000/(D + 1)^{8.46}$$

where

- SN = pavement structural number, an abstract index that reflects the composite strength of the layers of the flexible pavement section;
- D = pavement (slab) thickness;
- PSR_t = effective terminal pavement serviceability rating, a composite measure of the highway's condition that, when reached, results in the decision to rehabilitate;
- G = damage index, a function of PSR_t; and
- β = damage function coefficient as estimated by regression analysis.

Pavement data for each highway section were obtained from the Kansas Department of Transportation's (KDOT's) Bureau of Transportation Planning and from various county engineer's offices in south-central Kansas.

Measuring Road Consumption

The consumption of pavement life constitutes an economic cost. In this study, the concept of short-run marginal cost reflects the additional consumption of fixed highway capacity caused by one more axle pass over a highway section. The marginal cost (in ESALs) of an axle pass is determined for vehicles of different axle groups and loads. The individual marginal costs for each axle group of a truck are then summed to reflect a truck pass for a particular vehicle class. Total road damage attributable to a certain class of traffic is the sum of the costs of all individual truck trips for that class of traffic.

For calculating the degree of road damage of a particular highway section, the average loaded and empty weights for each axle group were obtained from statewide truck weight data.

The AASHO traffic equivalency formulas were then used to convert the average loaded and empty axle loads into axle-specific marginal cost (in ESALs) given the strength and condition rating of each highway section (*13*). The formulas for single axles are as follows:

Flexible Pavement

$$\log_{10}(N_r/N_x) = 4.79 * \log_{10}(L_x + 1) - 4.79 * \log_{10}(L_r + 1) + G/\beta_r - G/\beta_x$$

$$G = \log_{10}[(5 - \text{PSR})/3.5]$$

Rigid Pavement

$$\log_{10}(N_r/N_x) = 4.62 * \log_{10}(L_x + 1) - 4.62 * \log_{10}(L_r + 1) + G/\beta_r - G/\beta_x$$

where

$\log_{10}(N_r/N_x)$ = log of the traffic equivalency formula;

L_r = reference axle weight (18 kips);
L_x = axle weight (kips); and
PSR = present pavement serviceability rating.

The corresponding formulas for the tandem axles are as follows:

Flexible Pavement

$$\log_{10}(N_r/N_x) = 4.79 * \log_{10}(L_x + 2) - 4.79 * \log(L_r + 1) - 4.33 * \log_{10}(2) + G/\beta_r - G/\beta_x$$

Rigid Pavement

$$\log_{10}(N_r/N_x) = 4.62 * \log_{10}(L_x + 2) - 4.62 * \log_{10}(L_r + 1) - 3.28 * \log_{10}(2) + G/\beta_r - G/\beta_x$$

The damage function coefficient β is as follows:

Flexible Pavement

$$\beta = 0.40 + 0.081\ (L1 + L2)^{3.23}/[(SN + (6/SN)^{0.5})^{5.19}L2^{3.23}]$$

Rigid Pavement

$$\beta = 1 + 3.63(L1 + L2)^{5.20}/[(D + 1)^{8.46}L2^{3.62}]$$

where

L1 = the axle load (kips); and
L2 = axle type (1 = the single axle, 2 = tandem axle).

The damage function coefficient β is computed with respect to the reference axle β_r and axle group (β_x), i.e., single or tandem axle.

The empty and loaded ESALs for each axle group were calculated using the preceding formulas. The empty and loaded ESALs were then summed for all axle groups to obtain the degree of road damage per round-trip vehicle-mile traveled (VMT) for a given road segment. The number of annual truck trips for a given road segment (as derived from the network model) multiplied by the road damage (in ESALs) per round-trip VMT equals the total annual damage for the road segment. Two sets of road damage calculations were done to obtain the degree of road damage before and after branch line abandonment.

Measuring Truck Accountability

The cost responsibility of trucks for pavement damage for each road segment is the product of pavement rehabilitation cost per ESAL-mile, road damage (in annual ESALs) and the number of miles for the segment. Estimated pavement rehabilitation costs per mile by road classification were obtained from KDOT's Bureau of Management and Budget. Pavement rehabilitation cost per ESAL-mile was obtained by dividing per-mile pavement rehabilitation cost by the effective ESAL life (as calculated by the HPMS damage function).

Two sets of truck-accountable road damage costs were calculated because of the difference in road use by trucks before and after rail abandonment. The impact of rail branch line abandonment on rural highways is the difference between the truck-accountable costs before and after abandonment.

RESULTS AND CONCLUSIONS

Abandoning the MP branch lines in south-central Kansas will mean an increase in average distance traveled from farms to study area elevators of from 4.7 to 7.0 mi. Most of the increase in distance traveled can be explained by an increase in wheat moved from farms to elevators retaining rail (ATSF and SP) service. Movement to elevators that lost rail (MP) service is reduced.

Abandoning the MP branch lines in south-central Kansas will mean an additional 740,000 bushels of wheat transported by trucks out of local elevators to terminal elevator transit points for shipments by rail or truck to final destination points. These additional shipments represent a 42 percent increase in grain moved by trucks from local elevators. To some extent, the amount of grain traffic diverted from rails to trucks is held down by increased wheat receipts from local elevators with rail access points to ATSF and SP.

Truck-accountable road damage costs associated with pre- and postabandonment periods for farm-to-elevator and intercity movements are presented in Tables 1 and 2, respectively. These costs are categorized by (a) road system, to reflect the level of government jurisdiction; and (b) road type, to reflect differences in structure and design among Kansas roads. Abandoning the designated branch lines in south-central Kansas is estimated to result in additional annual truck damage to Kansas rural highways amounting to $138,274, a 43 percent increase in farm-to-elevator delivery truck-accountable costs (see Table 1). Incremental truck damage to roads is attributed to farmers trucking their wheat over longer distances to local elevators—an average increase of 49 percent over the preabandonment period.

Abandoning the designated lines is estimated to result in an additional annual truck damage to Kansas rural highways amounting to $55,961 for intercity movements of wheat. This amount represents the highway use cost of hauling wheat diverted to trucks, a 24 percent increase in truck damage cost over the preabandonment period. The increase in truck-accountable road damage cost can be attributed to additional truck traffic resulting from grain diversion from rails to trucks.

Last, the cost of rail abandonment was converted in a bushel-mile cost of moving wheat by truck (see Table 3). Abandonment of the branch lines will result in additional truck damage to Kansas rural highways amounting to 0.90 cent per bushel-mile of wheat moved for farm-to-elevator movements and 0.17 cent per bushel-mile moved for intercity movements. Study results indicate that the intercity roads, in general, are better designed to handle increases in traffic than local roads.

Minor arterials and other principal arterials make up about 77 percent of the total miles of state road maintained in south-central Kansas. Many of these roads were not designed to handle heavy trucks. Grain trucks cause road damage cost to increase rapidly on roads not designated for heavy vehicles. The majority of farm-to-elevator roads are local roads, collectors, and minor arterials. On the other hand, incremental road damage cost for intercity grain traffic could have been

TABLE 1 ANNUAL PAVEMENT DAMAGE COSTS FOR FARM-TO-ELEVATOR GRAIN MOVEMENT, BY ROAD SYSTEM AND ROAD TYPE, FOR PRE- AND POSTABANDONMENT PERIODS

Road/System Road Type	Pavement Damage Costs ($) Pre-Abandonment	Post-Abandonment	Abandonment Cost ($)
State			
Arterial	299,688	430,559	130,871
Collector	3,982	7,039	3,057
Interstate	-	-	-
Sub-Total	303,670	437,598	133,928
Municipal/City			
Arterial	127	255	127
Collector	-	-	-
Interstate	-	-	-
Sub-Total	127	255	127
County			
Local	17,584	21,802	4,218
Sub-Total	17,584	21,802	4,218
Total	321,381	459,655	138,274

TABLE 2 ANNUAL PAVEMENT DAMAGE COSTS FOR INTERCITY GRAIN MOVEMENT, BY ROAD SYSTEM AND ROAD TYPE, FOR PRE- AND POSTABANDONMENT PERIODS

Road System/ Road Type	Pavement Damage Costs ($) Pre-Abandonment	Post-Abandonment	Abandonment Cost ($)
State			
Arterial	231,657	280,580	48,924
Collector	2,522	4,398	1,876
Interstate	650	456	(193)
Sub-Total	234,828	285,435	50,607
Municipal/City			
Arterial	1,794	1,752	(42)
Collector	-	-	-
Interstate	-	-	-
Sub-Total	1,794	1,752	(42)
County			
Local	733	6,129	5,395
Sub-Total	733	6,129	5,395
Total	237,355	293,316	55,961

much more had not some portion of traffic traveled on roads designed to handle heavy loads. These highway routes include some major arterial sections along U.S. Highway 50 (southwest of Hutchinson) and U.S. Highway 54 (west of Wichita).

The goal of public policy is to come up with measures to minimize damages to Kansas roads resulting from shifts in modal choice and traffic patterns that result from rail abandonments. Two general choices come to mind: (a) a state-supported short-line rail program to keep branch line abandonments to a minimum, and (b) additional road funding to upgrade roads in areas facing severe impacts from rail branch line abandonment.

This analysis demonstrates the usefulness of the methodology for estimating additional truck damage to Kansas roads in the event of branch line abandonment. This methodology will enable planners and policymakers to determine the impact of proposed abandonments and hence will provide an additional decision tool for use in choosing among various alternative strategies for responding to decisions by rail carriers to abandon service on branch lines in Kansas.

TABLE 3 PAVEMENT DAMAGE COST (IN CENTS PER BUSHEL-MILE) CAUSED BY RAIL ABANDONMENT, BY MOVEMENT TYPE

Movement Type/ Road System	Abandonment Cost (in cent/bu-mile)
Farm-to-Elevator	
State	0.87
Municipal/City	0.00
County	0.03
Sub-Total	0.90
Elevator-to-Market	
State	0.15
Municipal/City	-
County	0.02
Sub-Total	0.17

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Economic Evaluation of Toll Plaza Operations

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Costs and revenues for conventional toll plaza operations are examined. Information on highway user costs is assembled and incorporated into the economic evaluation. An analytical method is presented for estimating user costs of toll plaza operations. Applied to an example scenario, the method indicates that conventional toll collection systems are inherently economically infeasible. The amount of toll to be charged should be a function of vehicular demand as well as the implied value of time.

The New Transportation Policy (NTP) statement unveiled in March of 1990 emphasizes the need for increased investment in the U.S. transportation system. At the same time, NTP appears to suggest a declining role in federal funding level as proportional to the total funds required. The state and local governments are therefore left to find the additional dollars needed for transportation improvement investments (*1*). Among the fund-raising mechanisms available to state and local governments is collection of tolls. The potential exists for a significant increase in the number of toll-operated facilities across the nation.

Roadway toll collection is popular for a number of reasons. First, toll-funded projects can be implemented considerably faster than tax-supported projects. Complete funding is available at the start and toll projects do not necessarily have to comply with federal regulations. In addition, the pay-as-you-go financing constitutes perhaps the most equitable financing mechanism. Finally, ready access to funds usually translates to better maintained facilities.

Despite these advantages, a toll-financed facility generally results in increased user costs because of capacity reductions, increases in delay, emissions, and accidents. The user cost at toll facilities, particularly at high demand levels can indeed exceed revenues generated.

Because of the costs, the need exists to develop efficient means of toll collection. As a first step, the actual cost incurred by users from the toll collection operation itself must be assessed. Revenues must be compared to the overall cost of operating toll facilities including the user as well as environmental costs. The operation of conventional highway toll plazas is examined in this spirit. A methodology is presented for assessment of the overall user cost of toll booth operations as a basis for decisions such as the number of toll booths to be opened and the amount of toll to be charged. In addition, the methodology may be used to examine the feasibility of automatic vehicle identification (AVI) and other innovative toll collection strategies.

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TOLL SYSTEM CAPACITY

An accurate assessment of capacity in a toll booth thus involves the consideration of factors such as vehicular composition, driver behavior, and degree of congestion. However, the capacity of a toll booth can be adequately approximated as a percent of the service rate.

The range of service rate values for toll booths that are commonly used in the design of a toll plaza are as follows:

Type of Booth	*Volume (veh/hr)*
Manned	600– 700
Exact-change	700– 800
Heavy-vehicle	300– 400
Tandem	900–1,000

These ranges were obtained from values suggested by Wood and Hamilton (*2*), Hall and Daganzo (*3*), and Larsen (*4*).

The capacity of a toll plaza may be determined by adding the capacity of each one of the booths; however, the distribution of vehicles before the plaza should be considered as well. For example, Wood and Hamilton (*2*) point out that the patronage of toll booths in outer lanes is lower than that in the central lanes, even under congested conditions.

Several measures can be taken to increase the capacity of a toll plaza. Among them, the most frequently implemented are as follows:

1. Use of exact-change booths,
2. Use of tandem toll booths,
3. Use of tokens,
4. Widening of the toll plaza approach,
5. Exemption of high-occupancy vehicles,
6. Sorting of vehicles, and
7. Fixing the toll amount to nonfractionary values.

Despite such measures to increase capacity, toll plazas at high-speed, high-demand roadways constitute major bottleneck points. In heavily traveled corridors, collection of tolls often results in substantial delays to travelers. In the following sections, the magnitude of the cost to users caused by toll collection is quantified. A typical toll collection scenario is examined and user costs are estimated. Cost-revenue comparisons are made and a number of toll collection strategies are addressed.

TOLL COLLECTION COSTS

The cost of collecting roadway tolls can be classified into three categories: operating cost, user cost, and environmental cost.

Operator salaries, facility operation and maintenance costs, and revenue processing fees are the major operating cost items to be considered. The user cost sources include fuel and oil consumption, tire wear, vehicle maintenance and repair, depreciation, accidents, and delay. The environmental costs are associated with excess emissions and noise pollution at toll facilities.

The operating cost of toll facilities is highly variable depending on, among other factors, the number of employees, the location and number of booths, and the collection mechanism. For purposes of this study, a value of $500 per hour of operation is used. The use of other hourly rates would require a linear adjustment proportional to the hours of operation and to the total cost estimates. However, the total toll facility operating cost is minimal when compared to the user cost values. On the other hand, the environmental cost caused by toll plaza operations is difficult to assess and will only be reported in the amounts of various pollutants generated.

The user cost estimation entails a number of user cost models. Because of the large number of vehicles affected, user cost rates and models must be accurate. A selection of such models considered to provide reliable user cost estimates are discussed in the following sections.

Fuel Consumption

Excess fuel is consumed because of the deceleration and acceleration maneuvers as well as the waiting in queue and while in service before a toll barrier. The model suggested to measure the excess fuel consumed is as follows (*5*):

$$\mathrm{FC} = I_F D_S + N S_F(v) \quad (1)$$

where

FC = fuel consumption (gal),
I_F = idle fuel flow rate per 1,000 hr,
D_s = total stopped delay (veh-hr),
N = number of vehicles joining the queue, and
$S_F(v)$ = fuel consumed during the deceleration and acceleration cycle starting from speed v (gal per 1,000 stops).

Tables 1 and 2 present typical values of I_F and S_F, respectively.

Oil Consumption

Compared to other vehicle operating costs, engine oil cost is among the lowest. Oil consumption rate is influenced by a number of factors including vehicle age, driver characteristics, roadway alignment, and ambient and engine temperatures. Speed changes also induce additional oil consumption.

The model used here includes two variables most pertinent to the toll plaza operations, namely, delay and number of stops, as follows:

$$\mathrm{OC} = I_o D_S + N S_o(v) \quad (2)$$

where

OC = oil consumed (qt),
I_o = oil consumed during idling per 1000 veh-hr, and
$S_o(v)$ = oil consumed during the deceleration-acceleration cycle starting from speed v (qt per 1,000 stops).

Typical values of I_o and S_o are presented in Tables 1 and 2, respectively.

Tire Wear

Tire wear is mainly a function of distance traveled, driving surface, roadway geometry, speed changes, weather conditions, and speed change cycles. This last factor is the only

TABLE 1 VEHICULAR IDLING COST AND EMISSIONS COMPONENTS PER 1,000 hr (*5*)

Cost Item	Vehicle Type							
	Small Car	Medium Car	Large Car	Pickup	2-Axle SU	3-Axle SU	2-Axle Trailer	3-Axle Trailer
Oil (quarts)	5.8	5.8	5.8	3.5	3.2	3.46	3.46	3.46
Maintenance and Repair (% of average cost per 1000 miles)	57	57	59	60	23	26	24	24
Depreciation (% of new price)	0.81	0.81	0.81	0.50	1.10	1.10	0.38	0.38
Fuel (gallons)	271	563	563	756	1198	398	470	470
Carbon Monoxide (tons)	1.105	1.105	1.105	1.105	1.105*	1.105*	1.105*	1.105*
Hydrocarbons (tons)	0.073	0.073	0.073	0.073	0.073*	0.073*	0.073*	0.073*
Nitrogen Oxides (tons)	0.023	0.023	0.023	0.023	0.023*	0.023*	0.023*	0.023*

*Rates assumed equal to the ones for light vehicles.

Note: Emission rates are suggested by Dale (11).

TABLE 2 TYPICAL UNIT COST VALUES FOR A STOPPING DECELERATION-ACCELERATION CYCLE FROM 65 mph FOR VARIOUS VEHICLE TYPES (5)

Cost Item	Vehicle Type							
	Small Car	Medium Car	Large Car	Pickup	2-Axle SU	3-Axle SU	2-Axle Trailer	3-Axle Trailer
Fuel Consumption (gal/1000 stops)	15.60	24.30	28.30	30.20	123.00	168.00	179.00	217.00
Oil Consumption (quarts/1000 stops)	0.046	0.042	0.039	0.039	0.182	0.361	0.361	0.662
Tire Wear (% worn/1000 stops)	2.43	2.97	3.64	2.93	4.46	3.11	2.57	3.29
Depreciation (% of Price of new veh/1000 stops)	0.027	0.018	0.013	0.013	0.024	0.031	0.013	0.013
Maintenance & Repair (% avg. cost/1000 stops)	5.51	5.61	5.28	5.52	5.28	5.18	5.63	6.78
Carbon Monoxide (tons/million stops)	36.0	37.0	40.0	35.0	130.0	36.0	37.0	15.0
Hydrocarbons (tons/million stops)	9.0	9.0	8.9	8.7	9.0	14.0	5.4	3.6
Nitrous Oxides (tons/million stops)	52.0	52.0	51.0	51.0	10.0	42.0	67.0	87.0

one of relevant importance in this analysis, as it accounts for the stopping maneuver before toll booths. On this basis, the model used to evaluate tire wear is

$$\mathrm{TW} = NS_{\mathrm{TW}}(v) \tag{3}$$

where

TW = number of sets of tires completely worn out, and
$S_{\mathrm{TW}}(v)$ = number of sets worn out during the deceleration-association cycle starting from speed v, in sets per 1000 stops

Typical S_{TW} values are presented in Table 2.

Depreciation

A direct relationship exists between miles traveled by a vehicle and its depreciation. Also, the age of the vehicle is closely related to its depreciation. Because vehicles do not undergo significant depreciation while idling or stopping, the depreciation caused by toll plazas is not a considerable expense compared to the other costs discussed. The depreciation model used is as follows:

$$\mathrm{DP} = I_{\mathrm{DP}}D_s + NS_{\mathrm{DP}}(v) \tag{4}$$

where

DP = number of vehicles completely depreciated,
I_{DP} = depreciation rate while in idle (per 1,000 veh-hr),
$S_{\mathrm{DP}}(v)$ = percentage of depreciation caused by stopping from and resuming speed v.

Typical I_{DP} and S_{DP} values are presented in Tables 1 and 2, respectively. Depreciation cost is obtained as the product of DP and the value of a new vehicle.

Maintenance and Repair

Maintenance and repair expenses are difficult to evaluate, because they depend on the care provided by the owner of the vehicle and the specific conditions under which the vehicle operates. In general, the major cause of repair and maintenance expenses is the engine, followed by chassis, electrical equipment, brakes, body and power train, in the order of importance. Tire wear is considered separately.

Maintenance and repair cost is originated by the two major sources of inconvenience to the toll facilities user, delay and stops. The model is as follows:

$$\mathrm{MR} = I_{\mathrm{MR}}D_S + NS_{\mathrm{MR}}(v) \tag{5}$$

where

MR = percentage of running cost per 1,000 mi,
I_{MR} = percentage of 1,000-mi running cost per 1,000 veh-hr of stopped delay, and
$S_{\mathrm{MR}}(v)$ = percentage of 1,000-mi running cost per 1,000 stops from speed v.

Typical I_{MR} and S_{MR} percentages are presented in Tables 1 and 2, respectively. The 1,000-mi running costs are also presented in Table 3.

The maintenance and repair expense is evaluated as the product of MR and the corresponding running cost per 1,000 mi of travel.

TABLE 3 VEHICULAR UNIT PRICES (1980 U.S. DOLLARS)

Type of vehicle	Oil (quart)	Maintenance and Repair (Average cost per 1000 mi)	Depreciation (New Vehicle)	Fuel (gallon)	Tires** (set)
Small car	2.5	34.30	6360	1.098	43
Medium Car	2.5	41.60	7501	1.098	68
Large Car	2.5	48.04	9990	1.098	75
Pickup	2.5	52.81	6625	1.098	75
2 Axles SU	1.0	99.00	8673	1.098*	194
3 Axles SU	1.0	140.00	45350	0.886*	465
2 Axles Trailer	1.0	145.00	48687	0.886*	465
3 Axles Trailer	1.0	145.00	51630	0.886*	465

*Gas Price = 1.221 - 0.123(tax), Diesel Price = 1.01 - 0.124(tax)

**Truck tire cost includes recaps

Value of Time

Perhaps the most difficult item to evaluate among the ones considered in this analysis is the cost of the time lost by the patrons when waiting before a toll booth. There exists a basic distinction in the way the cost of time is assessed for passenger cars and for trucks. Automobile travel time savings represent nonmarket costs and they are often transformed into opportunities for additional activities, such as additional time for personal business or social activities. On the other hand, for trucks, travel time savings represent market costs.

On this basis, travel time value for a passenger car is a function of trip purpose, traveler's income level, and vehicle occupancy. The *Manual on User Benefit Analysis of Highway and Bus-Transit Improvements* (*6*) suggests a 1-hr value of (1975) U.S. $3.90 for an average trip by a passenger car. This value was obtained from the average hourly family income prevailing in 1975 as well as the adult occupancy factor observed at that time.

For trucks, the value of time is assumed to be equivalent to the wage rate of the driver of the vehicle. According to AASHTO (*6*), the hourly values for single-unit and combination trucks, in 1975 dollars, are $7.00 and $8.00, respectively.

The model which evaluates the time value is as follows:

$$\mathrm{TV} = \mathrm{RVT}(D_S + ND_{\mathrm{AC}}) \tag{6}$$

where

$\mathrm{TV} = \mathrm{UVT}\ (D_S + ND_{\mathrm{AC}})$
TV = time value,
UVT = unit value of time (dollars per hour), and
D_{AC} = delay of the acceleration-deceleration cycle.

Accident Cost

For purposes of this study, only one type of accident is considered, namely, the rear-end collision. This conflict is originated by the stopping maneuver before the toll booths.

A technique developed by Brown (*7*) to predict accidents at an intersection is used here, because the stopping maneuvers are similar at an intersection and before a toll booth.

Brown suggests the following model for an intersection:

$$\mathrm{AC} = Rk(X_iX_j)^{1/2} \tag{7}$$

where

AC = number of accidents per million vehicles,
R = constant that depends on the type of accident, and
k = regression constant that accounts for variations of the vehicular flow in 1 year.
X_i, X_j = two conflicting movements (veh/hr).

Brown (*7*) obtained a mean k value of 0.0227 with a standard deviation of 0.0017 and a mean standard error of 0.000555. For rear-end collisions, R = 0.7. The quantity $(X_iX_j)^{1/2}$ is equal to the number (N) of vehicles arriving at the toll plaza. So the number of rear-end collisions before a toll barrier can be estimated as

$$\mathrm{Acc} = 0.01589 \times 10^{-6}\, N \tag{8}$$

Accidents are divided into three major types according to their severity:

1. Fatal,
2. Injury (nonfatal), and
3. Property damage.

Accident costs cited by NHTSA (*8*) are as follows:

Accident Type	*Cost (1975 U.S. Dollars)*
Fatal	307,210
Injury	14,600
Property damage	650

More up-to-date accident cost values have been provided by Rollins and McFarland (*9*).

Meyers (*10*) presents accident data obtained from a survey conducted between 1976 and 1978. In this survey, data from

21 toll expressways were collected. Table 4 presents the percentages of occurrences computed from the values given by Rollins and McFarland (*9*).

The cost per accident is the summation of the products of costs and percentages of occurrences corresponding to three types of accident, as follows:

$$C_{acc} = C_{fat}P_{fat} + C_{inj}P_{inj} + C_{pd}P_{pd} \tag{9}$$

where

C_{acc} = cost per accident ($),
C_{fat} = cost of a fatal accident ($),
P_{fat} = occurrence percentage of a fatal accident,
C_{inj} = cost of an injury accident,
P_{inj} = occurrence percentage of an injury accident,
C_{pd} = cost of a property damage accident, and
P_{pd} = occurrence percentage of a property damage accident.

The unit cost obtained in Equation 9 is multiplied by the number of accidents computed using Equation 8 to estimate the total accident cost.

TOXIC EMISSIONS MODELS

Vehicular emissions constitute a major source of environmental pollution. In this work, models to evaluate carbon monoxide, hydrocarbons, and oxides of nitrogen are presented. However, no attempt is made to estimate the cost of the environmental deterioration caused by these vehicular emissions. Carbon monoxide and hydrocarbon emissions result from incomplete combustion of fuel during the operation of internal combustion engines. Oxides of nitrogen are produced when the oxygen and nitrogen in the air used by internal combustion engines combine under the heat and pressure of the combustion process.

The emission model for carbon monoxide is

$$ECO = I_{CO}D_S + NS_{CO}(v) \tag{10}$$

where

ECO = total carbon monoxide emitted (lb),
I_{CO} = carbon monoxide emission per 1,000 veh-hr (lb), and
$S_{CO}(v)$ = carbon monoxide emitted per 1,000 stops from speed v (lb).

Hydrocarbons emitted are evaluated according to the following model:

$$EHC = I_{HC}D_s + NS_{HC}(v) \tag{11}$$

where

EHC = total hydrocarbons emitted (lb),
I_{HC} = hydrocarbon emission per 1,000 veh-hr (lb), and
$S_{HC}(v)$ = hydrocarbon emission per 1,000 stops from speed v (lb).

The model used to estimate nitrogen oxide emissions is

$$ENOX = I_{NOX}\, D_S + NS_{NOX}(v) \tag{12}$$

where

ENOX = nitrogen oxide emitted (lb),
I_{NOX} = NOX emissions per 1,000 veh-hr, and
$S_{NOX}(V)$ = nitrogen oxides emitted per 1,000 stops from speed v.

The variables in these emissions models are presented in Table 2 for several types of vehicles. The values caused by stopping were provided by Zaniewsky et al. (*5*). Dale (*11*) suggests the values presented in Table 1 for emissions from idling time.

REVENUE ESTIMATION

Revenue, the amount of money collected by the toll charging system, is computed as

$$\text{Rev}_i = \left(\sum_{j=1}^{m} \text{Toll}_j \cdot p_j\right)(N_i - Q_i) \tag{13}$$

where

Rev_i = total revenue at the end of the ith time interval ($),
Toll_j = toll for a vehicle of Class j ($),
P_j = percentage of vehicles of Class j,
m = number of classes of vehicles considered,
N_i = number of vehicles that have arrived at t_i, and
Q_i = number of vehicles waiting to pay at t_i.

A value of revenue can be computed for every time interval, and then compared to the value of total user cost obtained as described in the following section.

USER COST EVALUATION

Interactive software has been developed to estimate costs and revenues of a toll system using the models and unit costs discussed earlier. The user, however, can specify unit costs other than the default values. Also to be specified are the capacity of the toll facility, the mix of vehicles, and the vehicular demand in terms of number of vehicles approaching the toll plaza during constant time intervals. No limit is placed on the time interval duration.

TABLE 4 ACCIDENT RATES

Class of Severity	Passenger Cars	Light Trucks	Heavy Trucks
Fatal	1.2	1.6	1.6
Injury	32.9	29.7	28.5
Property Damage	65.9	68.7	69.9

Figure 1 shows the steps for determining total user costs and revenues. Table 5 presents the default values related to light and heavy vehicles that were used in cost computations. Other default values used were as follows:

Item	*Value*
Manned-booth service rate	550 veh/hr
Exact-change-booth service rate	650 veh/hr
Accidents per million vehicles	0.01589
Fatal accident cost	$654,350
Nonfatal accident cost	$31,100
Property damage accident cost	$1,350

All unit cost values were in 1988 U.S. dollars. Once costs and revenues are computed, a break-even toll can be determined as the amount of toll per vehicle required to overcome the user and administrative costs.

A scenario is studied in which four manned and four exact change booths are in operation. A 7 a.m. to 5 p.m. period is studied. Figure 2 shows the input data for this scenario including toll booth capacities, vehicular mix, value of time, initial speed, accident rate and cost, unit administrative cost, and vehicle unit cost values. Figure 3 shows the pattern of vehicle arrivals at the plaza in 15-min intervals.

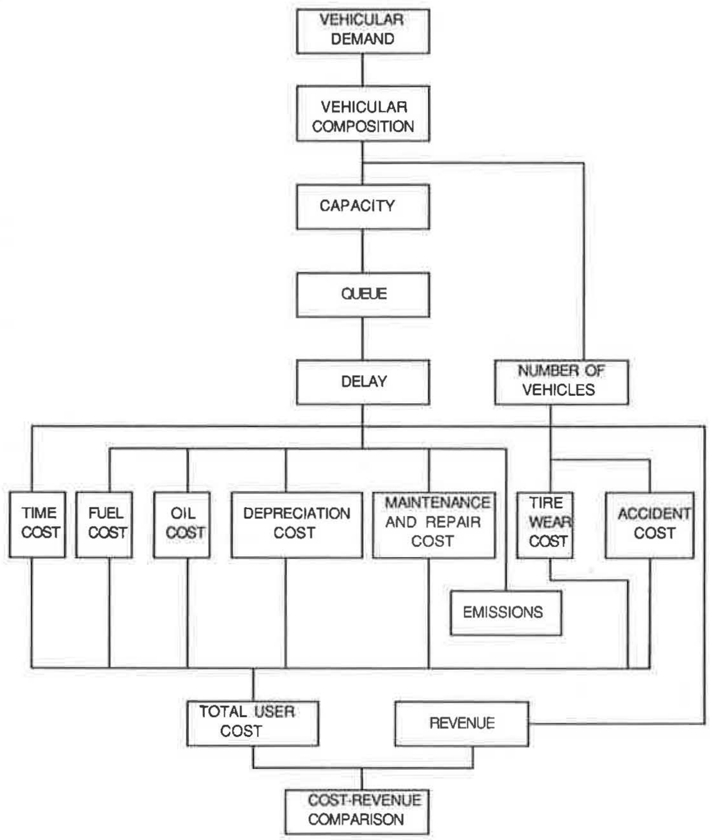

FIGURE 1 User cost evaluation methodology.

TABLE 5 DEFAULT VALUES USED FOR LIGHT AND HEAVY VEHICLES

	Light Vehicles	Heavy Vehicles
Fuel Cost (dollars/gal)	1.01	0.89
Oil Cost (dollars/quart)	2.5	1.0
Tires (dollars/set)	105	636
1000 mi. running cost (dollars)	70.7	212
New vehicles cost (dollars)	12,190	61,736
Value of time (dollars/hr)	8.3	16
Acceleration rate (mph/sec)	5	2
Deceleration rate (mph/sec)	10	7

```
        PERIOD OF STUDY

Initial time     7:00
Ending time     17:00
Time increment   0:15

        TOLL PLAZA CAPACITY

# of manned booths        4          Capacity (veh/hr)  550
# of exact change booths  4          Capacity (veh/hr)  650

        VEHICULAR COMPOSITION

Percentage of Heavy Vehicles          : 15.0
Percentage of High Occupancy Vehicles:  0.0

        VALUE OF TIME AND SPEED

                              LIGHT VEHICLES    HEAVY VEHICLES

VALUE OF TIME
Dollars/hour                        8.30              16.00
SPEED STOPPED FROM
AND RESUMED TO (mph):              65.00              55.00
ACCELERATION RATE (mph/sec):        5.00               2.00
DECELERATION RATE (mph/sec):       10.00               7.00

        ACCIDENT  RATE AND COSTS

Accident Rate (acc/millions of vehs)  .01589
Fatal Accident Cost:               654350.00
Non-Fatal Accident Cost:            31100.00
Property Damage Accident Cost:       1350.00

        OPERATION VALUES

Toll Plaza Operation cost (dollars/hour):     500.00
Toll per light vehicle (dollars/veh):           0.75
Toll per heavy vehicle (dollars/veh):           2.00
```

FIGURE 2 Input data echo.

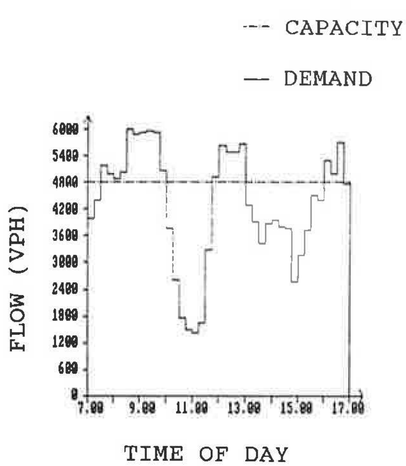

FIGURE 3 Vehicular demand.

The queue length at the end of each period and the corresponding total delay incurred are then computed using an input-output analysis of vehicular demand versus the toll plaza capacity. Table 6 presents the resulting accumulated user and administration costs for light and heavy vehicles for the entire study period. The revenue collected and total emissions are also output, as follows:

Item	*Amount (U.S. dollars)*
Gross revenue	40,095.00
Administration cost	5,000.00
User cost	40,095.95
Net revenue	−5,000.94
Break-even toll per car	0.92
Break-even toll per truck	1.74

Compound	*Emission (lb)*
Carbon monoxide	25,981.5
Hydrocarbons	2,451.2
Nitrogen oxides	7,640.0

TABLE 6 COST SUMMARY OUTPUT FOR LIGHT AND HEAVY VEHICLES

Cost Item	Light Vehicles	Heavy Vehicles	Total ($)
Fuel	2,601.92	1,055.58	3,657.51
Accident cost	11.06	2.11	13.17
Oil	44.53	3.70	48.22
Maintenance	256.74	81.87	338.61
Depreciation	357.32	314.75	672.07
Value of time	26,186.09	8,959.25	35,145.34
Tire wear	115.19	105.83	221.02
Total user cost	29,572.85	10,523.09	40,095.95

In this example, the major user cost is the user time ($35,145), followed by fuel ($3,657); the remaining costs do not significantly contribute to the total user cost amount. The sum of the user and administration costs ($45,096) is higher than the gross revenue ($40,095). The listing also indicates the tolls to be charged to obtain a benefit-cost ratio of one ($0.92 per car and $1.74 per truck for the conditions in this scenario).

Figure 3 shows the variation of the vehicular flow arriving at the toll plaza. In this figure, the three periods during which the capacity is less than the vehicular arrival rate can be easily identified. The pattern of the variation of the queue generated is shown in Figure 4. The three different queues created correspond to the congestion periods observed in Figure 3. Figure 5 shows a comparison of the gross revenue and the user cost. According to this figure, for the period between 7:00 and 9:30 a.m. the total revenue collected is higher than the total user cost incurred; however, for almost the rest of the analysis period the user cost surpasses the gross revenue, particularly following the congested periods.

Figures 6 and 7 show the variations of the break-even toll for light and heavy vehicles, respectively. Comparing these two graphs with that of the queue length shown in Figure 4, it can be seen that the maximum points in these curves occur almost at the same time, thus indicating that a close relationship exists between break-even toll and vehicular arrival rate. The difference in the occurrence of the maximum points between the queue curve and the break-even toll curves is caused by the decrease in the level of demand.

As the vehicular arrival rate decreases, the administration cost per vehicle per hour increases; therefore, the value of the total cost per vehicle remains high until the unit user cost is decreased significantly.

The scenario discussed demonstrates how, even for small values of average delay (less than 5 min per vehicle), the user cost can easily surpass the revenues generated. Particularly significant is the fact that around 85 percent of the user cost is caused by the time lost by the drivers while waiting to pay. If this cost had not been considered, the revenue would have easily exceeded the total cost.

On the basis of these results, the toll to be charged to overcome the user cost or the total administration and user cost can be examined. A family of curves is generated to determine the break-even toll for the toll plaza conditions and unit cost values presented in Figure 2. Only user costs are considered because they are the major component of the total cost.

Figures 8 and 9 show the value of time as a variable ranging from $5/hr to $15/hr. In Figure 8, the break-even toll (based

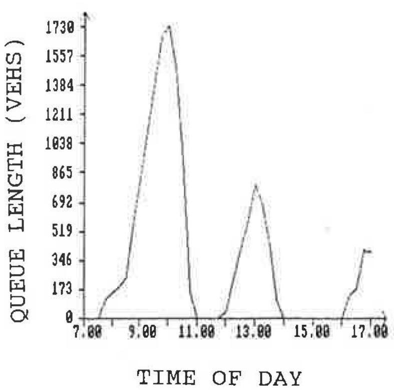

FIGURE 4 Queue length dynamics.

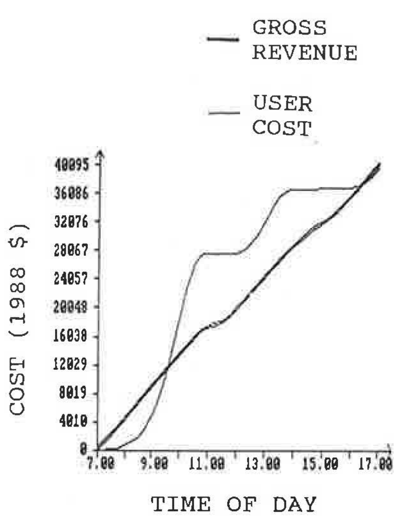

FIGURE 5 User cost-revenue.

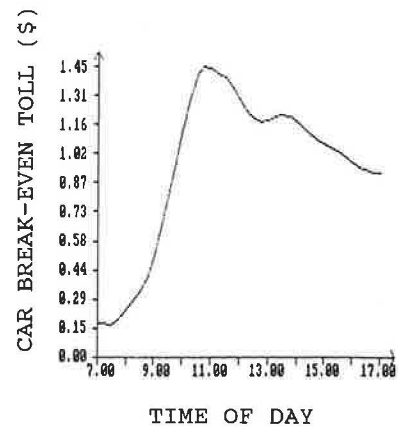

FIGURE 6 Break-even toll variation for light vehicles.

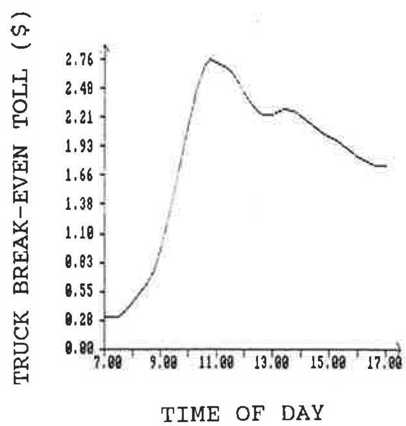

FIGURE 7 Break-even toll variation for heavy vehicles.

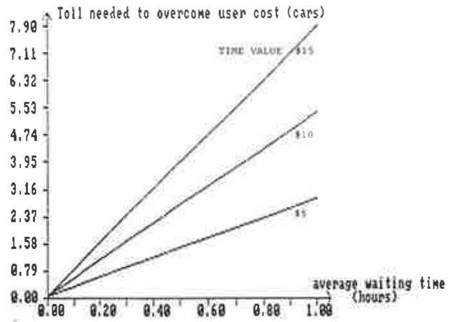

FIGURE 8 Toll to be charged as a function of waiting time in queue.

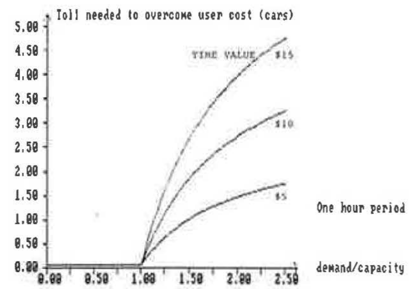

FIGURE 9 Toll to be charged as a function of the demand-capacity ratio for some values of times.

on user cost) plotted as a function of the average delay per vehicle indicates a linear relation between the two variables. On the other hand, Figure 9 shows the break-even toll versus the demand-capacity ratio. Both figures suggest that to compensate for user costs, higher tolls should be charged at higher demand levels. However, as shown in Figure 9, the toll values are asymptotic at high demand-capacity values. For example, at a $5/hr value of time, the asymptotic toll amount is about $1.50 per car, versus about $3.50 per car for a $10/hr value of time. These values assume that the demand-capacity values specified persist for a 1-hr period.

SUMMARY AND DISCUSSION

An attempt has been made to assess the cost incurred by drivers when using a toll facility. A major concern has been to provide estimation models for all the possible cost generators, even if, as observed for some items, the contribution to the total user cost is relatively small.

For the economic analysis described, variables such as degree of congestion and vehicular composition should be taken into account in the evaluation of the toll plaza capacity. Including these variables would constitute research in itself, because the literature on toll facility operations is not extensive. If a criterion to assess a unit cost for toxic emissions is eventually set, the effectiveness of the procedure described could also be significantly enhanced.

A major contribution of this work has been the collection and synthesis of a large amount of scattered information on highway user costs and their incorporation into the economic analysis of toll plaza operations. The procedure described can be easily applied to determine the cost-effectiveness of the charging process in a toll plaza. Furthermore, its use could be expanded to a whole set of toll collection points, allowing the evaluation of a complete collection system.

The break-even toll has been defined as the toll to be charged to compensate for the toll collection cost. The user cost has been used in this study as the basis for calculating the break-even toll because it constitutes a major portion (up to 90 percent) of the total toll collection cost. The break-even toll may be considered in setting the toll value for a facility. For example, the toll authority may define a total toll cost as the sum of the toll to be charged and the break-even toll. The policy may then be to set the toll value such that the so-defined total toll cost will not exceed the excess travel cost on alternative routes. From this viewpoint, tolls could only be increased if the facility operator took actions to reduce user and other costs or if the travel cost on alternative routes increased.

This methodology is also useful in assessing the economic feasibility of an AVI method and in setting demand-related variable toll charges for AVI systems. A study carried out by the Hong Kong government (*12*) indicated that there are no major technological barriers for the implementation of an AVI system; however, its introduction depends on political considerations (*13*) as well as the economical advantages it could offer compared with traditional charging systems. One such economic advantage is the reduction or elimination of the user costs evaluated in this research.

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Quantitative Method for Road Investment Policy Analysis

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Preliminary research addresses the question of whether highway departments allocate their limited funds consistent with maintenance and congestion demands. The approach uses a model explaining a state's highway budget allocation to the various counties within the state. Explanatory variables are volume of usage, congestion, and road deterioration in each county. The coefficients of the estimated model enable an interpretation of the influences underlying state roadway policy. The state used for this research is Florida. The model was estimated twice, once with Interstate highway data for each county, and once with state highway data, not including Interstates. Results for both estimations were similar, although stronger for the Interstate estimation. The number of urban lane–miles that a county has explains the size of highway budgets more than any of the other variables does. This result runs counter to the expectation that more congestion would induce greater construction and operational spending to relieve it. The results also suggest that truck-caused damage is being insufficiently addressed. Results are preliminary and more experience is needed with this approach before its veracity can be judged.

Most transportation analysts agree that the escalating highway financial shortfall results from the failure of highway users to pay their way. User fees fail to pay for user-caused road and bridge deterioration, as well as for delays that every user imposes on every other user. They also fail to pay for other externalities. In the past, those who did not benefit directly from roads paid for many of the cost liabilities that users imposed on the system, as did those suffering externalities. Increasingly, however, nonusers resist subsidizing users, while those suffering externalities succeed in gaining compensation from road budgets. User-caused cost liabilities thus remain increasingly unfunded. Inflation compounds the problem.

Highway departments also may compound the effects of the financial shortfall by not allocating the funds that are available in accordance with the greatest maintenance and congestion pressures on the system. This failure of the highway departments is addressed. The question is asked to what extent highway departments allocate their limited funds consistent with maintenance and congestion demands on their road systems. The approach specifies a model explaining a state's highway budget allocation to the various counties within the state. Explanatory variables depict congestion and road deterioration in each county. The coefficients of the estimated model enable an interpretation of forces underlying state roadway policy. The state highway department used for this research is that of Florida.

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BACKGROUND

Politics usually determines the allocation of state highway budgets to administrative districts and counties. In some states, formula-based allocations prevail; in others, discretionary allocations are the rule; whereas still others use a combination of formulas and discretionary allocations.

Regardless of allocation method, most money likely goes to areas with the greatest political clout. Clout generally reflects population size, but other factors could modify the importance of population. The commitment of special interests, such as developers, and the ideological perspective of engineers and planners within departmental bureaucracies are two potentially powerful modifying factors (*1*).

An allocation process reflecting political clout may or may not reflect maintenance and congestion pressures on roads. Even where population size heavily influences budget allocations, highway dollars may not go to locations where congestion is most severe. This is because population density may be more of a determinant of congestion than absolute population. Developers also may influence expenditures to enhance the value of peripheral development; highway departments may build roads where they are easier to build, or they may build them in anticipation of future traffic rather than because of the pressure of existing traffic.

A method is proposed for determining the extent to which politically driven highway budget allocations reflect maintenance and congestion pressures on roads. The method is inspired by railroad cost studies, which examine fluctuations of different railroad cost accounts as traffic volumes vary. Although railroad cost studies are directed at a different objective than this study, their methods, when applied to highway budget data, would achieve some desired results. However, railroad and highway cost data reflect different assumptions and similar models built on them yield different inferences.

The objective of railroad cost studies is to determine the long-run marginal costs of different types of traffic. Analysts obtain data from cross-sectional samples of railroad companies. Dependent variables are the magnitudes of different railroad cost accounts. Explanatory variables include freight and passenger gross ton-miles, miles of track, and level of investment. The central assumption of such studies is that each railroad company adjusts the size of its plant to optimally carry the traffic for which there is demand, and that it efficiently maintains and operates its system while accommodating such traffic. Under such assumptions, the coefficients for freight and passenger ton-miles indicate the degree to which costs are variable, and in conjunction with the coefficients on track-miles and investment, they reveal the impact of traffic density on cost variability. To the extent that individual railroad managements err by investing too little or too much, or by inefficiently operating their services, the error term grows in magnitude. However, with a sufficiently large sample, the broad statistical regularities between traffic volume and costs should become obvious (*2–4*).

Such studies are possible because the Interstate Commerce Act had required railroads to keep uniform systems of accounts since 1907. Data are thus available. The assumptions underlying the data also likely hold true. As private industries, railroads attempt to operate at a profit, which forces them to adjust their plant and services to economic demand.

Such an approach extended to highway costing yields different results, because of differences between railroad and highway cost data. Because the country has few private highway companies, there is nothing in the highway area analogous to the Interstate Commerce Commission's (ICC's) uniform system of accounts, leaving a difficult task of assembling a cross-sectional highway data base. A study could be based on data files from all state highway departments, but the various departments do not maintain their accounts in similar fashion. Although an alternative approach would be a time series study of expenditures on one or more road segments over their lifetimes, attempts to find historical data in Florida that would enable such a study were fruitless. The only data were state highway budgets and usage and system statistics for each county in Florida.

Superficially, county-based highway data resemble data for a railroad cost study. Highway expenditures could be the dependent variable to be explained, while levels of use and investment could be explanatory independent variables. Despite the existence of such analogies, the assumptions underlying highway data and railroad data are different. Because a highway budget is a political matter, the amounts expended in each category do not necessarily reflect highway demand. Investments may not meet the dictates of demand, or they may far exceed them. Highway authorities may or may not operate efficiently. They may or may not maintain their road facilities. The absence of a profit motive in highways removes the pressure on most highway authorities to react to the market. For such reasons, those attempting to find the marginal costs of highway users have abandoned efforts at inferring the marginal costs of highway traffic from the relationship of state highway budgets and usage and system data (*5*). Instead, they rely on engineering studies of the cost consequences of different types of highway traffic on various components of the highway infrastructure.

Although the railroad costing method when applied to highway cost data is not useful for finding highway marginal costs, it yields the degree to which highway budgets are explained by variables reflecting usage. In this study, explanatory variables include those describing traffic and maintenance pressures, and investment.

APPROACH

A model is used to explain a county's highway budget in terms of traffic pressures in the county. The model is then estimated with two data sets. One set includes county budgets and usage for Florida Interstate highways; the other includes similar information for Florida state highways. Finally, the results are interpreted.

Knowledge of Florida highway budgeting procedures assists in interpreting the results. The Florida Department of Transportation (FDOT) builds and operates all nonlocal roads in Florida, including the Florida Turnpike. Financing for nontoll roads comes both from state and national gas taxes, assisted by registration and truck weight fees. National sources finance up to 90 percent of Interstate budget items, while they finance up to 50 percent of state highways that are part of the federal aid primary, secondary, and urban systems. State financing supplies the remainder of the financing, as well as all of the financing for state highways that are not part of the several systems.

FDOT budgets part of its revenues to statewide activities; part goes to the seven administrative districts in the state. Each district in turn budgets part of its revenues to districtwide projects and part to the counties. The amount that goes to the counties is based to some extent on population and gas tax receipts.

The amounts budgeted to the counties are used as the dependent variable. To the extent that vehicle miles of travel (VMT) is used as an explanatory variable, the model may be doing nothing more than reflecting a formula-driven budgetary process. VMT is the primary determinant of gas tax receipts; however, there is an element of discretion in the budgetary process; hence other considerations may influence budgeted amounts. If so, the model might reveal the other influences.

THE MODEL

In this model, the variable to be explained, designated "COST," is the annual Interstate and state expenditure in each Florida county. COST includes capital and maintenance costs for urban and rural roads. The maintenance category is included with capital because the distinction between the two is small; maintenance costs include heavy road and bridge reconstruction, which many budgeters consider to be capital costs.

Explanatory variables are those that would lead to optimal road investments. Small et al. (*6*) specified a welfare function of road benefits and costs, the first-order conditions of which yielded optimal road pricing and investment criteria. Their optimal-capacity rule stated that road authorities should invest in additional road capacity when the reduction in congestion costs brought about by the added capacity exceeded the added discounted construction costs. The most significant variable affecting the optimal-capacity rule is the ratio of traffic volume to capacity. Congestion costs increase as this ratio increases, making an optimal-capacity investment addition more likely.

Similarly, the durability rule is that when marginal maintenance and user cost savings exceed marginal construction costs, road authorities should invest in stronger pavements. The most significant variable affecting this rule is the axle loading per unit of pavement of a given thickness. As this variable increases, maintenance costs increase, eventually triggering an investment in thicker pavement.

Both rules imply that if road budgets reflected optimal investments, they would tend to increase as either traffic or axle loading increased per unit of pavement. Small et al. (*6*) also argued that axle loadings and traffic volumes acted on road costs interactively.

The variables UPDEN and RPDEN denote urban and rural traffic volume-to-capacity ratios in Florida counties, respectively. UPDEN and RPDEN are defined as urban and rural passenger car equivalent (PCEU and PCER, respectively) miles divided by urban and rural lane-miles (LMU and LMR, respectively) in each county. PCEU and PCER are passenger car miles added to twice the truck miles operated in each county. In symbols, UPDEN = PCEU/LMU, and RPDEN = PCER/LMR.

The accepted measure of axle loadings is the ESAL, which is the equivalent damage done by one axle with an 18,000-lb load. AASHTO-conducted engineering studies during the 1960s concluded that pavement damage increases with the fourth power of axle weight, although Small's (*6*) recent reestimation of equations using this data concludes that the damage increases with the third power. According to Small's reestimation, an automobile with a 1,000-lb axle load does the damage of $(1{,}000^3)/(18{,}000^3)$ ESALs, or 0.0001714 ESAL.

The FDOT does not have data on the number of ESALs using different roads prepared in a manner that could be used for this study. It does have somewhat over 400 classification stations, where 1 day per year it counts the numbers of different types of vehicles passing the stations. Vehicles are classed as motorcycles, automobiles and light trucks, buses, and heavier trucks according to the number of axles on the truck. ESALs can be estimated from such data, but their accuracy would be questionable, because truck weights vary widely for each axle configuration. As Small et al. (*6*) pointed out, heavy trucks with two axles do much more damage than even heavier trucks where the load is spread out over many axles.

Vehicle-miles of urban and rural heavy truck traffic in each county, TVMU and TVMR, respectively, are used as surrogate variables for ESALs. If the ratio of ESALs to TVMU or TVMR is the same in each county, this variable should yield the effect of truck damage on the budgetary process. Although currently there is no way of determining this ratio, it is assumed to be relatively constant.

The measures of urban and rural axle loading per unit of pavement are UTDEN = TVMU/LMU and RTDEN = TVMR/LMR, respectively. Pavement thickness is assumed to be the same everywhere for each category of road.

To capture the interactive effect of volume and axle loadings on a lane-mile of pavement, exponential functions are used: $\exp[C(2) * \text{UPDEN} + C(3) * \text{UTDEN}]$ for urban roads, and $\exp[C(5) * \text{RPDEN} + C(6) * \text{RTDEN}]$ for rural roads. $C(2)$, $C(3)$, $C(5)$, and $C(6)$ are coefficients to be estimated.

A county's road budget, COST, is the first exponential multiplied by the urban lane-miles in the county, plus the second exponential multiplied by the rural lane-miles. There also is a weight, $C(1)$, that determines the relative importance of urban and rural roads on the road budget. Congestion in urban areas places greater budgetary pressure on FDOT primarily because right-of-way costs are so much greater in urban areas.

These considerations yield the following equation, which is the model for this study:

$$\begin{aligned}\text{COST} = {} & C(1) * \text{LMU} * \exp[C(2) * \text{UPDEN} \\ & + C(3) * \text{UTDEN}] + \text{LMR} \\ & * \exp[C(5) * \text{RPDEN} \\ & + C(6) * \text{RTDEN}] + C(7) \end{aligned} \tag{1}$$

where $C(7)$ is another constant whose value is to be estimated.

Equation 1 was estimated twice, once with Interstate highway data, and once with state highway data.

Of particular interest in interpreting the results are the budgetary implications of marginal changes to the explanatory variables giving rise to the density and truck ratio variables. In the case of the urban variables, UPDEN = PCEU/LMU and UTDEN = TVMU/LMU. Thus, in the case of the urban variables, the marginal changes in COST with respect to PCEU, LMU, and TVMU are of interest. These expressions are given by the partial derivatives of Equation 1 with respect to each of the explanatory variables.

$$\begin{aligned}\partial\text{COST}/\partial\text{PCEU} = {} & C(2) * C(1) * \exp[C(2) \\ & * \text{UPDEN} + C(3) * \text{UTDEN}]/365; \end{aligned} \tag{2}$$

$$\begin{aligned}\partial\text{COST}/\partial\text{TVMU} = {} & C(3) * C(1) * \exp[C(2) \\ & * \text{UPDEN} + C(3) * \text{UTDEN}]/365; \end{aligned} \tag{3}$$

$$\begin{aligned}\partial\text{COST}/\partial\text{LMU} = {} & C(1) * \exp[C(2) * \text{UPDEN} \\ & + C(3) * \text{UTDEN}] * \{1 - [C(2) \\ & * \text{PCEU} + C(3) * \text{TVMU}]/\text{LMU}\} \end{aligned} \tag{4}$$

DATA

FDOT maintains a computerized data base for the state's highway system, from which county level usage and system statistics can be extracted. The system contains lane-miles for Interstate and state highways in each county, broken down into urban and rural categories (LMU and LMR). It also contains VMT data for each county both on Interstate and state highways, again broken into urban and rural categories (VMTR and VMTU). FDOT estimates VMTR and VMTU from traffic counters positioned throughout the state, and the miles of road for which the counters apply. FDOT periodically publishes LMU, LMR, VMTU, and VMTR data by county (*7,8*).

As stated earlier, FDOT maintains a much smaller number of classification stations, from which it is possible to decompose traffic into vehicle categories. FDOT does not print summaries of truck traffic VMT data on different classes or road, although it might be possible to have a special program written that would do this. Instead, to estimate TVMU and TVMR for Interstate and state highways, truck and automobile counts were extracted from a published source (*9*), the counts were organized by county and type of road (urban or rural Interstate; urban or rural state highway), the ratio of trucks was calculated using each category of road in each county (truck factors), and then these ratios were applied to the appropriate VMT data in each county. This work yielded rough estimates of truck travel on urban and rural Interstates and state highways in each county. For some counties, there were not a sufficient number of counting stations to obtain truck ratios for each category of road. In such instances, truck factors were substituted from neighboring counties with similar characteristics.

FDOT did not collect such data for several counties, most notably the urban counties in the Tampa-St. Petersburg area. Because of insufficient data, these counties were excluded from the study.

Budgetary data came from the adopted *Five Year Transportation Plan, 1 July 1989 through 30 June 1994* (*10*). For each county, Interstate and state highway construction and maintenance budgeted amounts were summed over the 5 years of the plan, and then the annual average of each was taken. Construction accounts included items sometimes thought of as maintenance, such as resurfacing roads and strengthening bridges. Maintenance accounts included more routine work. Excepting Orange and Dade counties, significant maintenance entries were made for only the first 2 years of the plan; consequently, to obtain the annual maintenance amount the data were divided by two, except for Orange and Dade counties. For construction, the 5-year total was divided by five. The resulting amounts for state highways were designated "budgeted state highway construction, annual" (BSHCA), and "budgeted state highway maintenance, annual" (BSHMA). The analogous Interstate designations were BIMA and BICA. The dependent variable, COST, is the sum of these variables.

RESULTS

Data Covariance

The nonlinear least squares program in the statistical software package, TSP, Version 5.1., was used to estimate the model for both the Interstate and state highway data sets. Before the equations were estimated, the correlation between the variables was examined. High multicollinearity is observed between PCEU, LMU, and TVMU in both data sets. However, when ratios of the variables were used in the model, the multicollinearity was greatly reduced.

Estimating COST from Equation 1 with Interstate Highway Data

Table 1 presents the results for the estimation of Equation 1 with the Interstate highway data set. Table 2 presents the results for the variables in Equation 1 when placed in a simple linear model and estimated with Interstate data and ordinary least squares. Comparison of Tables 1 and 2 indicates that Equation 1 fits the data moderately better than the standard linear model. This suggests that Equation 1 is a better specification.

Table 3 presents results for the marginal pressures on county road budgets from each of the explanatory variables, as given

TABLE 1 EQUATION 1 ESTIMATED WITH INTERSTATE HIGHWAY DATA

	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C(1)	105.71851	43.157392	2.4496037	0.020
C(2)	0.0480215	0.0222606	2.1572451	0.039
C(3)	-0.7606273	0.1462690	-5.2001957	0.000
C(5)	-0.0801812	1.0715590	-0.0748267	0.941
C(6)	1.3662039	4.8331762	0.2826721	0.779
C(7)	1098.3378	849.62140	1.2927379	0.206

Number of observations:	37		
R-squared	0.859196	Mean of dependent var	5672.411
Adjusted R-squared	0.836485	S.D. of dependent var	8423.143
S.E. of regression	3406.064	Sum of squared resid	3.60D+08
Durbin-Watson stat	1.930553	F-statistic	37.83270
Log likelihood	-350.1601		

TABLE 2 LINEAR ESTIMATION OF VARIABLES IN EQUATION 1 WITH INTERSTATE HIGHWAY DATA

VARIABLE	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C	3657.7178	2444.3179	1.4964165	0.145
LMU	77.513343	14.230666	5.4469229	0.000
UPDEN	658.27945	303.73582	2.1672763	0.038
UTDEN	-6589.8667	2652.5079	-2.4843910	0.019
LMR	-3.4863618	13.392698	-0.2603181	0.796
RPDEN	-342.61415	365.03163	-0.9385876	0.355
RTDEN	846.26646	2197.4994	0.3851043	0.703

Least Squares: Dependent Variable is COST
Number of observations: 37

R-squared	0.811889	Mean of dependent var	5672.411
Adjusted R-squared	0.774267	S.D. of dependent var	8423.143
S.E. of regression	4001.947	Sum of squared resid	4.80D+08
Durbin-Watson stat	1.733604	F-statistic	21.58012
Log likelihood	-355.5187		

TABLE 3 MARGINAL BUDGETARY IMPACTS OF EXPLANATORY VARIABLES FOR INTERSTATE HIGHWAY SYSTEM

	OBS	BUDGET[a] (1000s)	EST. BUD., URBAN[b] (1000s)	MC LMU[c] (1000s)	MC PCEU[d] ($/mi)	MC TVMU[e] ($/mi)
LEE	1	$1,498	$2,756	$101	$0.010	($0.155)
MANATEE	2	$6,371	$2,065	$104	$0.011	($0.179)
POLK	3	$2,958	$4,498	$104	$0.012	($0.184)
SARASOTA	4	$8,729	$2,196	$101	$0.010	($0.158)
ALACHUA	5	$3,318	$1,380	$78	$0.005	($0.082)
COLUMBIA	6	$1,352	$0	ERR	ERR	ERR
HAMILTON	7	$5,031	$0	ERR	ERR	ERR
MADISON	8	$655	$0	ERR	ERR	ERR
SUWANNEE	9	$1,883	$0	ERR	ERR	ERR
DUVAL	10	$25,221	$26,259	$102	$0.010	($0.165)
NASSAU	11	$4,037	$0	ERR	ERR	ERR
ESCAMBIA	12	$3,180	$6,623	$104	$0.012	($0.187)
GADSDEN	13	$2,098	$0	ERR	ERR	ERR
HOLMES	14	$2,368	$0	ERR	ERR	ERR
JACKSON	15	$1,773	$0	ERR	ERR	ERR
JEFFERSON	16	$981	$0	ERR	ERR	ERR
LEON	17	$2,495	$3,668	$105	$0.012	($0.196)
OKALOOSA	18	$592	$0	ERR	ERR	ERR
SANTA ROSA	19	$300	$0	ERR	ERR	ERR
WALTON	20	$1,098	$494	$104	$0.016	($0.257)
WASHINGTON	21	$803	$0	ERR	ERR	ERR
COLLIER	22	$7,334	$188	$105	$0.012	($0.196)
BROWARD	23	$37,457	$25,516	$104	$0.011	($0.180)
INDIAN RIVER	24	$555	$0	ERR	ERR	ERR
MARTIN	25	$904	$0	ERR	ERR	ERR
PALM BEACH	26	$14,541	$18,456	$102	$0.011	($0.168)
ST LUCIE	27	$661	$1,306	$106	$0.013	($0.209)
SUMTER	28	$3,182	$0	ERR	ERR	ERR
MARION	29	$4,759	$1,625	$104	$0.011	($0.178)
BREVARD	30	$2,804	$6,009	$105	$0.013	($0.202)
FLAGLER	31	$1,395	$0	ERR	ERR	ERR
ORANGE	32	$6,778	$8,820	$101	$0.010	($0.157)
SEMINOLE	33	$7,196	$3,765	$102	$0.010	($0.163)
ST JOHNS	34	$6,891	$0	ERR	ERR	ERR
VOLUSIA	35	$7,010	$6,284	$105	$0.012	($0.195)
OSCEOLA	36	$322	$0	ERR	ERR	ERR
DADE	37	$31,349	$30,597	$87	$0.023	($0.364)

ERR means that there were no urban roads.
a See Data section of text.
b Calculated from the urban half of Equation 1, using the estimated parameters of Table 1.
c Equation 2, with parameters from Table 1.
d Equation 3, with parameters from Table 1.
e Equation 4, with parameters from Table 1.

in Equations 2–4, for each county for which Interstate highway data could be obtained. In particular, Table 3 presents the amount of the Interstate budget allocated to each county, the part of the budget predicted by the urban variables, and the marginal impact of each of the urban variables.

From Tables 1 and 3, it is obvious that LMU explains much of the roadway budget, and that its marginal impact remains remarkably constant, regardless of the size of the budget. Thus, regardless of the number of lane-miles that a county has, it is likely to spend about the same amount per lane-mile in next year's budget as most other counties. Although the coefficient of the density variable is positive and significant, the marginal impact of lane-miles runs counter to the expectation that more congestion would induce greater construction spending to relieve it. This counterintuitive result reflects an appropriation of funds formula largely based on urban lane-miles in each county.

Traffic, measured in PCEUs, offers ambivalent explanatory power. Automobiles generate from $0.002 to $0.006 per mile in federal gas tax revenue; Table 3 indicates that their marginal impact on county budgets ranges from $0.005 to $0.023. No pattern to the variation is apparent. Some counties with heavy congestion, such as Dade, exhibit high marginal impacts of added vehicle miles, but other counties with heavy congestion, such as Orange or Palm Beach, do not.

The marginal contribution of truck traffic is uniformly and decidedly negative, a result far from expectations. This contrary result could derive from a poor measure of ESALs, from multicollinearity, or from the fact that truck damage is being insufficiently addressed in highway budgets. The only additional information bearing on this point is that an increasing amount of deferred maintenance is being incorporated into the state transportation plan (*11*).

Estimating Equation 1 with State Highway Data

Table 4 presents the results of estimating Equation 1 with the state highway data, while Table 5 presents the results of estimating a simple linear model with the same variables that are in Equation 1.

Table 6 presents the marginal impact of the explanatory variables on the state highway budgets in each county. Generally, the results support those from the Interstate data, except that the overall marginal impacts of both LMU and PCEU are considerably smaller, whereas the negative impact of truck traffic is far weaker. The marginal results of all three variables also exhibit much less variation between counties.

CONCLUSIONS

Although interesting, these results are preliminary and need to be carefully reviewed, along with the data underlying them. They suggest that neither traffic congestion nor the wear and tear on roads from heavy truck traffic influence the Florida state highway budget for individual counties. Thus, not only the low level of highway financing, but also its distribution contributes to what most Floridians experience: increasingly congested roads and an accumulating backlog of highway damage caused by trucks.

Most transportation analysts now agree that motorists and truckers do not pay the economic costs of the congestion that they create, while truckers do not pay for the damage that they impose. Although benefits would accrue to users if the state made improvements in these areas, costs to nonusers would more than outweigh their benefits, suggesting that the investments themselves may be inefficient and also inequitable. Although users may be unwilling to pay for what benefits them, there is little justification for the state to pick up their tabs.

Additional models should be estimated with the dependent variable, budgeted highway expenditures, split into two components. One part would be the construction and reconstruction budgets; the other, routine maintenance. Such a procedure may strengthen and clarify the results, particularly for the state highway data, in which the percentage of the budget accounted for by routine maintenance is much higher than for the Interstate budgets.

TABLE 4 ESTIMATION OF EQUATION 1 WITH STATE HIGHWAY DATA

	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C(1)	25.015938	8.8384451	2.8303550	0.007
C(2)	0.0489636	0.0374722	1.3066663	0.197
C(3)	-0.5378900	0.7769887	-0.6922752	0.492
C(5)	0.6366192	0.1736572	3.6659528	0.001
C(6)	-0.5643309	1.2713711	-0.4438758	0.659
C(7)	1489.1097	795.72483	1.8713877	0.067

Number of observations:	59		
R-squared	0.860812	Mean of dependent var	8507.113
Adjusted R-squared	0.847681	S.D. of dependent var	11340.13
S.E. of regression	4425.837	Sum of squared resid	1.04D+09
Durbin-Watson stat	1.841369	F-statistic	65.55585
Log likelihood	-575.8713		

TABLE 5 LINEAR ESTIMATION OF VARIABLES CONTAINED IN EQUATION 1, USING STATE HIGHWAY DATA

VARIABLE	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C	-798.97111	1883.1107	-0.4242826	0.673
LMU	31.244161	2.3284122	13.418656	0.000
UPDEN	166.60221	498.41914	0.3342613	0.740
UTDEN	-4686.6620	8444.7017	-0.5549825	0.581
LMR	0.6560692	5.5314618	0.1186068	0.906
RPDEN	1739.2657	907.18198	1.9172180	0.061
RTDEN	-3589.8195	4368.2480	-0.8217985	0.415

Number of observations:	59		
R-squared	0.862546	Mean of dependent var	8507.113
Adjusted R-squared	0.846686	S.D. of dependent var	11340.13
S.E. of regression	4440.268	Sum of squared resid	1.03D+09
Durbin-Watson stat	1.768960	F-statistic	54.38468
Log likelihood	-575.5014		

TABLE 6 MARGINAL BUDGETARY IMPACTS OF EXPLANATORY VARIABLES FOR STATE HIGHWAY SYSTEM

	OBS	BUDGET[a] (1000s)	EST. BUD., URBAN[b] (1000s)	MC LMU[c] (1000s)	MC PCEU[d] ($/mi.)	MC TVMU[e] ($/mi.)
DESOTO	1	$4,152	$677	$24.932	$0.004	($0.040)
GLADES	2	$4,298	$0	ERR	ERR	ERR
HARDEE	3	$2,134	$0	ERR	ERR	ERR
HENDRY	4	$3,451	$269	$24.944	$0.004	($0.040)
HIGHLANDS	5	$5,993	$2,251	$24.829	$0.004	($0.041)
LEE	6	$24,386	$6,457	$24.721	$0.004	($0.043)
MANATEE	7	$13,112	$8,209	$24.832	$0.004	($0.041)
POLK	8	$27,590	$14,348	$25.002	$0.003	($0.038)
SARASOTA	9	$13,971	$8,794	$24.068	$0.004	($0.047)
ALACHUA	10	$10,108	$8,192	$24.707	$0.004	($0.043)
BRADFORD	11	$863	$725	$24.713	$0.004	($0.043)
COLUMBIA	12	$2,712	$2,157	$24.943	$0.004	($0.040)
GILCHRIST	13	$1,258	$0	ERR	ERR	ERR
HAMILTON	14	$796	$0	ERR	ERR	ERR
LAFAYETTE	15	$1,077	$0	ERR	ERR	ERR
LEVY	16	$1,422	$0	ERR	ERR	ERR
MADISON	17	$1,922	$0	ERR	ERR	ERR
SUWANNEE	18	$1,446	$508	$24.957	$0.004	($0.039)
TAYLOR	19	$1,463	$958	$25.012	$0.003	($0.036)
UNION	20	$1,045	$0	ERR	ERR	ERR
CLAY	21	$7,752	$1,859	$24.553	$0.004	($0.044)
DUVAL	22	$47,094	$30,545	$24.713	$0.004	($0.043)
NASSAU	23	$1,785	$1,111	$24.933	$0.004	($0.040)
BAY	24	$8,496	$8,783	$24.743	$0.004	($0.042)
CALHOUN	25	$1,901	$0	ERR	ERR	ERR
ESCAMBIA	26	$13,167	$12,976	$24.700	$0.004	($0.043)
FRANKLIN	27	$3,683	$0	ERR	ERR	ERR
GADSDEN	28	$1,060	$848	$25.016	$0.003	($0.037)
GULF	29	$4,855	$0	ERR	ERR	ERR
HOLMES	30	$1,026	$0	ERR	ERR	ERR
JACKSON	31	$3,706	$499	$25.016	$0.003	($0.037)
JEFFERSON	32	$1,947	$0	ERR	ERR	ERR
LEON	33	$13,251	$7,074	$24.904	$0.004	($0.040)
LIBERTY	34	$283	$0	ERR	ERR	ERR
OKALOOSA	35	$5,454	$8,821	$24.906	$0.004	($0.040)
SANTA ROSA	36	$3,016	$2,007	$24.634	$0.004	($0.043)
WAKULLA	37	$508	$0	ERR	ERR	ERR
WALTON	38	$5,264	$851	$24.966	$0.004	($0.039)
WASHINGTON	39	$941	$0	ERR	ERR	ERR
COLLIER	40	$8,369	$2,887	$24.342	$0.004	($0.046)
BROWARD	41	$26,501	$36,325	$24.300	$0.004	($0.046)
INDIAN RIVER	42	$7,818	$3,055	$24.656	$0.004	($0.043)
MARTIN	43	$18,315	$4,192	$24.633	$0.004	($0.044)
OKEECHOBEE	44	$1,096	$0	ERR	ERR	ERR
PALM BEACH	45	$19,332	$20,544	$24.957	$0.004	($0.039)
ST LUCIE	46	$3,741	$4,554	$24.556	$0.004	($0.044)
CITRUS	47	$7,017	$0	ERR	ERR	ERR
LAKE	48	$5,481	$3,419	$24.815	$0.004	($0.042)
SUMTER	49	$2,047	$0	ERR	ERR	ERR
MARION	50	$5,097	$4,090	$24.648	$0.004	($0.043)
BREVARD	51	$13,484	$18,286	$24.508	$0.004	($0.045)
FLAGLER	52	$2,635	$0	ERR	ERR	ERR
ORANGE	53	$23,180	$17,907	$24.832	$0.004	($0.041)
PUTNAM	54	$5,888	$1,008	$24.845	$0.004	($0.041)
SEMINOLE	55	$9,375	$5,945	$24.755	$0.004	($0.042)
ST JOHNS	56	$8,014	$3,347	$24.616	$0.004	($0.044)
VOLUSIA	57	$20,825	$12,809	$24.622	$0.004	($0.044)
OSCEOLA	58	$2,536	$1,719	$24.824	$0.004	($0.042)
DADE	59	$62,787	$57,109	$23.538	$0.005	($0.050)

Notes:
ERR means that there were no urban roads.
a See data section of text
b Calculated from the urban half of Equation 1, using the estimated parameters of Table 4.
c Equation 2, with parameters from Table 4.
d Equation 3, with parameters from Table 4.
e Equation 4, with parameters from Table 4.

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Roadway Congestion in Major Urban Areas: 1982 to 1988

JAMES W. HANKS, JR., AND TIMOTHY J. LOMAX

The results of the third year of analysis of a 6-year research effort focused on quantifying urban mobility are described. Roadway information is provided for 39 urban areas representing a geographic cross section throughout the country. The data base used for this research contains vehicle travel, urban area information, facility mileage, and vehicle travel per lane-mile information. Various federal, state, and local information sources were used to develop and update the data base with the primary source being the FHWA's Highway Performance Monitoring System. Vehicle-miles of travel (VMT) and lane-mile data were used to develop roadway congestion index values for the 7 largest Texas and 32 other U.S. urban areas. These index values serve as indicators of the relative mobility level within an urban area. An analysis of the cost of congestion was performed using travel delay, increased fuel consumption, and increased automobile insurance premiums as the economic analysis factors. Congestion costs were estimated on urban-areawide, per-registered-vehicle, and per-capita bases. The 39 urban areas were categorized in five geographic regions: northeastern, midwestern, southern, southwestern, and western. Comparing the amount of VMT served by freeway and principal arterial street systems and roadway congestion index values, it was concluded that the amount of urban area VMT served by freeway and principal arterial street systems indicated which system urban areas relied on for mobility. Analyses indicated that the Northwestern and Southern regions tended to rely equally on both systems, whereas the remaining regions had a greater reliance on their freeway systems. A comparison of regional roadway congestion index values indicated that the northeastern area was the only region with increasing congestion growth rate. The largest decrease in congestion growth rate was exemplified by the Southwestern region. In 1988, the total annual cost of congestion exceeded \$34 billion. The average annual congestion cost, studywide, was approximately \$880 million; however, 10 of the urban areas had annual costs exceeding \$1 billion. The largest contribution (65 percent) to congestion costs may be directly attributed to travel delay.

During the past decade, congestion has become common place in most urban areas throughout the country. Today, urban mobility has become one of the key issues facing the transportation professionals. Because urban areas largely depend on freeway and principal arterial street systems to provide the majority of travel demand requirements, the mobility in urban areas has been adversely affected by undesirable traffic congestion levels on these systems.

During the past 20 years, there has been a decline in new highway construction. This may be attributed to reduced funding, increased construction costs, and public resistance to construction of additional highways. The most noticeable effect of these factors on urban mobility, from the public's perspective, is increased travel delay. Traffic congestion directly affects the travel time that motorists experience during daily commutes. In most urban areas, rush-hour traffic is no longer encountered only during morning and afternoon peak-periods, but rather extends into much of the day.

In more recent years, an increasing negative public perception of transportation mobility levels has spurred renewed interest in the transportation infrastructure. The net result of this public reaction has been an increase in reconstruction, restoration, and rehabilitation of urban roadway systems.

Existing data are taken from federal, state, and local agencies to develop planning level estimates of mobility on the freeway and principal arterial street systems in 39 urban areas. Currently, the data base developed for this research contains vehicle travel, travel per lane-mile, population, urban area size, and facility mileage from 1982 to 1988.

Urban mobility is characterized by urban travel volume and capacity statistics. The relative level of mobility can be estimated by the roadway congestion index (RCI). RCI values are based on the major indicators of daily vehicle-miles of travel (DVMT) per lane-mile for freeways and principal arterial streets. Combining the freeway and principal arterial street DVMT per lane-mile into an RCI value provides a quantitative method for estimating the urban areawide mobility. An RCI value $\geqq 1.0$ indicates an undesirable level of congestion.

Transportation professionals and the general public have become increasingly aware of the economic impact of congestion. Three factors in the analysis of the cost of congestion are considered. Travel delay is by far the most critical factor affected by congestion. Traffic congestion also increases the amount of fuel consumed and insurance premiums paid by motorists operating vehicles in these conditions. Combining the effects of these factors, congestion costs were estimated on areawide, per-registered-vehicle, and per-capita bases. Estimating congestion costs allows comparison of urban mobility from one urban area to another but, more important, it defines a method for tracking changes in congestion levels and their impact on an urban area over time.

URBAN AREAWIDE CONGESTION MEASUREMENT AND COST METHODOLOGY DEVELOPMENT

Previous research (*1–4*) on area wide mobility levels in Texas and other U.S. cities resulted in methodologies for comparing roadway congestion levels and the costs associated with congestion. The methodologies, outlined in the following sec-

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tions, use generally available data from federal, state, and local agencies.

Measurement of Areawide Urban Congestion

This methodology uses the major indicators of DVMT per lane-mile for freeways and principal arterial streets combined in an RCI for estimating and ranking the relative areawide mobility. An RCI value of 1.0 or greater indicates an undesirable areawide congestion level. This methodology has some limitations induced by population densities, development and land use patterns, and overall urban area mobility characteristics.

Methodology

Congestion indicators and indices used in this study are the result of research conducted by the Texas Transportation Institute (TTI) (*1–4*). The most important indicators of congestion used in this methodology are values of freeway and principal arterial street DVMT per lane-mile. Equation 1 illustrates how these values are used to calculate the roadway congestion index.

$$\mathrm{RCI} = \frac{\left(\frac{\text{Freeway}}{\text{VMT/ln-mi}} \times \frac{\text{Freeway}}{\text{VMT}}\right) + \left(\frac{\text{Principal Arterial Street}}{\text{VMT/ln-mi}} \times \frac{\text{Principal Arterial Street}}{\text{VMT}}\right)}{\left(13{,}000 \times \frac{\text{Freeway}}{\text{VMT}}\right) + \left(5{,}000 \times \frac{\text{Principal Arterial Street}}{\text{VMT}}\right)} \tag{1}$$

The two constant values, 13,000 and 5,000, are the results of the TTI research. It was found that when areawide freeway travel volumes reached 13,000 DVMT per lane-mile, congested conditions [level of service (LOS) D] are estimated to occur. The corresponding LOS value for principal arterial street travel volumes is represented by a system average of 5,000 DVMT per lane-mile.

Lack of comparable and significant urban travel data has hampered the analysis of congestion levels on a national basis. The amount of roadway system performance statistics collected and reported by local and state agencies varies significantly across the nation. Differences in roadway functional classification terminology have resulted in significant variations between major and minor arterial street mileage. The Highway Performance Monitoring System (HPMS) data base (*5*) compiled by FHWA since 1980 was used as the basic source of data for this analysis. Local planning and transportation agencies, and state departments of transportation (DOTs) were contacted to obtain relevant data and provide local review.

The urban areawide congestion methodology also uses a relationship between average daily traffic (ADT) per lane and average travel speed. This relationship was developed using travel time and ADT data for freeways and principal arterial streets in Houston, Texas (*6*), to obtain better estimates of travel delay. Peak-period speeds were established for the various ADT per lane ranges (Table 1).

The percentage of the total DVMT operating under moderate, heavy, and severe conditions was estimated for each urban area. The travel delay was estimated applying the speeds. This procedure provides a better estimate of travel delay within individual urban areas because the operating characteristics of the freeway and principal arterial street systems are defined in a more disaggregate form.

Limitations of Roadway Congestion Estimates

The RCI is intended to be an urban area value, representing the entire area and not site-specific locations. This index is based on areawide freeway and principal arterial street travel. Therefore, if a large percentage of these systems have good operational characteristics, the effects of point or specific facility congestion may be underestimated by this analysis. It should also be noted that the RCI and its methodology were developed for urban areas similar to those in Texas. Urban areas in the northeast and midwestern states have different roadway and development patterns. The RCI methodology also does not include considerations of traffic signal system operations, freeway designs, freeway system configuration,

TABLE 1 SPEED RELATIONSHIPS WITH ADT PER LANE VOLUMES

Functional Class	Parameters	Severity of Congestion[1,2]		
		Moderate	Heavy	Severe
Freeway/Expressway	ADT/Lane	15,000 - 17,500	17,501 - 20,000	Over 20,000
	Speed (mph)[3]	40	35	32
Principal Arterial Streets	ADT/Lane	5,750 - 7,000	7,001 - 8,500	Over 8,500
	Speed (mph)[3]	32	28	25

Note: [1]Assumes congested freeway operation when ADT/Lane exceeds 15,000.
[2]Assumes congested principal arterial street operations when ADT/lane exceeds 5,750.
[3]Values represent weighted average (6).

Source: TTI Analysis and Houston-Galveston Regional Transportation Study arterial street continuity, HOV lanes, or the role of transit. Although these factors have a definite impact on urban congestion, much more detailed urban area information is required than presently is available through regional data bases.

Congestion Cost Methodology

This methodology outlines the procedure used to evaluate the impact of congestion in a specific urban area. The procedure had two basic input units. These units were daily DVMT and population. Table 2 presents a summary of the basic data for each urban area analyzed. The DVMT data were obtained from the HPMS (*5*) and various state and local agencies. The population data were estimated from HPMS and U.S. Census Bureau estimates.

Congestion costs were based on the congested peak-period VMT for both freeways and principal arterial streets. The congested VMT data consist of the percentage of total vehicle travel operating in congested conditions. Congested conditions were estimated to begin at the transition from LOS C to LOS D. Traffic volumes representative of congested conditions were estimated as 15,000 vehicles per lane per day for freeway or expressway facilities, and 5,750 vehicles per lane per day for principal arterial street facilities. HPMS sample data were used to estimate the percentage of an urban area's DVMT value occurring on facilities with traffic volumes exceeding congested levels.

The amount of DVMT operating in congested conditions was identified for each urban area; then congested DVMT was categorized by severity. Congestion severity affects travel time and delay by causing decreased facility speeds as the congestion increases. The categories and associated peak-period speeds used in this study are presented in Table 1. Categorizing facility congestion levels and assigning the appropriate travel speed allows a more appropriate areawide representation of congestion and the associated costs.

The congested daily travel values were adjusted by a factor to represent the percentage of travel occurring in the peak period. This factor was calculated using Texas State Department of Highways and Public Transportation (SDHPT) 1986 Automatic Traffic Recorder Data (*8*) for the study areas in Texas. Using these data, the percentage of ADT occurring during the morning and evening peak periods was estimated using these data. These data indicated that a relatively consistent value of 45 percent of total daily traffic occurred during the peak periods. This factor was applied to all the study areas.

Once the DVMT was converted to peak-period congested VMT (Table 3), the recurring vehicle-hours of delay were computed from Equation 2. Recurring delay is caused by the peak facility conditions during normal operations, excluding delay resulting from accidents, construction, or maintenance operations.

$$\left(\begin{array}{c}\text{Recurring}\\ \text{Vehicle-Hours of}\\ \text{Delay Per Day}\end{array}\right) = \left(\frac{\text{Peak-Period Congested DVMT}}{\text{Average Peak-Period Speed}}\right) - \left(\frac{\text{Peak-Period Congested DVMT}}{\text{Average Off-Peak Speed}}\right) \quad (2)$$

This calculation was performed both for freeways and principal arterial streets in a study area; the total recurring vehicle-hours of delay is the sum of the two. The result of these calculations is presented in Table 4.

TABLE 2 SUMMARY OF 1988 DVMT VALUES AND POPULATION FOR CONGESTION COST ESTIMATES

	Daily Vehicle-Miles of Travel (1000)			
Urban Area	Freeway/ Expressway	Principal Arterial Street	Freeway and Arterial	Population (1000)
Boston MA	22,720	12,860	35,580	2,910
New York NY	78,010	49,710	127,720	16,320
Philadelphia PA	16,680	22,120	38,790	4,130
Washington DC	23,600	18,800	42,400	3,040
Chicago IL	31,970	26,070	58,030	7,340
Detroit MI	22,020	21,670	43,690	3,900
Atlanta GA	22,970	9,790	32,750	1,780
Miami FL	7,890	13,740	21,630	1,810
Nashville TN	5,250	5,390	10,640	540
Tampa FL	3,440	4,070	7,510	670
Dallas TX	22,380	8,150	30,530	1,950
Denver CO	10,490	10,450	20,940	1,550
Houston TX	27,100	10,190	37,290	2,850
Phoenix AZ	5,550	16,680	22,230	1,830
Los Angeles CA	102,140	78,240	180,380	11,140
Portland OR	7,100	3,280	10,380	950
Sacramento CA	8,420	6,660	15,080	1,040
San Diego CA	25,040	8,850	33,880	2,180
San Fran-Oak CA	40,370	13,540	53,910	3,610
Seattle-Everett WA	17,190	8,820	26,010	1,630

Note: Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (7).

Source: TTI Analysis and Local Transportation Agency References

TABLE 3 1988 CONGESTED DVMT

Urban Area	Daily Vehicle-Miles of Travel Frwy (1000)	Daily Vehicle-Miles of Travel Prin.Art.Str. (1000)	Percent of Peak-Period[1,2] VMT on Congested Roads Frwy (%)	Percent of Peak-Period[1,2] VMT on Congested Roads Prin.Art.Str. (%)	Peak Period Congested DVMT[1,3] Frwy (1000)	Peak Period Congested DVMT[1,3] Prin.Art.Str (1000)	Peak Period Congested DVMT[1,3] Frwy & Prin. Art. St. (1000)
Boston MA	22,720	12,860	45	40	4,600	2,310	6,910
New York NY	78,010	49,710	55	80	19,310	17,900	37,210
Philadelphia PA	16,680	22,120	25	75	1,880	7,460	9,340
Washington DC	23,600	18,800	65	85	6,900	7,190	14,090
Chicago IL	31,970	26,070	55	65	7,910	7,620	15,530
Detroit MI	22,020	21,670	40	60	3,960	5,850	9,810
Atlanta GA	22,970	9,790	45	65	4,650	2,860	7,510
Miami FL	7,890	13,740	60	70	2,130	4,330	6,460
Nashville TN	5,250	5,390	25	40	590	970	1,560
Tampa FL	3,440	4,070	25	60	390	1,100	1,490
Dallas TX	22,380	8,150	55	30	5,540	1,100	6,640
Denver CO	10,490	10,450	50	50	2,360	2,350	4,710
Houston TX	27,100	10,190	70	50	8,540	2,290	10,830
Phoenix AZ	5,550	16,680	60	80	1,500	6,000	7,500
Los Angeles CA	102,140	78,240	75	50	34,470	17,600	52,070
Portland OR	7,100	3,280	40	60	1,280	890	2,170
Sacramento CA	8,420	6,660	45	50	1,710	1,500	3,210
San Diego CA	25,040	8,850	45	30	5,070	1,190	6,260
San Fran-Oak CA	40,370	13,540	80	60	14,530	3,660	18,190
Seattle-Everett WA	17,190	8,820	70	55	5,410	2,180	7,590

Notes: [1]Daily vehicle-miles of travel
[2]Represents the percentage of daily vehicle-miles of travel on each roadway system during the peak period operating on congested conditions
[3]Daily vehicle-miles of travel multiplied by peak-period vehicle travel and percent of congested DVMT
Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (7).

Source: TTI Analysis and Local Transportation Agency References

An incident will have varying effects on different types of facilities; for the purpose of this study, incident delay for arterial streets is defined as 110 percent of arterial street recurring delay. This incident delay factor was calculated using Equation 3.

$$\begin{pmatrix}\text{Principal Arterial Street Incident}\\ \text{Vehicle-Hour Delay}\\ \text{Per Day}\end{pmatrix} = \begin{pmatrix}\text{Principal Arterial Street Recurring}\\ \text{Vehicle-Hour Delay}\\ \text{Per Day}\end{pmatrix} \times 1.1 \qquad (3)$$

The factor of 1.1 is based on the following assumptions as they relate to delay:

1. Arterial street systems designs are more consistent from city to city than freeway design.
2. The side streets, drives, median openings, and other appurtenances associated with arterial streets allow numerous opportunities to remove incidents from the traveled way.
3. Historical data show the accident rate on arterial streets to be approximately twice that of freeways, but, as stated in the second assumption, there is a greater opportunity to remove the incident from the roadway.

Table 4 presents the results of the freeway and principal arterial street recurring and incident delay calculations.

Before the congestion costs were calculated, two other variables were calculated to simplify the cost equations. These variables were the average vehicular speed and the average fuel mileage for the vehicles operating in congested conditions. The average vehicular speed, which is a weighted average of the operating speeds on the facility under consideration, is defined by Equation 4.

$$\text{Average Speed (mph)} = \left[\begin{pmatrix}\text{Freeway}\\ \text{Speed}\end{pmatrix} \times \begin{pmatrix}\text{Peak-Period}\\ \text{Freeway VMT}\end{pmatrix} + \begin{pmatrix}\text{Principal}\\ \text{Arterial}\\ \text{Speed}\end{pmatrix} \times \begin{pmatrix}\text{Peak-Period}\\ \text{Principal}\\ \text{Arterial}\\ \text{Street VMT}\end{pmatrix}\right] \div \text{Total Peak-Period VMT} \qquad (4)$$

In this equation, freeway speed and principal arterial speed are determined by congestion severity (Table 1).

Economic Impact Estimates

The economic impact of congestion was estimated by three cost components: traffic delay, excess fuel, and increased vehicle insurance premiums. Traffic delay and excess fuel costs were estimated for incident and recurring events encountered by motorists. For the purpose of this study, recurring conges-

TABLE 4 RECURRING AND INCIDENT DELAY RELATIONSHIPS FOR 1988

Urban Area	Peak Period Congested DVMT[1,2]			Ratio of Incident[3] Delay to Recurring Delay		Daily Recurring Vehicle-[4] Hours of Delay			Daily Incident Vehicle-[4] Hours of Delay		
	Frwy (1000)	Prin.Art.Str. (1000)	Frwy & Prin. Art. St. (1000)	Frwy	Prin.Art. Street	Frwy	Prin.Art. Street	Total	Frwy	Prin.Art. Street	Total
Boston MA	4,600	2,310	6,910	3.50	1.10	58,790	19,190	77,980	205,760	21,100	226,870
New York NY	19,310	17,900	37,200	2.50	1.10	225,070	159,800	384,870	562,680	175,780	738,460
Philadelphia PA	1,880	7,460	9,340	2.10	1.10	20,430	68,530	88,960	42,900	75,380	118,280
Washington DC	6,900	7,190	14,090	2.20	1.10	80,540	64,400	144,940	177,180	70,840	248,020
Chicago IL	7,910	7,620	15,540	1.20	1.10	100,060	62,080	162,150	120,080	68,290	188,370
Detroit MI	3,960	5,850	9,810	2.20	1.10	49,020	56,130	105,150	107,840	61,740	169,580
Atlanta GA	4,650	2,860	7,510	1.10	1.10	56,930	22,320	79,240	62,620	24,550	87,170
Miami FL	2,130	4,330	6,460	1.50	1.10	27,870	43,250	71,110	41,800	47,570	89,370
Nashville TN	590	970	1,560	1.10	1.10	6,880	9,270	16,150	7,570	10,190	17,760
Tampa FL	390	1,100	1,480	1.50	1.10	4,610	10,380	14,990	6,920	11,420	18,340
Dallas TX	5,540	1,100	6,640	1.80	1.10	67,090	7,300	74,390	120,750	8,030	128,790
Denver CO	2,360	2,350	4,710	1.00	1.10	28,230	13,950	42,180	28,230	15,340	43,570
Houston TX	8,540	2,290	10,830	1.40	1.10	109,260	17,020	126,280	152,960	18,730	171,690
Phoenix AZ	1,500	6,000	7,500	0.40	1.10	17,720	48,690	66,410	7,090	53,560	60,640
Los Angeles CA	34,470	17,600	52,080	1.20	1.10	478,860	146,570	625,430	574,630	161,230	735,860
Portland OR	1,280	890	2,160	2.00	1.10	14,280	6,590	20,870	28,550	7,250	35,800
Sacramento CA	1,710	1,500	3,200	0.60	1.10	18,640	11,160	29,810	11,190	12,280	23,470
San Diego CA	5,070	1,190	6,260	0.60	1.10	62,180	8,520	70,700	37,310	9,380	46,680
San Fran-Oak CA	14,530	3,660	18,190	1.30	1.10	194,350	33,600	227,950	252,660	36,960	289,610
Seattle-Everett WA	5,410	2,180	7,600	1.40	1.10	63,790	17,720	81,510	89,300	19,490	108,800

Notes: [1]Daily vehicle-miles of travel
[2]Represents the percentage of Daily Vehicle-Miles of travel on each roadway system during the peak period operating in congested conditions
[3]Percentage of Incident Delay related to Recurring Delay
[4]Facility delays as calculated by type and urban area
Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (7).

Source: TTI Analysis and Local Transportation Agency References

tion was defined as congestion resulting from normal daily facility operations. Incident congestion occurs as a result of an accident, vehicle breakdown, or any other event not typically encountered during normal operations.

Study Constants

The congestion cost analysis and calculations used six independent variables. The following constant values were used in the calculations for each urban area studied.

1. Average vehicle occupancy, 1.25 persons;
2. Working days per year, 250;
3. Average cost of time (*10*), $8.80 per person-hour;
4. Commercial vehicle operations cost (*11*), $1.75 per mile;
5. Vehicle mix, 95 percent passenger and 5 percent commercial; and
6. Vehicular speeds, as presented in Table 1.

These variables do not account for individual variation between urban areas. However, the areawide approach of this research allows the use of these average values describing average cost of time, vehicle mix, and vehicular speeds. The intent of this research is to develop a method to measure and compare urban mobility using existing and readily available data. Without question, urban area roadway congestion index values may be improved by specific area values not readily available to the general transportation community.

Urban Area Variables

Five area-specific variables were also used in the congestion cost estimate. These variables are presented in Table 5.

1. Daily vehicle-miles of travel (DVMT), the average daily traffic (ADT) of a section of roadway multiplied by the length (in miles) of that roadway section.
2. Insurance rates, the difference between the urban average, excluding large metropolitan areas, and the average premium paid within a specific urban area.
3. Fuel cost, the state average fuel cost per gallon for 1988 (*12*).
4. Registered vehicles, the number of registered vehicles are reported by local agencies.
5. Population, estimated using 1988 U.S. Census Bureau estimates and 1988 HPMS data (*13*).

Congestion Cost

Three cost components can be associated with congestion (a) delay cost, (b) fuel cost, and (c) insurance cost. These costs can be directly related to the vehicle-hours of delay, with the exception of the insurance cost. Table 5 presents the cost calculations for the component congestion cost per each urban area.

The average fuel mileage represents the fuel consumption of the vehicles operating in congested conditions. Equation 6 is a linear regression applied to a modified version of fuel consumption reported by Raus (*13*).

Average Fuel Mileage (mpg)

$$= 8.8 + 0.25\,(\text{Average Vehicular Speed}) \qquad (5)$$

Delay Cost The delay cost is the cost of lost time due to congested roadways. This cost was calculated by Equation 6.

TABLE 5 1988 CONGESTION COST ESTIMATE VARIABLES

Urban Area	Daily VMT Frwy (1000)	Daily VMT Prin.Art.Str. (1000)	Auto Insurance Rates,$	Annual Insurance Difference,$	State Avg Fuel Cost, $	Registered Autos (1000)	Population (1000)	Popn. Per Reg.Veh.
Boston MA	22,720	12,860	800	110	1.07	1,540	2,910	1.89
New York NY	78,010	49,710	860	430	1.09	5,850	16,320	2.79
Philadelphia PA	16,680	22,120	820	410	1.08	2,720	4,130	1.52
Washington DC	23,600	18,800	790	190	1.16	1,640	3,040	1.85
Chicago IL	31,970	26,070	650	190	1.17	4,030	7,340	1.82
Detroit MI	22,020	21,670	730	230	1.14	2,890	3,900	1.35
Atlanta GA	22,970	9,790	630	90	1.09	1,530	1,780	1.16
Miami FL	7,890	13,740	1,020	460	1.17	1,350	1,810	1.34
Nashville TN	5,250	5,390	490	110	1.12	500	540	1.09
Tampa FL	3,440	4,070	640	80	1.17	600	670	1.11
Dallas TX	22,380	8,150	580	150	1.14	1,600	1,950	1.22
Denver CO	10,490	10,450	570	70	1.20	1,360	1,550	1.14
Houston TX	27,100	10,190	630	200	1.14	2,240	2,850	1.27
Phoenix AZ	5,550	16,680	650	50	1.23	1,170	1,830	1.56
Los Angeles CA	102,140	78,240	810	300	1.18	7,790	11,140	1.43
Portland OR	7,100	3,280	480	120	1.05	620	950	1.53
Sacramento CA	8,420	6,660	620	110	1.18	1,250	1,040	0.83
San Diego CA	25,040	8,850	620	110	1.18	1,390	2,180	1.57
San Fran-Oak CA	40,370	13,540	670	160	1.18	3,010	3,610	1.20
Seattle-Everett WA	17,190	8,820	460	70	1.16	1,170	1,630	1.39

Note: Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (*7*).

$$\text{Annual Delay Cost} = \frac{\text{Vehicle-Hr of Delay}}{\text{Day}} \times \frac{1.25\text{ person}}{\text{Vehicle}} \times \frac{\$8.80}{\text{Hour}} \times \frac{250\text{ Workdays}}{\text{Year}} \quad (6)$$

where vehicle-hours of delay/day is the combined freeway and principal arterial street representing the city's recurring or incident delay. This equation is used to separately calculate delay costs resulting both from incident and recurring delays.

Fuel Cost Fuel cost was also related to vehicle-hours of delay per day and speed by Equation 7 for passenger vehicles and Equation 8 for commercial vehicles.

$$\text{Passenger Fuel Cost} = \frac{\frac{\text{Vehicle-hr of Delay}}{\text{Day}} \times 95\% \times \text{Average Speed} \times \text{Average Urban Area Fuel Cost}}{\text{Average Fuel Mileage}} \quad (7)$$

$$\text{Commercial Fuel Cost} = \frac{\frac{\text{Vehicle-hr of Delay}}{\text{Day}} \times 5\% \times \text{Average Speed} \times \text{Average Urban Area Fuel Cost}}{\text{Average Fuel Mileage}} \quad (8)$$

where vehicle-hours of delay is the combined value for freeways and principal arterial streets representing either recurring or incident delay.

These calculations were completed both for incident and recurring delay. The respective portions, i.e., incident and recurring, were combined in Equation 9 to determine the yearly fuel cost due to congestion resulting from incident and recurring delay.

$$\text{Average Urban Area Fuel Cost} = (\text{Passenger Fuel Cost} + \text{Commercial Fuel Cost}) \times \frac{250\text{ Days}}{\text{Year}} \quad (9)$$

This calculation was done for each study area using the specific area or state fuel cost, peak-period congested VMT, and vehicle-hours of recurring and incident delay per day.

Insurance Cost Insurance cost was calculated by multiplying the insurance rate differential by the number of registered vehicles within the area (Equation 10). The factor of 0.70 represents the approximate percentage of an insurance premium used to provide insurance coverage for the vehicle. Thirty percent of the premium was estimated to be used for the overhead expenses.

$$\text{“Excess” Insurance Cost per year} = \left[\left(\text{Study Area Rate}\right) - \left(\text{Average State Rate}\right)\right] \times 0.70 \times \text{Number of Registered Vehicles} \quad (10)$$

The 70/30 ratio was a factor generally agreed on after several interviews with insurance carriers. The insurance costs do not include commercial vehicles because of the wide variance in rates and the difficulty in identifying the registered commercial vehicles actually operating within a particular area.

RESULTS OF URBAN AREA CONGESTION AND CONGESTION COST ANALYSES

The statistics, in this section, are the result of TTI's analyses of the data base compiled for the 39 urban areas from 1982 to 1988 included in this study. Mobility within these regions, as well as within individual urban areas, was compared on the base of DVMT per lane-mile and congestion cost.

1988 Urban Congestion

Urban area freeway and principal arterial street system travel volume and travel volume per lane-mile are presented in Table 6. Combining these statistics (Equation 1) results in the 1988 estimated RCI value. An RCI value of 1.0 or greater indicates an undesirable areawide congestion level.

Of the 39 urban areas studied, 18 have RCI values equal to or greater than 1.0. The 10 most congested urban areas have RCI values ranging from 1.52 (Los Angeles) to 1.10 (New York and Atlanta). Eight urban areas have roadway congestion index values between 0.99 and 0.90. Cities in this range could reach undesirable congestion levels in the near future. Urban areas in the western region had the highest average RCI value, whereas the southwestern region experienced the lowest (Figure 1).

Traffic Congestion Growth, 1982 to 1988

The RCI values for each urban area from 1982 to 1988 are presented in Table 7. From 1982 to 1988, San Diego, Nashville, and San Francisco–Oakland were estimated to have the fastest congestion growth rate, whereas Phoenix, Detroit, and Houston experienced the lowest.

The annual percent change in RCI value for the 11 most congested urban areas in 1988 is shown in Figure 2. This figure illustrates the change for the entire study period (1982 to 1988), an intermediate period (1985 to 1988), and the most recent percent change (1987 to 1988). Los Angeles and Atlanta data indicate that the congestion growth rate has declined in recent years. Conversely, Boston has experienced an increasing congestion growth rate for all years included in this study. Houston is the only urban area in the top 11 that has shown a consistent decreasing congestion growth rate for these time periods.

The summary statistics indicate that all regions have experienced annual increases in average RCI values during the study period with the exception of the southwestern region (Figure 3). This region had approximately a 1 percent decrease in the average regional RCI value from 1987 to 1988.

Figure 3 shows RCI changes during the same time periods as Figure 2. The northeast was the only region with increasing congestion growth rates. The urban areas in Texas account

TABLE 6 1988 RCI VALUES

Urban Area	Freeway/Expressway		Principal Arterial Street		Roadway[3] Congestion Index	Rank
	DVMT[1] (1000)	DVMT/[2] Ln-Mile	DVMT[1] (1000)	DVMT/[2] Ln-Mile		
Los Angeles CA	102,140	20,590	78,240	6,520	1.52	1
San Fran-Oak CA	40,370	17,360	13,540	6,620	1.33	2
Washington DC	23,600	15,850	18,800	8,250	1.32	3
Chicago IL	31,970	14,500	26,070	6,940	1.18	4
Miami FL	7,890	13,710	13,740	6,800	1.18	4
Seattle-Everett WA	17,190	15,080	8,820	5,980	1.17	6
Houston TX	27,100	15,140	10,190	5,150	1.15	7
San Diego CA	25,040	14,770	8,850	5,460	1.13	8
Boston MA	22,720	15,040	12,860	4,780	1.12	9
New York NY	78,010	13,430	49,710	6,990	1.10	10
Atlanta GA	22,970	13,920	9,790	6,570	1.10	10
Detroit MI	22,020	13,430	21,670	6,160	1.09	12
Philadelphia PA	16,680	11,910	22,120	6,850	1.07	13
Portland OR	7,100	13,150	3,280	6,250	1.05	14
Tampa FL	3,440	11,860	4,070	6,500	1.03	15
Sacramento CA	8,420	12,470	6,660	6,340	1.03	15
Dallas TX	22,380	13,360	8,150	4,810	1.02	17
Phoenix AZ	5,550	10,670	16,680	5,790	1.00	18
Nashville TN	5,250	11,930	5,390	5,890	0.99	19
Denver CO	10,490	12,200	10,450	5,690	0.99	19

Notes: [1]Daily vehicle-miles of travel
[2]Daily vehicle-miles of travel per lane-mile
[3]See Equation 1

Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (7).

Source: Equation 1 and Tables 2 and 5

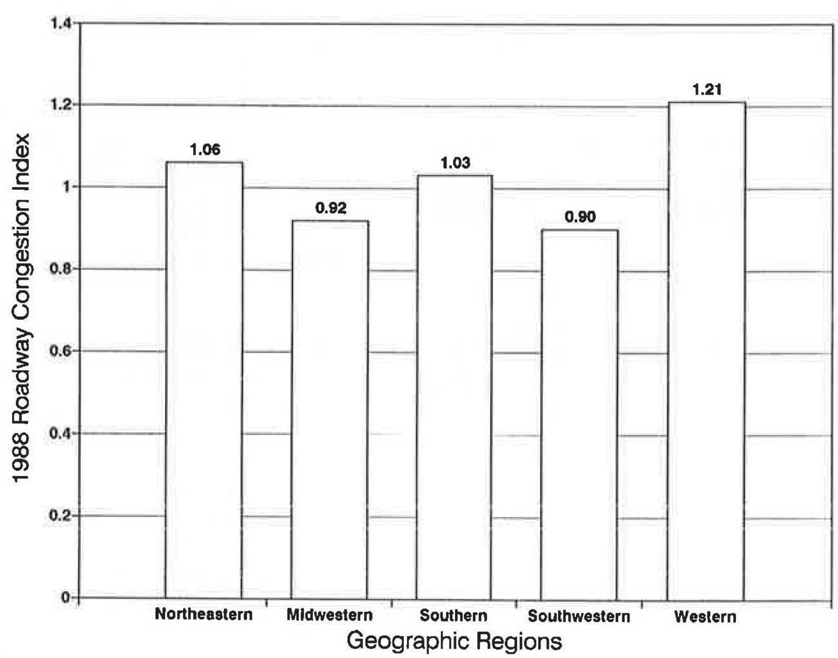

FIGURE 1 1988 roadway congestion index.

TABLE 7 RCI VALUES, 1982 TO 1988

Urban Area	Year 1982	1983	1984	1985	1986	1987	1988	Percent Change 1982 to 1988
Phoenix AZ	1.15	1.16	1.10	1.13	1.20	1.18	1.00	-13
Detroit MI	1.13	1.10	1.13	1.12	1.11	1.10	1.09	-4
Houston TX	1.17	1.21	1.25	1.23	1.21	1.19	1.15	-2
Philadelphia PA	1.00	1.03	1.04	0.90	1.06	1.06	1.07	7
New York NY	1.01	1.02	0.99	1.00	1.06	1.06	1.10	9
Tampa FL	0.94	0.91	1.03	1.00	0.96	1.02	1.03	10
Miami FL	1.05	1.09	1.07	1.13	1.10	1.14	1.18	12
Chicago IL	1.02	1.02	1.05	1.08	1.15	1.15	1.18	16
Denver CO	0.85	0.88	0.93	0.96	0.97	0.95	0.99	16
Dallas TX	0.84	0.89	0.94	0.98	1.04	1.02	1.02	21
Portland OR	0.87	0.86	0.88	0.93	0.97	1.00	1.05	21
Washington DC	1.07	1.09	1.12	1.20	1.28	1.30	1.32	23
Seattle-Everett WA	0.95	0.99	1.02	1.05	1.09	1.14	1.17	23
Boston MA	0.90	0.93	0.95	0.98	1.04	1.04	1.12	24
Atlanta GA	0.89	0.94	0.97	1.02	1.09	1.15	1.10	24
Los Angeles CA	1.22	1.27	1.32	1.36	1.42	1.47	1.52	25
Sacramento CA	0.80	0.84	0.88	0.92	0.95	1.00	1.03	29
San Fran-Oak CA	1.01	1.05	1.12	1.17	1.24	1.31	1.33	32
Nashville TN	0.74	0.76	0.83	0.81	0.86	0.95	0.99	34
San Diego CA	0.78	0.83	0.91	0.95	1.00	1.08	1.13	45

Note: Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (7).

Source: Equation 1 and TTI Data Base 1982-1988

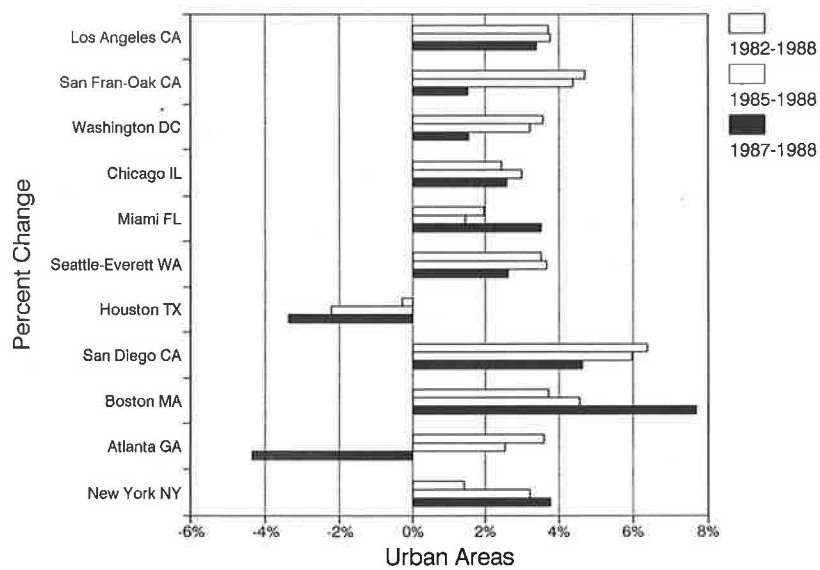

FIGURE 2 Annual percent change of RCI value for the 11 most congested urban areas.

for much of the decrease in the growth rate in the southwest. Between 1987 and 1988, however, Phoenix had the largest decrease in congestion growth at a rate of 15 percent. The graph indicates the other three regions are all experiencing decreasing congestion growth rates. The southern region has the highest increase of those regions from 1987 to 1988.

Cost Estimate Calculations

Using the methods and equations discussed in the previous section, the annual cost for each urban area was calculated (Table 8). Reviewing the component costs of delay, fuel, and insurance, it is shown that congestion costs associated with delay make up the majority of annual congestion cost.

Table 9 presents the impacts of the component and total congestion cost per capita and per registered vehicle. Table 10 presents the categorical ranking of the urban study areas by annual congestion cost, annual cost per capita, and annual cost per registered vehicle, including and excluding insurance costs. Elimination of insurance costs from the annual congestion cost did marginally affect the ranking of the top 10 urban areas. The remaining 15 in the top 25 urban areas, however, were not affected by exclusion of the insurance cost.

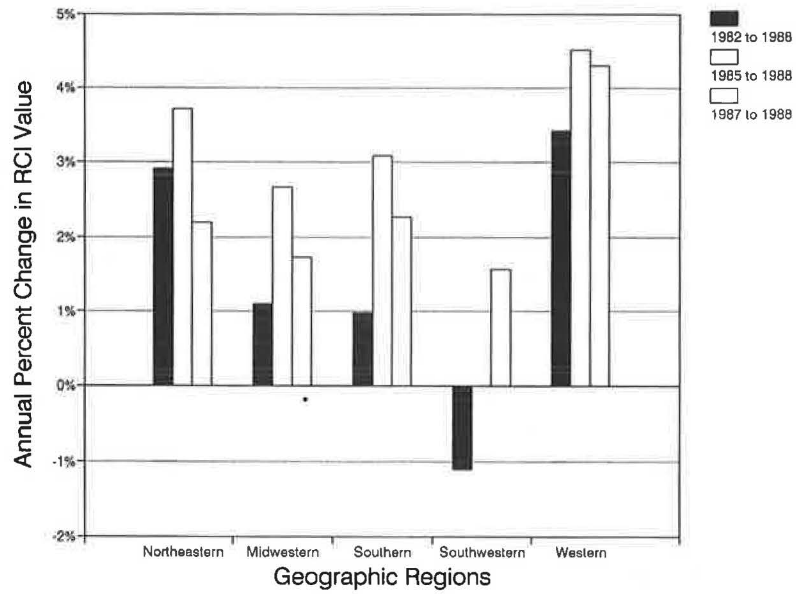

FIGURE 3 Annual percent change in RCI values by geographic region.

TABLE 8 COMPONENT AND TOTAL CONGESTION COSTS BY URBAN AREA FOR 1988

Urban Area	Annual Cost Due to Congestion ($Millions)							Rank
	Recurring Delay	Incident Delay	Recurring Fuel	Incident Fuel	Delay&Fuel Cost	Insurance	Total Delay, Fuel &Insurance	
Los Angeles CA	2,060	2,420	350	410	5,240	1,640	6,880	1
New York NY	1,270	2,440	200	380	4,290	1,760	6,040	2
San Fran-Oak CA	760	960	130	160	2,010	340	2,340	3
Chicago IL	530	620	90	100	1,340	540	1,880	4
Washington DC	480	820	80	130	1,510	220	1,730	5
Philadelphia PA	290	380	40	60	770	780	1,550	6
Detroit MI	340	550	50	90	1,030	470	1,510	7
Houston TX	420	570	70	90	1,150	310	1,470	8
Boston MA	260	750	40	120	1,170	120	1,280	9
Miami FL	230	290	40	50	610	430	1,040	10
Dallas TX	250	430	40	70	790	170	960	11
Seattle-Everett WA	270	360	50	60	740	60	800	12
Atlanta GA	260	290	40	50	640	100	730	13
San Diego CA	240	160	40	30	470	110	570	14
Phoenix AZ	220	200	40	30	490	40	520	16
Denver CO	140	140	20	20	320	70	400	18
Sacramento CA	100	80	20	10	210	100	300	22
Portland OR	70	120	10	20	220	50	270	24
Nashville TN	50	60	10	10	130	40	170	26
Tampa FL	50	60	10	10	130	30	160	27

Note: Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (7).

Source: TTI Analysis and Local Transportation Agency References

TABLE 9 ESTIMATED ECONOMIC IMPACT OF CONGESTION IN 1988

Urban Area	Cost Per Registered Vehicle		Cost Per Capita	
	Total Congestion (Dollars)	Delay & Fuel (Dollars)	Total Congestion (Dollars)	Delay & Fuel (Dollars)
Boston MA	830	760	440	400
New York NY	1,030	730	370	260
Philadelphia PA	570	280	380	190
Pittsburgh PA	470	260	310	170
Washington DC	1,050	920	570	500
Chicago IL	470	330	260	180
Detroit MI	520	360	390	270
Atlanta GA	480	420	410	360
Miami FL	770	450	570	330
Nashville TN	340	260	310	240
Tampa FL	270	210	240	190
Dallas TX	600	500	490	410
Denver CO	290	250	260	220
Houston TX	660	520	520	410
Phoenix AZ	450	410	290	260
Los Angeles CA	880	670	620	470
Portland OR	440	350	280	230
Sacramento CA	240	170	290	200
San Diego CA	410	330	260	210
San Fran-Oak CA	780	670	650	560
Seattle-Everett WA	680	630	490	460

Note: Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (7).

Source: TTI Analysis and Local Transportation Agency References

TABLE 10 1988 RANKINGS OF URBAN AREA BY ESTIMATED ECONOMIC IMPACT OF CONGESTION

Urban Area	Areawide Cost		Cost Per Capita		Cost Per Registered Vehicle	
	Total Congestion	Delay&Fuel	Total Congestion	Delay&Fuel	Total Congestion	Delay&Fuel
Boston MA	9	6	8	7	4	2
New York NY	2	2	12	12	2	3
Philadelphia PA	6	10	11	20	10	19
Washington DC	5	4	3	2	1	1
Chicago IL	4	5	21	22	14	14
Detroit MI	7	8	10	11	11	12
Atlanta GA	13	12	9	8	13	10
Miami FL	10	13	3	9	6	9
Nashville TN	26	27	15	15	21	21
Tampa FL	27	27	24	20	26	25
Dallas TX	11	9	6	5	9	8
Denver CO	18	16	21	17	24	23
Houston TX	8	6	5	5	8	7
Phoenix AZ	16	14	17	12	16	11
Los Angeles CA	1	1	2	3	3	4
Portland OR	24	22	19	16	17	13
Sacramento CA	22	23	17	19	27	28
San Diego CA	14	15	21	18	18	14
San Fran-Oak CA	3	3	1	1	5	4
Seattle-Everett WA	12	11	6	4	7	6

Note: Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (7).

CONCLUSIONS

Relative mobility levels between 1982 and 1988 were presented and discussed in this report. Seven of these urban areas are in Texas and represent the largest metropolitan areas in the state. The 39 urban areas evaluated in this study represent a wide variety of travel and development patterns. These urban areas characterize a cross section of urban development with varying populations, densities, travel demands, and roadway systems.

Urban Area Mobility

One measure of urban mobility levels is the roadway congestion index. This value is based on the travel volume (DVMT) per lane-mile operating under undesirable conditions on the freeway and principal arterial street systems. The roadway congestion index, as stated earlier, is intended to be an urban area value representing the entire area, and not site-specific locations, i.e. bridges, tunnels, or other points of congestion.

Comparing the amounts of VMT served by the freeway and principal arterial street systems indicates which system urban areas rely on for mobility. Figure 4 graphically shows the percent of the total travel volume served by urban area freeway and principal arterial street systems. The northeastern and southern regions tend to rely on both systems equally, whereas the remaining three regions are more freeway oriented.

Table 7 summarizes RCI values from 1982 to 1988. Of the 39 urban areas included in this study, 3 have lower 1988 RCI values than were estimated for 1982 (Phoenix, Detroit, and Houston). Trends in congestion growth rates for the individual regions are shown in Figure 3. The Northeastern area was the only region with increasing congestion growing rates. The largest decrease in the congestion growth rate is in the Southwestern region, with Texas congestion levels being the major contributing factor in the decline.

Economic Impact of Congestion

Three factors were used to estimate the economic impact of congestion.

- Travel delay caused by congested roadways and incidents,
- Increased fuel consumption, and
- Increased insurance premiums.

For comparative purposes, the annual estimated congestion cost represents the economic impact on an urban area of an inadequate roadway system. Large urban areas will have significant congestion cost values by virtue of their size. The estimate of congestion experienced by individual motorists in different urban areas may be achieved by normalizing the areawide economic impact by urban population and number of registered vehicles.

The total annual cost of congestion exceeded $34 billion in 1988. Ten of the urban areas studied were estimated to have annual congestion costs exceeding $1 billion. The average annual cost for 39 urban areas was approximately $880 million, with 65 percent being attributed to travel delay. Table 11 presents the estimated economic impact of congestion per capita and per registered vehicle. These values represent the congestion cost paid by urban area residents and motorists.

Table 11 presents the comparison between ranking urban areas by the RCI, cost per capita, and per registered vehicle. The comparison between the RCI and cost per capita ranks indicates the effect of urban population. Chicago and New York are both removed from the top 10 by virtue of their large urban area populations that dilute the cost of congestion. Comparing the cost per registered vehicle value to the RCI,

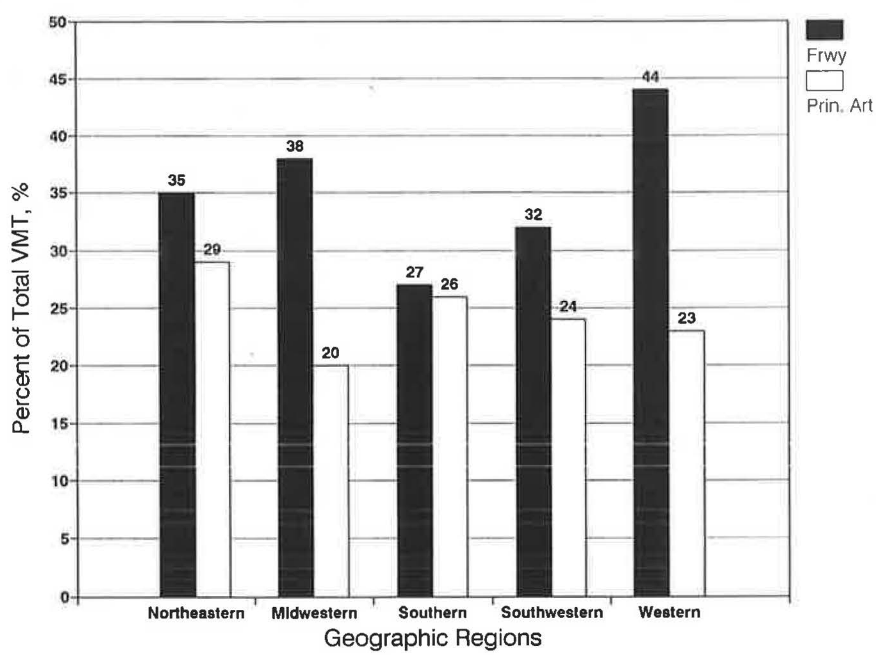

FIGURE 4 Facility travel volume by geographic region.

TABLE 11 1988 URBAN AREA RANKINGS BY RCI AND COST PER CAPITA

Urban Area	Roadway Congestion Index	Rank	Congestion Cost Per Capita (Dollars)	Rank	Congestion Cost Per Vehicle (Dollars)	Rank
Los Angeles CA	1.52	1	620	2	880	3
San Fran-Oak CA	1.33	2	650	1	780	5
Washington DC	1.32	3	570	3	1,050	1
Chicago IL	1.18	4	260	21	470	14
Miami FL	1.18	4	570	3	770	6
Seattle-Everett WA	1.17	6	490	6	680	7
Houston TX	1.15	7	520	5	660	8
San Diego CA	1.13	8	260	21	410	18
Boston MA	1.12	9	440	8	830	4
New York NY	1.10	10	370	12	1,030	2
Atlanta GA	1.10	10	410	9	480	13
Detroit MI	1.09	12	390	10	520	11
Philadelphia PA	1.07	13	380	11	570	10
Portland OR	1.05	14	290	19	440	17
Tampa FL	1.03	15	240	24	270	26
Sacramento CA	1.03	15	290	17	240	27
Dallas TX	1.02	17	490	6	600	9
Phoenix AZ	1.00	18	290	17	450	16
Nashville TN	0.99	19	310	15	340	21
Denver CO	0.99	19	260	21	290	24

Note: Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (7).

Source: TTI Analysis

New York is ranked second. This ranking represents the effect of the lower vehicle ownership rates within the area. In general, ranking urban areas by congestion cost per capita and per registered vehicle corresponds to ranking areas by RCI values.

The material in this paper is an overview of *Roadway Congestion in Major Urban Areas 1982 to 1988*, Research Report 1131-3 (*7*). The methodology used in this research provides an areawide rather than site-specific urban mobility analysis. Analyses and data are intended to estimate the effects and level of congestion within an urban area, not as a basis for project selection or funding allocations.

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Highway District and Economic Sector Employment Effects of Transportation Expenditures

LAURENCE M. CRANE, DOCK BURKE, AND CLAY HANKS

The determinants of total highway construction and maintenance expenditures in the highway districts of Texas and how these expenditures on transportation infrastructure affect employment levels are described. Pooled time series and cross-sectional time series linear regression models were used to measure economic and political relationships to highway expenditures. Research results indicate that there is a positive relationship between total employment, personal income, expenditures on transportation, and expenditures on transportation lagged. The length of the lag varies among the economic sectors and major industries of the state. Some lag patterns of transportation expenditures and employment follow a decreasing linear function, whereas others more closely resemble a second order polynomial. There is a difference between the highway districts as to the amount of effect transportation expenditures have on employment. The impacts are greatest in the more urban districts, and least in the more rural districts. The political influences as defined in this study were not significant in determining the level of public funds spent on highway infrastructure.

Transportation investment has long been an important factor contributing to the economic infrastructure base of Texas. The State Department of Highways and Public Transportation's (SDHPT) expenditures for construction, maintenance, and rehabilitation of the transportation network create direct, secondary, and tertiary benefits. The relationships between these benefits and transportation expenditures, and the variables that determine the level of public expenditure on transportation facilities need to be examined.

Expenditures for public highways support the third largest function of state and local governments; expenditures for education and welfare are first and second. Texas has over 72,000 mi of highways, including 3,200 mi of Interstate highways, over 27,000 mi of primary (U.S. or state-numbered) roads, about 41,000 miles of secondary (farm-to-market) roads, over 100 miles of recreational roads, and about 20,000 bridges (*1*). Highway policy outcomes are of interest to diverse groups. These groups range from the automotive and construction industry to the agriculture industry, real estate investors, municipal and regional transportation planners, tourism industry, large and small businesses, and almost anyone who uses the state's highways.

Policy outcomes express the value allocations of a society, and these allocations are the chief output of the society's political system (*2*). This study investigates the determinants of total highway expenditures in Texas and how these expenditures on transportation infrastructure affect the state's economy. An understanding of these relationships will be of value to highway policy makers as they act to meet the simultaneous goals of the different state agencies.

Policy makers are faced with difficult choices to provide adequate transportation facilities, fund education and other competing state programs, and increase economic activity, all within the bounds of a limited budget and limited resources. As some sectors within the state economy grow, and as others decline, policy makers are faced with the difficult task of being able to target programs that are not only geographically specific, but economically specific as well.

This difficult task involves governmental decisions affecting the use of public resources. Noted political theorist Thomas R. Dye (*3*) states, "Public policy regulates conflict within societies; distributes a great variety of symbolic awards and material services to members of the society; and extracts money from society, most often in the form of taxes." On the other hand, Davis and Frederick (*4*) define public policy as "a plan of action undertaken by government to achieve some broad purpose affecting a large segment of the citizenry." Texas' ability to maintain its existing network of roads in good condition and to increase capacity in time to prevent bottlenecks is important to all highway users and ensures strong economic growth. A 1987 study indicates that merely halting deterioration in the nation's highway network would improve economic growth for the economy as a whole, with national income 3.2 percent higher by 1995, employment 2.2 percent higher, and inflation 8 percent lower than if road conditions were allowed to continue to deteriorate, as in the late 1970s (*5*).

Another important aspect of public policy is an understanding of its formation. Scholars of public policy are not harmonious concerning whether socioeconomic variables, political variables, or both, determine public policy. Dye and Gray (*6*) provide a premise for policy analysts to consider before commencing investigations into public policy. Policy analysts, they posit, must be willing to look at several disciplines to find determinants of public policy by putting good theory first and must be willing to accept ideals and theories from other academic disciplines.

Both economic and political variables will be used in this analysis; however, there is conflict as to what influence and the amount of influence that political variables play in determining public policy. To simply dismiss pluralist politics as not important could result in leaving out essential variables that determine highway policy in Texas. Fundamentally, pluralist politics indirectly affect SDHPT policy decisions in the

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following manner. The SDHPT is in charge of highway construction and maintenance in Texas; however, a three-member commission appointed by the governor with the concurrence of the senate oversees the SDHPT.

The general objective is to improve the understanding of how economic and political determinants of highway policy can enhance the effectiveness of highway planning, promote economic development, and improve transportation policy in Texas. Specifically, it is to improve the understanding of how expenditures for transportation construction and maintenance promote and impact economic activity.

Political and economic variables may affect total highway expenditures in the state of Texas in one or more of the following manners:

1. Political competition, party affiliation, and participation may influence the level of highway expenditures.
2. Membership of the Texas House of Representatives Committee on Transportation may influence the level of highway expenditures.
3. Employment, income, and the price of oil may influence the level of highway expenditures.
4. The amount of expenditures on transportation may impact the employment level of the citizens.

The economic variables that will be used in this study are per capita personal income in a highway district, total employment, and employment by economic sector within a highway district. Also, expenditures on transportation construction and maintenance, and the average price for crude oil for each year in the period 1969 to 1986 are included.

The political variables used are voter participation, partisanship, intraparty competition, and representation on the House Committee on Transportation. The first three political variables are the same variables that Dye (*2*) used in his study of highway policy in the American states in the early 1960s. The fourth political variable, membership on the House Committee on Transportation, is included here to determine the effect of committee members, if any, on highway expenditures in those districts they represented. The data were collected on a county basis where available and then aggregated into highway district aggregates.

LITERATURE REVIEW

Previous research has indicated significant linkages between economic development and transportation expenditures (*7–10*). The need for an understanding of the timing and strengths of these linkages has recently become more pronounced. As the various economic sectors of the country, including the economic and geographic sectors in Texas, rebound from the severe recession in the agriculture and mining sector, various agencies and political bodies have become more vocal in advocating a move towards so-called "economic diversification" (*11*). Understanding and documenting the effects transportation expenditures have on a specific area are increasingly important to governmental and administrative bodies, as are all public expenditure programs (*10*). In the future, agencies are also going to need to justify their budgets in an economic development and diversification context more so than they have been required to do in the past.

Expansion of economic activity is a leading priority of state governments (*11*). As a means of promoting and sustaining economic development activity, state governments are increasing their levels of support for various growth strategies, including, for example, casino bus transportation to Atlantic City (*12*) as well as promotion of market expansion through manufacturing export promotion (*13*). There has been practically no statistical analysis of the effects of state expenditures promoting manufacturing exports to other states and countries. Furthermore, the funding of these growth and diversification strategies and the funding of their transportation requirements need to be analyzed in an economic as well as a political framework (*14*).

Several states have passed legislation creating enterprise development areas or zones (*15*). The enterprise zone concept is founded on the belief that the formation of new business activity that will create employment opportunities can be fostered through incentives and innovative projects. However, little is known about the factors that influence where new business locations will occur and how much employment will be generated.

Location theory has been used in various studies to examine the relationship between transportation costs and level of service and regional economic development (*16*). It was used in an attempt to determine whether public transportation infrastructure and freight subsidies can be expected to stimulate industrial development in a region.

Carlton (*17*) simultaneously modeled both the location and employment choice of new branch plants. He found energy costs and existing concentrations of employment to have a surprisingly large effect on plant location decisions, whereas taxes and state incentive programs do not seem to have major effects. For highly sophisticated industries, the available technical expertise, specialized resources such as labor skills and education, and factors that help attract and maintain a skilled labor force such as state and local taxes are important (*18*). Less technical industries are influenced more by the traditional location factors of market access and transportation. Population migration and growth are affected by the economic employment climate of the state. For employment, differences in county growth are most often determined by the economic and demographic conditions (*19*).

The FHWA issued administrative criteria for the selection of economic growth areas as they relate to transportation facilities and needs (*20*). The effects of highway improvements on development pass through three different stages. In the first, it is not developed to a level at which it is capable of encouraging regional development. In the second stage, it acts as a vehicle for development, and in the third stage, it becomes an agent for personal mobility (*21*). That is, as the highway network becomes saturated, it exhibits less of a developmental effect and begins to act as an agent to increase personal mobility.

Economic development is also increasingly being used by state departments of transportation as a criterion and justification for highway funding decisions. Past studies of the interactions between highway expenditures and economic development have provided little evidence supporting this funding justification criterion (*16,22*). However, it has been found in recent econometric studies that highway expenditures lead to temporary increases in employment during the construction stage (*23,24*). The effects of transportation expenditures on employment and income have also been shown to be distributed differently between urban and rural areas (*25*).

The determinants of general economic growth have been modeled in a whole menu of theories (*26,27*). The project and regionally specific models are of more practical use to the highway department personnel (*28*). However, there is a need for further research at the project, district, and state levels in all areas of transportation management, administration and policy planning (*29*).

The published literature also offers many diverse theories, models, and conclusions on the determinants of public policy (*30–32*). Few published articles include both economic and political variables in determining highway policy outputs; however, many of the findings of public policy studies presented in the published literature include highway policy outputs as one of the policy variables (*33–36*).

In 1980. Dye (*37*) examined the differences in taxing and spending among the American states and their impact on economic growth and development. He investigated why the rates of growth for some state economies are larger than rates of growth for other state economies. Dye specifically asked, "What public policies of the states are likely to be influential determinants of variation in growth in income, employment, and productivity in the 1970s?" Dye developed a time-lagged taxing and spending model, because taxing and spending are two areas that can be manipulated by (elected) decision makers. He examined the period between 1967 and 1970 for taxing and spending policies and its lagged effect on economic development in the period between 1972 and 1976.

Dye found that there was little association between taxing policies and economic growth. However, the spending policies of a state were strongly correlated to economic development in a state. The strongest relationship was between highway spending and economic development. Spending in the late 1960s correlated with economic development in the early and middle 1970s. He concludes that the data suggest investment in all areas of a state's infrastructure—highways, energy, water, mass transit, etc.—promote economic development. Tax incentives did not have a significant impact in the development of a state's economy.

Forkenbrock and Plazak (*38*) found that the impact highways would have on economic development played a significant role in highway planning. Economic development is becoming a major goal of highway planning in most states. Many states have created programs designed to find the economic impact of highway development. For example, the Revitalize Iowa's Sound Economy (RISE) program, administered by the Iowa DOT, investigates the impact that highway construction and maintenance expenditures will have on economic development. In the current time of fiscal austerity, taxpayers are demanding the most effectiveness of publicly financed programs, including highway construction and maintenance expenditures (*39*).

METHODOLOGY

Data

The data consist of annual observations for the 254 counties of Texas covering a time period from 1969 through 1986. The political variables include participation, partisanship, competition, and membership on the Texas House Committee on Transportation. The political variables are measured in the following manner:

1. Participation—the percentage of registered voters that participated in the gubernatorial election (1966 to 1982);
2. Partisanship—the percentage of voters voting Democrat (1966 to 1982);
3. Competition—the percentage difference between the winner and loser in the general election for governor (1966 to 1982); or the lower the percentage, the higher the competition; and
4. Membership—the number of legislative representatives from the counties within a given highway district that hold membership on the Texas House Transportation Committee.

Although this study examines a period from 1969 to 1986, the gubernatorial election in 1966 was included so that data are available for 1969 and 1970 (*40*). The results of a gubernatorial election are held constant for 4 years or until the next gubernatorial election. The fourth political variable, membership, is a variable that will be used to investigate variation in highway expenditures according to membership on the Texas House Transportation Committee. The data for this variable are collected every biennium. Before 1973, the Texas House Committee on Transportation did not exist; thus for the years 1969 to 1972, membership is measured according to membership on the Texas House Committee on Common Carriers and the Texas House Committee on Highways and Roads (*41*).

The data for the economic variables are personal income and employment values as collected by the U.S. Department of Commerce by major industry, expenditures for transportation (maintenance and construction), and crude oil prices (*42*). Oil prices were used as a surrogate variable to measure the general health of the Texas state economy. Because the oil industry in Texas is a dominant industry, general economic conditions could be measured from it. A major source of state revenue is from the oil industry and its related businesses.

For use in the statistical analysis for highway districts, the individual county employment data and the total personal income data are aggregated annually within each highway district. The transportation expenditure data is likewise aggregated. However, for the per capita personal income data, and the price of crude oil, the mean values (calculated from the counties within each district) are used. To exclude the effects of inflation, all nominal dollar values were deflated into real dollars using the GNP implicit price deflators (1982 = 100) (*43*).

Statistical Analysis

The study objectives were fashioned into two basic structural models as follows:

1. Total employment as a function of transportation expenditures both current and lagged, oil prices both current and lagged, and per capita personal income); and
2. Transportation expenditures as a function of (political variables, oil prices both current and lagged, per capita personal income, and total employment).

A series of linear regression models were used to test the above structural relationships. These regression models were of two types: (a) time series models using dummy variables to pool the data, and (b) cross-sectional time series models with dummy variables. Pooled data provides more observations than nonpooled cross-sectional or time series alone, and thus increases the degrees of freedom available in the analysis (*23,44*). By pooling the data, more lagged terms could be used as variables than otherwise would have been possible with only 18 annual observations.

Pooling refers to the process of combining data. When time series data are pooled using dummy variables, it is assumed that the cross-sectional parameters are constant over time. This assumption means that the cross-sectional differences between the districts have stayed the same during the study years. When it is assumed that the cross-sectional parameters shift over time, it is appropriate to pool with both cross-sectional and time series explanatory variables. However, when this procedure is followed, the structure of the error term in the regression equation becomes more complex. The complexity arises because the error term consists of time series related disturbances, cross-sectional disturbances, and a combination of both error components (*45*). There are different techniques available to pool the data, and the one used reflects the assumptions made about the structure and components of the error or disturbance term (*46*).

There are 24 highway districts in Texas, Districts 1 to 21 and Districts 23 to 25. District 22, which no longer exists, was integrated into Districts 7 and 15. Twenty-three dummy variables were used to pool the data in the time series models and to measure the differences between highway districts within each model. There is one less dummy variable than there are districts allowing the dummy variable coefficients in the regression analysis to be interpreted with respect to the omitted district. In this study, District 1 was the omitted district and is the one from which the difference in the other districts is based.

Aggregating the data within each district and pooling the data using dummy variables made it possible to make interdistrict comparisons of the effects of the independent variables on the dependent variables. It was assumed that district aggregates would give a more realistic representation of the actual relationships between economic activity, expenditures on transportation, and the political process. Intuitively, the effects of the independent variables on the dependent variable are felt over a wider range than just within the immediate county. Aggregating within districts had the effect of capturing these intercounty relationships within districts. This assumption means that when a highway is constructed, the economic benefits of this expenditure are felt in the surrounding geographic area and not only in those counties that it intersects.

The particular pooled cross-sectional time series procedure used is the TSCSREG procedure available in the Statistical Analysis System (SAS) computer program (*47*). PROC TSCSREG allows use of three different methods to model the statistical characteristics of the error components in a pooled cross-sectional time series regression model. The three methods are the Parks, Da Silva, and Fuller and Battese model approaches.

The Parks method is a first-order autoregressive error structure model that assumes contemporaneous correlation between cross sections and is solved using a two-stage generalized least squares procedures. The Da Silva method is a mixed variance component moving average error process used to estimate a suitable estimator to replace the unknown covariance matrix. The regression parameters are estimated using a two-stage generalized least squares procedure. The Fuller and Battese (*48*) method was selected for use in this analysis and assumes a "variance component model error structure similar to the common two-way random effects model with covariates." The variance components are estimated by the "fitting of constants" method, rather than by creating dummy variables, and estimates of the regression parameter are made using generalized least squares. Dummy variables are then used to test the differences between districts. Another reason for selecting the Fuller and Battese method is that the computer core storage needed in performing the analysis is smaller than for the Parks and for the Da Silva methods.

Dummy variables are used in the economic analysis to measure the differences in effects between highway districts. The null hypothesis (H_0: $B = 0$) tested is that the effect of the independent variables on the dependent variable is not different between districts. By pooling the data for all districts with dummy variables, the differences between districts can be isolated. The dummy variables whose *t*-statistics from the regression analysis are significant are the ones for which the null hypothesis that there is no difference can be rejected, with the conclusion that there is a difference. The amount of difference is measured by adding the coefficient for the dummy variable to the intercept term in the regression equation.

Statistical Results

The statistical results are presented in the following three sections. The first section is for models having total employment as the dependent variable. The second section is for models developed at the sector level where sector employment is the dependent variable. The last section is for models in which the amount of expenditures on transportation maintenance and construction is the dependent variable.

Total Employment Models

Using the two pooled procedures, two equations for estimating total employment were developed, as outlined in the first structural relationship, total employment as a function of transportation expenditures both current and lagged, oil prices both current and lagged, and per capita personal income. Equation 1 was developed using ordinary least squares (OLS) time series regression, and Equation 2 was developed using the previously discussed PROC TSCSREG cross-sectional time series procedure. These two equations are

$$\begin{aligned}\text{TOTES} = {} & -337926.49 + 0.1454\ \text{RTES} \\ & + 0.1058\ \text{RTE2S} + 0.0909\ \text{RTE4S} \\ & + 3797.81\ \text{RPCPIM} \qquad (1)\end{aligned}$$

and

$$\text{TOTES} = -11645.0 + 0.0241\ \text{RTES} + 0.0674\ \text{RTE2S} + 0.0324\ \text{RTE4S} + 3921.96\ \text{RPCPIM} \quad (2)$$

Figure 1 shows the definitions of all model variables appearing in the equations and in the tables.

DUMi = **Intercept dummy variable for District *i*,**
$INT = **Intercept,**
ROILP4M = **Real oil price lagged 4 years,**
RPCPIM = **Real per capita personal income,**
RTES = **Real transportation expenditures,**
RTE1S = **Real transportation expenditures lagged 1 year,**
RTE2S = **Real transportation expenditures lagged 2 years,**
RTE3S = **Real transportation expenditures lagged 3 years,**
RTE4S = **Real transportation expenditures lagged 4 years,**
RTPIS = **Real total personal income,**
SEDUMi = **Total employment slope dummy for District *i*,**
SIDUMi = **Real total personal income slope dummy for District *i*,**
SPIDUMi = **Personal income slope dummy for District *i*,**
STEDUMi = **Real transportation expenditures slope dummy for District *i*, and**
TOTES = **Total employment.**

FIGURE 1 Definitions of model variables.

From these two equations, the estimates of the effects of transportation expenditures, oil prices, and per capita income on total employment using time series techniques are similar to those estimates when using the cross-sectional time series technique. The same coefficients are significant in both models, and the transportation expenditure lags appear to follow a 2-year pattern. However, there is a difference in this pattern between the two models. In Equation 1, the effect of transportation expenditures on employment follows a decreasing linear function. In Equation 2, a second-order polynomial would more closely resemble the lagged impact. For example, the coefficients could be viewed as multipliers having an effect of 0.0241 in the immediate year, increasing to a peak of 0.0674 2 years later, and then declining to 0.0324 4 years after the initial impact. This difference between the two models is most likely attributable to some characteristic of the data that is captured when cross-sectional affects are accounted for in this model. This could be interpreted to mean that the cross-sectional effects on total employment regarding coefficient significance have not shifted through time but have remained relatively constant during the years of this study, whereas the pattern of impact, resulting from structural changes, may have changed over time.

These models indicate that expenditures on transportation, in the lag patterns described above, do positively affect the amount of total employment. Table 1 presents the standard errors, *t*-statistics, and significant dummy variable coefficients for the time series equation, Equation 1. This equation would be used to estimate effects on total employment assuming no cross-sectional shifts. The dummy variables in Equation 1 for which the null hypothesis (that there is no difference between

TABLE 1 TIME SERIES REGRESSION ESTIMATES WITH TOTAL EMPLOYMENT AS THE DEPENDENT VARIABLE

SOURCE	B VALUES	STD ERR B	T FOR H:B = 0	PROB>{T}
$INT	-337926.49	24308.83	-13.901	0.0001
RTES	0.1452	0.0177	8.185	0.0001
RTE2S	0.1058	0.0221	4.773	0.0001
RTE4S	0.0909	0.0221	4.107	0.0001
RPCPIM	3797.81	255.30	14.876	0.0001
DUM2	152657	22889.92	6.669	0.0001
DUM4	-116702.53	19945.03	-5.851	0.0001
DUM6	-70719.82	18895.64	-3.743	0.0002
DUM7	-56112.02	18190.81	-3.085	0.0022
DUM9	96396.28	18278.42	5.274	0.0001
DUM10	49657.31	18192.68	2.730	0.0066
DUM12	745981.23	47199.06	15.805	0.0001
DUM13	-51333.55	18291.77	-2.806	0.0052
DUM14	135902.67	18464.83	7.360	0.0001
DUM15	226025.93	26283.75	8.599	0.0001
DUM16	66715.81	18304.74	3.645	0.0003
DUM18	580747.01	32539.82	17.847	0.0001
DUM21	166222.93	19416.79	8.561	0.0001
DUM24	106618.70	18331.66	5.816	0.0001
DUM25	-51533.48	1.8787.31	-2.743	0.0064

Degrees of Freedom for T-Statistics	= 412
Model F Value	= 521.019
Prob > F	= 0.0001
Adjusted R Square	= 0.9582
Mean Square Error	= 5343435969
Durbin-Watson D	= 0.462

these districts and District 1) was not rejected, are Districts 3, 5, 8, 11, 17, 19, 20, and 23.

The dummy variable coefficients presented in Table 1 are for those districts that were found to be statistically different from District 1. A positive coefficient indicates that the effects of the independent variables on total employment were greater than in those districts listed earlier. This means that the employment effects of a dollar spent in Districts 2, 9, 10, 12, 14, 15, 16, 18, 21, and 24 are greater than for a dollar spent in Districts 1, 3, 5, 8, 11, 17, 19, 20, and 23. A negative coefficient indicates that the effect on total employment would be less than in the nonsignificant districts. This means that the employment effects of \$1 spent in Districts 4, 6, 7, 13, and 25 are less than for \$1 spent in Districts 1, 3, 5, 8, 11, 17, 19, 20, and 23.

The amount of the difference for any particular significant district can be calculated by adding the dummy variable coefficient for that district to the intercept term in Equation 1. For example, to find the effect on employment in District 2, one would add the District 2 dummy variable (DUM2) coefficient value of 152,657 from Table 1 to the intercept value of −337,926.49 in Equation 1.

The Durbin-Watson statistic of 0.462 in this time series model suggests the presence of autocorrelation. Autocorrelation is a condition in which the stochastic disturbance terms are not independent of one another but are serially correlated through time leading to an incorrect measure of the true error variance. One result of autocorrelation is that the standard errors are biased downwards, leading to the conclusion that the parameter estimates are more precise than they really are. Generally, this problem occurs because of the way the model is specified. For example, the autocorrelation in this model is apparently caused by the inclusion of lagged variables and the exclusion of other relevant variables from the model. As a result, the regression estimates and their corresponding significance statistics in this time series model are possibly overstated. However, the size of the significance statistics are sufficiently large for the overall model, and for most all of the variables, to overcome most reasonable questions concerning validity of the results.

In order to correct for autocorrelation, the number of lagged variables used in the model specification was minimized. Preliminary models were tested excluding the lagged transportation expenditure variable. As expected, with these model specifications the Durbin-Watson statistic indicated a decrease in autocorrelation. However, a lagged transportation variable was included in the attempt to capture the important time pattern of the effects of transportation expenditures on employment, as has been demonstrated by other studies (*16,24–26*). Moreover, an effort was made to include all of the relevant variables in the specification of the model. Because the analysis was done on a county basis, with the county data being aggregated at the district level as explained earlier, only variables for which county data, for all 254 counties, was available over the 18-year study period were possible candidates for inclusion.

Table 2 presents the Fuller and Battese estimates from the pooled cross-sectional time series model. The differences between districts can be seen by looking at the dummy variables for which there was significant evidence to reject the null hypothesis that there is no difference in effects between the districts. In this model, dummy variables were used to also

TABLE 2 TIME SERIES CROSS-SECTIONAL REGRESSION ESTIMATES (FULLER AND BATTESE METHOD) WITH TOTAL EMPLOYMENT AS THE DEPENDENT VARIABLE

SOURCE	B VALUES	T FOR H:B=0	PROB>{T}	STD ERR B
$INT	-11645.0	-0.68434	0.4941	17016
RTES	0.0241	2.1574	0.0316	0.011196
RTE2S	0.0674	8.4449	0.0000	0.0079833
RTE4S	0.0324	4.1900	0.0000	0.0077348
RPCPIM	3921.96	3.3725	0.0008	11.629
DUM12	-558945.	-9.8536	0.0000	56725.
DUM18	-905027.	-12.997	0.0000	69633.
SPIDUM2	479.039	11.721	0.0000	40.870
SPIDUM6	61.9934	2.8558	0.0045	21.708
SPIDUM9	194.508	4.2806	0.0000	45.440
SPIDUM10	212.226	5.4445	0.0000	38.980
SPIDUM12	1930.59	40.974	0.0000	47.118
SPIDUM14	340.013	11.971	0.0000	28.404
SPIDUM15	358.087	13.813	0.0000	25.924
SPIDUM17	80.3471	2.4852	0.0133	32.330
SPIDUM18	2157.01	48.759	0.0000	44.238
SPIDUM20	128.613	3.1417	0.0018	40.938
SPIDUM21	280.610	5.5870	0.0000	50.226
SPIDUM24	366.810	5.4041	0.0000	67.876
STEDUM2	0.0614248	2.5351	0.0116	0.024229
STEDUM12	0.0625535	4.6244	0.0000	0.013527
STEDUM14	0.0770131	2.1340	0.0334	0.036089
STEDUM18	0.118575	6.0162	0.0000	0.019709

Degrees of Freedom for T-Statistics = 409 test the slope of the regression equation and not just the intercept. These slope dummies identify the source of the difference. For example, the dummy variables in Table 2 that are coded as STEDUMi are the districts for which the expenditures on transportation have differing affects, and the SPIDUMi dummies are measuring the differing affects of personal income.

Sector Employment Models

To evaluate if this positive effect on total employment was universal across the different industries in the state, the time series model developed in Equation 1 was tested on a sector basis for five industries. OLS time series equations were estimated for the construction, manufacturing, mining, services, and wholesale trade sectors. In each of these models, the dependent variable was total employment within that industry. The results of these sector models are presented in Tables 3–7.

Table 3 presents the statistical results and variable coefficients for the construction sector, indicating the district differences in impact on construction sector employment for a given change in the independent variables. Likewise, Table 4 presents the statistical results and variable coefficients for the manufacturing sector, and shows by district the different effects on manufacturing employment for a given change in the independent variables. Coefficients and significance statistics for mining sector employment impact are presented by district in Table 5. Table 6 presents the district differences on employment in the services sector, with the corresponding statistics and coefficients. Finally, Table 7 presents the different impacts by district that transportation expenditures and per capita income have on total employment for the wholesale trade sector.

The results of the industry analysis are uniform across the sectors. Transportation expenditures exhibited a positive relationship to the level of total employment, with one exception. That exception is in the manufacturing sector where, as indicated in Table 4, there is a negative relationship between manufacturing employment and expenditures on transportation 3 years earlier. This counterintuitive result is likely an idiosyncrasy of the aggregated data, or perhaps is a result of the autocorrelation introduced through the inclusion of the lagged variable, or the exclusion of other relevant variables.

Moreover, in all other sectors and in all years that had statistically significant lagged-expenditure variables, the relationship between employment and expenditures on transportation, the relationship was positive. The wholesale trade sector, presented in Table 7, was the only sector where there was not also a lagged positive relationship. Only in the manufacturing and mining sectors, Tables 4 and 5, was total employment affected by oil prices, and in both cases it was a negative relationship with the price of 4 years previous. In all models, the level of per capita personal income was the dominant independent variable determining total employment.

The impacts on the various sectors differ across districts as expected. This variation is evident by looking at the dummy variables in the tables that were found most often to be significant in one or more of the models. Some interesting observations can be made from viewing the figures showing the district differences. For example, there appears to be a difference in effect between urban and rural districts as indicated by general district groupings. For instance, the districts that include the larger metropolitan concentrations of the state, Districts 2 (Fort Worth), 12 (Houston), 14 (Austin), 15 (San Antonio), and 18 (Dallas) are often grouped together. Likewise, the more rural districts in the state, Districts 4 (Amarillo), 6 (Odessa), 7 (San Angelo), and 13 (Yoakum) are similarly grouped with smaller employment impacts.

TABLE 3 TIME SERIES REGRESSION ESTIMATES WITH CONSTRUCTION SECTOR EMPLOYMENT AS THE DEPENDENT VARIABLE

SOURCE	B VALUES	STD ERR B	T FOR H:B = 0	PROB>{T}
$INT	-24500.00	2184.77	-11.214	0.0001
RTES	0.0090	0.0018	4.947	0.0001
RTE1S	0.0073	0.0021	3.424	0.0007
RPCPIM	254.83	22.9934	11.083	0.0001
DUM2	7939.37	2032.31	3.907	0.0001
DUM4	-6512.40	1814.84	-3.588	0.0004
DUM9	4135.38	1691.35	2.445	0.0149
DUM12	85022.48	3789.73	22.435	0.0001
DUM14	8722.88	1704.34	5.118	0.0001
DUM15	14436.94	2201.33	6.558	0.0001
DUM16	8437.38	1696.14	4.974	0.0001
DUM18	30189.23	2600.47	11.609	0.0001
DUM20	5908.66	1710.58	3.454	0.0006
DUM21	9960.70	1806.82	5.513	0.0001
DUM24	7002.72	1700.54	4.118	0.0001

Degrees of Freedom for T-Statistics	= 417
Model F Value	= 427.377
Prob > F	= 0.0001
Adjusted R Square	= 0.9327
Mean Square Error	= 47099515.67
Durbin-Watson D	= 0.415

TABLE 4 TIME SERIES REGRESSION ESTIMATES WITH MANUFACTURING SECTOR EMPLOYMENT AS THE DEPENDENT VARIABLE

SOURCE	B VALUES	STD ERR B	T FOR H:B = 0	PROB>{T}
$INT	-10973.66	3012.19	-3.643	0.0003
RTES	0.0083	0.0023	3.598	0.0004
RTE1S	0.0098	0.0028	3.474	0.0006
RTE3S	-0.0116	0.0025	-4.548	0.0001
ROILP4M	-14150.45	6891.57	-2.053	0.0407
RPCPIM	430.38	37.01	11.627	0.0001
DUM2	62323.92	2719.79	22.915	0.0001
DUM3	-19204.79	2322.23	-8.270	0.0001
DUM4	-24007.79	2587.30	-9.279	0.0001
DUM5	-15627.37	2228.80	-7.012	0.0001
DUM6	-26667.74	2382.48	-11.193	0.0001
DUM7	-21799.83	2212.58	-9.853	0.0001
DUM8	-20954.94	2259.71	-9.273	0.0001
DUM11	-5334.86	2232.13	-2.390	0.0173
DUM12	155506.37	5573.77	27.900	0.0001
DUM13	-17520.95	2212.71	-7.918	0.0001
DUM15	20237.65	2981.07	6.789	0.0001
DUM16	-12779.37	2192.88	-5.828	0.0001
DUM17	-15731.46	2191.24	-7.179	0.0001
DUM18	148802.47	3830.64	38.845	0.0001
DUM19	-4496.37	2192.82	-2.050	0.0410
DUM20	13502.56	2231.47	6.051	0.0001
DUM23	-19046.92	2289.98	-8.317	0.0001
DUM24	8082.76	2196.40	3.680	0.0003
DUM25	-27057.52	2329.21	-11.617	0.0001

Degrees of Freedom for T-Statistics = 407
Model F Value = 689.611
Prob > F = 0.0001
Adjusted R Square = 0.9760
Mean Square Error = 49590525585
Durbin-Watson D = 0.514

TABLE 5 TIME SERIES REGRESSION ESTIMATES WITH MINING SECTOR EMPLOYMENT AS THE DEPENDENT VARIABLE

SOURCE	B VALUES	STD ERR B	T FOR H:B = 0	PROB>{T}
$INT	-28714.49	1704.67	-16.845	0.0001
RTES	0.0074	0.0012	6.196	0.0001
RTE1S	0.0114	0.0017	6.567	0.0001
RTE2S	0.0073	0.0016	4.503	0.0001
RTE4S	0.0034	0.0013	2.514	0.0123
ROILP4M	-8355.80	3748.47	-2.229	0.0263
RPCPIM	233.70	20.6990	11.291	0.0001
DUM2	-14647.59	1413.10	-10.366	0.0001
DUM3	3613.89	1151.36	3.139	0.0018
DUM4	-4388.38	1301.91	-3.371	0.0008
DUM6	16901.99	1184.54	14.269	0.0001
DUM8	4454.14	1118.70	3.982	0.0001
DUM10	5449.02	1096.08	4.971	0.0001
DUM11	3848.14	1125.70	3.418	0.0007
DUM12	8114.05	3100.92	2.617	0.0092
DUM14	-4362.09	1109.34	-3.932	0.0001
DUM15	-16042.54	1600.83	-10.021	0.0001
DUM16	7963.15	1091.93	7.293	0.0001
DUM18	-20035.88	2117.46	-9.462	0.0001
DUM20	-2356.74	1110.54	-2.122	0.0344
DUM21	6475.91	1191.74	5.434	0.0001
DUM23	5686.42	1151.75	4.937	0.0001
DUM25	3304.63	1164.94	2.837	0.0048

Degrees of Freedom for T-Statistics = 409
Model F Value = 195.598
Prob > F = 0.0001
Adjusted R Square = 0.9132
Mean Square Error = 19012939.21
Durbin-Watson D = 0.542

TABLE 6 TIME SERIES REGRESSION ESTIMATES WITH SERVICES SECTOR EMPLOYMENT AS THE DEPENDENT VARIABLE

SOURCE	B VALUES	STD ERR B	T FOR H:B = 0	PROB>{T}
$INT	-77852.74	5367.68	-14.504	0.0001
RTES	0.0303	0.0038	8.000	0.0001
RTE2S	0.0230	0.0047	4.854	0.0001
RTE4S	0.0244	0.0047	5.175	0.0001
RPCPIM	738.41	55.353	13.340	0.0001
DUM2	16055.90	4902.22	3.275	0.0011
DUM4	-24934.89	4261.84	-5.851	0.0001
DUM6	-14997.06	4038.91	-3.713	0.0002
DUM7	-8256.18	3903.41	-2.115	0.0350
DUM9	13495.53	3934.14	3.430	0.0007
DUM10	10179.11	3904.36	2.607	0.0095
DUM11	8828.68	3966.63	2.226	0.0266
DUM12	125282.83	9962.97	12.575	0.0001
DUM13	-8311.39	3929.55	-2.115	0.0350
DUM14	26544.74	3966.97	6.691	0.0001
DUM15	29039.42	5605.17	5.181	0.0001
DUM16	12879.28	3939.38	3.269	0.0012
DUM18	91008.51	6921.68	13.148	0.0001
DUM21	27295.69	4206.26	6.489	0.0001
DUM24	17898.58	3949.86	4.531	0.0001

Degrees of Freedom for T-Statistics	= 412
Model F Value	= 403.886
Prob > F	= 0.0001
Adjusted R Square	= 0.9467
Mean Square Error	= 246083140
Durbin-Watson D	= 0.422

TABLE 7 TIME SERIES REGRESSION ESTIMATES WITH WHOLESALE TRADE SECTOR EMPLOYMENT AS THE DEPENDENT VARIABLE

SOURCE	B VALUES	STD ERR B	T FOR H:B = 0	PROB>{T}
$INT	-19813.27	1727.88	-11.467	0.0001
RTES	0.0102	0.0012	8.056	0.0001
RPCPIM	236.33	18.77	12.585	0.0001
DUM2	10986.95	1532.30	7.170	0.0001
DUM3	-3390.61	1381.60	-2.454	0.0145
DUM4	-3467.65	1470.93	-2.357	0.0189
DUM7	-3345.44	1355.58	-2.468	0.0140
DUM12	76176.46	2577.77	29.551	0.0001
DUM15	13798.29	1624.09	8.496	0.0001
DUM16	2934.00	1359.82	2.158	0.0315
DUM18	73121.72	1832.48	39.903	0.0001
DUM21	11321.61	1445.17	7.834	0.0001
DUM24	6233.79	1367.24	4.559	0.0001
DUM25	-3404.58	1384.79	-2.459	0.0144

Degrees of Freedom for T-Statistics	= 418
Model F Value	= 744.162
Prob > F	= 0.0001
Adjusted R Square	= 0.9573
Mean Square Error	= 30664914.82
Durbin-Watson D	= 0.421

Thus, when money is spent on transportation, it increases the level of employment in the highway districts. However, there is a difference between the districts in the amount of employment that is generated. Also, there is a difference in the economic sectors regarding the timing of the employment effects and the length of those effects. This is important because as highway planners and SDHPT personnel go through the process of deciding where to construct roads, they can better estimate the timing and amount of economic growth as measured by total employment. This result also provides information that can be helpful to district personnel in promoting growth in specific industries within their districts.

Total Transportation Expenditures

Using the pooled procedures discussed earlier, equations for estimating the structural relationship of transportation expenditures were specified and tested in which transportation expenditures were a function of political variables, oil prices both current and lagged, per capita personal income and total employment.

The parameter estimates and standard errors for these estimates and their corresponding *t*-statistics are presented in Table 8 for the cross-sectional time series regression model. The coefficients for the significantly different dummy variables, Districts 2, 5, 12, 15, and 24, are also presented in the table. The variables representing oil prices in the current period and in the lagged periods were not significant in any of the expenditure models. Additionally, all of the political variables were found not to be significant. The political variables as they were defined and included in this study have no statistically significant relationship to public expenditures for transportation construction and maintenance.

CONCLUSIONS AND RECOMMENDATIONS

A series of linear regression models was used to test structural relationships between total employment, expenditures on transportation construction and maintenance, and selected economic and political variables. Current and lagged variables were used in the analysis of the data using both pooled cross-sectional time series procedures, and pooled time series techniques. For the structural relationship in which total employment is the dependent variable, practically identical results were achieved from a cross-sectional time series model and from the pooled time series model. From these model results it can be concluded that transportation expenditures positively affect the amount of total employment. This impact appears to follow a 2-year cycle lasting 4 years. Per capita personal income is also highly significant in determining the level of employment.

There is a difference in effects of transportation expenditures on employment between economic sectors within the state. Current expenditures were significant in the construction, manufacturing, mining, services, and wholesale trade sectors. The impact was lagged as long as 3 years in the manufacturing and mining sectors, and 4 years in the services sector. Twenty-three dummy variables were used to pool the data in the time series models and to measure the differences between highway districts within each model. For employment, the effect is stronger in the more populated districts.

For the model in which transportation expenditures is the dependent variable, only economic variables were found to be significant. The political variables as they were defined and included in this study have no statistically significant relationship to public expenditures for transportation construction and maintenance.

As a result of this research, it is recommended that in funding decisions regarding mutually exclusive projects, the impacts on employment should be estimated and considered for inclusion into project ranking, rating, and assessment techniques. Also, the differential effects on employment across industries can be estimated and included in strategic planning and policy formation regarding statewide economic diversification. Additional research should be initiated to further investigate the timing of impacts of highway policy and transportation expenditure decisions on the economic climate of the highway districts.

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TABLE 8 TIME SERIES CROSS-SECTIONAL REGRESSION ESTIMATES (FULLER AND BATTESE METHOD) WITH TRANSPORTATION EXPENDITURES AS THE DEPENDENT VARIABLE

SOURCE	B VALUES	T FOR H:B=0	PROB>{T}	STD ERR B
$INT	284525	8.1390	0.0000	34958.
RTPIS	8.35629	3.9838	0.0001	2.0976
TOTES	-1.01402	-2.0674	0.0393	0.49047
DUM2	186616.	-2.6728	0.0078	69821.
DUM5	-1421809.	-3.4601	0.0006	410917.
DUM12	2626277.	3.1384	0.0018	836811.
DUM15	385400.	5.1645	0.0000	74626.
DUM23	-126043.	-2.5845	0.0101	48769.
DUM25	-126094.	-2.5153	0.0123	50130
SIDUM12	29.7713	2.7618	0.0060	10.779
SIDUM18	-38.7568	-9.9172	0.0000	3.9080
SEDUM5	7.72355	3.7202	0.0002	2.0761
SEDUM12	8.64307	-2.7673	0.0059	3.1233
SEDUM18	-8.53968	9.8471	0.0000	0.86723

Degrees of Freedom for T-Statistics = 418

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Economic Feasibility of Exclusive Vehicle Facilities

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A microcomputer program called "exclusive vehicle facilities" (EVFS) that determines the economic feasibility of separating light vehicles from heavy vehicles on a given section of controlled-access highway by designating existing lanes and constructing new lanes to be used exclusively by light or heavy vehicles is described. On the basis of user inputs to a spreadsheet user interface, EVFS calculates the net present value, benefit-cost ratio, and other performance measures of the alternative exclusive vehicle facility specified. The three possible lane use policies allowed within EVFS are mixed-, light-, and heavy-vehicle lanes. EVFS accounts for the following potential benefits or cost savings both for person and for freight travel: (a) travel time savings; (b) vehicle operating cost savings; and (c) accident cost savings (fatalities, injuries, and property damage), because of less severe accidents by separating light and heavy vehicles; and (d) queuing delay savings because of fewer accidents causing blockages. EVFS also accounts for the following project costs: (a) initial construction costs, (b) initial right-of-way acquisition and demolition costs, and (c) periodic pavement resurfacing costs, which may be less frequent and less costly for light-vehicle lanes. EVFS is designed to evaluate any of the following five cases: (a) do nothing; (b) designate existing lanes for mixed, light, and heavy vehicles; (c) add mixed-vehicle lanes (no special lane use restrictions); (d) add non-barrier-separated lanes and designate new and existing lanes for mixed, light, and heavy vehicles; and (e) add barrier-separated lanes and designate new and existing lanes for mixed, light, and heavy vehicles. An example indicates that exclusive vehicle facilities are most warranted for congested urban highways with significant percentages of single-unit and combination trucks in the traffic stream.

As vehicle size differences, vehicle volumes, and relative truck volumes continue to increase across the United States, the question arises as to whether exclusive vehicle lanes are economically warranted on a greater number of urban highways. Although the average automobile has become smaller and lighter, partly in response to fuel economy pressures, the average truck has become larger and is carrying greater loads as carriers strive to increase productivity. The average curb weight of new cars sold in the United States dropped from 3,600 lb in 1976 to 2,700 lb in 1982, and has ranged between 2,700 lb and 2,800 lb since then (L. Williams, personal communication). For all U.S. highways, truck vehicle-miles of travel (VMT) relative to passenger VMT has been increasing as trucks are carrying a greater share of all freight shipments. Percentages of total VMT accounted for by trucks and passenger vehicles were 28 and 72 percent in 1976, but changed to 22 and 78 percent by 1985. Over this same period, the share of total VMT accounted for by larger combination vehicles increased from 3.5 to 4.5 percent.

A general description and example application of an analysis program that determines the economic feasibility of separating light vehicles from heavy vehicles on limited-access highways by designating existing lanes and constructing new lanes to be used exclusively by light or heavy vehicles is described. On the basis of user inputs to a spreadsheet user interface, a microcomputer program called "exclusive vehicle facilities" (EVFS) calculates the net present value, benefit-cost ratio, and other facility performance measures for each alternative specified. EVFS was developed in research for the FHWA as part of its efforts to assess ways of improving the overall performance of the highway system.

The major potential benefits of exclusive vehicle facilities are (a) lower travel times caused by smoother traffic flow, (b) fewer fatal and nonfatal accidents per unit of travel because of vehicle size separation, and (c) less delay for both person and freight travel as a result of fewer and less-severe accidents causing lane blockages. Exclusive vehicle facilities are expected to be most warranted in major metropolitan areas, because the benefits of vehicle separation increase with overall traffic volumes and truck volume percentages in the vehicle mix. However, because construction costs per lane-mile are lower for rural at-grade highway sections with less developed right-of-ways than for elevated sections in densely built urban areas, exclusive vehicle facilities might also be economically feasible for certain rural highway sections with high accident rates because of truck-car interactions.

EVFS is designed for site-specific analyses and not for regional or national network analyses. EVFS can be used to evaluate reversible lane options by adjusting the inputs and outputs of EVFS to recognize that the reversible lanes serve only one direction of traffic for one-half of each day, including one peak period. Other recurrent traffic conditions, such as weekend recreational travel, can also be included by aggregating the results of several analyses for days of the year with different traffic volumes and vehicle mixes. EVFS is not applicable to toll roads, because fee schedule adjustments, special financing arrangements, tolls, user charges, and cost allocation issues are not considered. EVFS cannot be used to evaluate the cost effectiveness of high-occupancy-vehicle lanes, because passenger vehicles are not differentiated on the basis of automobile occupancy.

In comparing alternative vehicle facilities, EVFS accounts for differences both to person and to freight travel in (a) total travel time, (b) vehicle operating costs, (c) accident costs (fatalities, injuries, and property damage), and (d) accident travel time delays because of fewer and less severe accidents by

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separating light and heavy vehicles. EVFS also accounts for facility cost differences, including (a) initial construction, right-of-way acquisition and demolition costs; and (b) periodic pavement resurfacing costs, which may be less frequent and less costly for light-vehicle lanes.

The economic evaluation approach used in EVFS is to estimate and compare the net present values and benefit-cost ratios of alternative facility designs as generally prescribed for project investment analyses by engineering economic textbooks such as Au and Au (*1*). Many aspects of the cost and benefit calculations performed by the analysis program are described in the manual on benefit-cost analyses published by the Association of State Highway and Transportation Officials (also referred to as the "AASHTO Red Book") (*2*). All costs and benefits are calculated in 1985 dollars, and all future amounts are discounted to present values. Cost data obtained for other years are adjusted to 1985 dollars by applying the consumer price index (CPI) or more specific construction cost indices.

Three lane use policies allowed within EVFS pertain to mixed-vehicle (MV), light-vehicle (LV), and heavy-vehicle (HV) lanes. Heavy vehicles include the two categories of all single-unit (SU) trucks above 10,000 lb and all combination vehicles. Mixed-vehicle lanes can be used by all vehicles, subject to state and federal truck size and weight limits. Light-vehicle lanes can also be referred to as "car-only" lanes, and heavy-vehicle lanes can also be referred to as "truck-only" lanes. Light-vehicle lanes can only be used by motorcycles, automobiles, pickup trucks, light vans, buses, and trucks below 10,000-lb gross vehicle weight. All other vehicles must use the mixed- or heavy-vehicle lanes. Although buses are similar in weight and operating characteristics to SU vehicles, buses are permitted to use light-vehicle lanes for safety considerations of the bus occupants.

Vehicle separation can be achieved at a low capital cost by designating existing lanes for light vehicles only during peak travel hours. On the other hand, barrier-separated lanes have the highest capital cost because of more complex interchanges needed to separate traffic for access to and egress from the rest of the highway system. EVFS is designed to evaluate any of the following five cases:

- *Case 0:* Do nothing.
- *Case 1:* Designate existing lanes for mixed, light, and heavy vehicles.
- *Case 2:* Add MV lanes (no special lane use restrictions).
- *Case 3:* Add non-barrier-separated lanes and designate new and existing lanes for mixed, light, and heavy vehicles.
- *Case 4:* Add barrier-separated lanes and designate new and existing lanes for mixed, light, and heavy vehicles.

The purpose of evaluating Case 0 is to generate base-level estimates of facility performance to which the other alternatives can be compared. These base-level performance results also indicate whether input values describing a particular site are reasonable in terms of traffic speeds, travel times, and accident costs. The analysis of Case 1 may not be warranted where there are three or less existing lanes in each direction, but it may be an attractive alternative for sites with heavy truck traffic and four or five existing lanes in each direction. The Dan Ryan Expressway in Chicago is one example of Case 1 in which heavy vehicles were restricted from using the left-most of three lanes in each direction without adding any new lanes or traffic barriers.

Case 2 is the first alternative in which lanes are added to an existing facility. Case 2 is conventional highway widening with no lane use restrictions. Case 2 enables the user to generate baseline estimates of costs and benefits for a particular site given that a more typical capital improvement is made. Again, many of the inputs required for Case 2 will also be needed for Cases 3 and 4. Cases 3 and 4 both involve highway widening, but they are distinguished by whether the lanes carrying light and heavy vehicles are barrier separated, which adds greatly to the capital cost of lane and interchange construction. The New Jersey Turnpike for roughly 40 mi southwest of New York City is an example of Case 4 in which barrier-separated mixed-vehicle lanes were added and some of the existing lanes were restricted to light use.

All adjustable inputs needed to specify a particular facility alternative are entered to EVFS by a spreadsheet user interface and used by EVFS to make the engineering economic calculations needed to compare different alternatives. The spreadsheet user interface offers default values on the basis of nationwide averages for many of the input items, although the user has the option to override any of the default values with preferred values. EVFS also uses many data tables and formulas from a variety of sources referenced later such as the AASHTO Red Book (*2*) and the *1985 Highway Capacity Manual* (*3*) to evaluate traffic speeds and vehicle operating costs for the facility alternatives.

SITE AND TRAFFIC CHARACTERISTICS

As presented in Table 1, the spreadsheet user interface requires that the user specify general characteristics of the highway facility, traffic conditions, and surrounding area right-of-way. Highway construction costs and accident rates vary by whether a highway section is in a rural, suburban, or urban area. In EVFS, construction costs are assumed to be directly proportional to the total number of newly constructed lanes, and resurfacing costs are assumed to be proportional to the total number of new and existing lanes. Construction costs are higher for Case 4 in which the exclusive vehicle lanes are barrier separated. The curvature and gradient of a highway section affect its traffic capacity, average travel speeds and times, and vehicle operating costs.

Estimation of all user costs (value of time, vehicle operating costs, accident costs) and the resurfacing frequency requires knowledge of current and future traffic volumes, and the vehicle mixes in these traffic volumes. The user can either specify the current average daily traffic (ADT) for all lanes in the direction of traffic being analyzed and the average annual increase in this ADT, or specify current and future hourly traffic volumes for peak and off-peak periods, for which traffic volumes are always given for all lanes in the direction of traffic being analyzed.

Because EVFS does not include travel demand forecasting, the user must take into account the relative attraction or diversion of traffic to a highway because of more or less ca-

TABLE 1 FACILITY SPECIFICATION INPUTS TO EVFS

General Site Information:

1.	Is this a rural, suburban, or urban highway section R/S/U?	S
2.	Current mixed-vehicle lanes in each direction (0-6)?	3
3.	Future mixed-vehicle lanes in each direction (0-6)?	3
4.	Future light-vehicle lanes in each direction (0-6)?	2
5.	Future heavy-vehicle lanes in each direction (0-4)?	0
6.	Number of new lanes of right-of-way to acquire (0-4)?	2
7.	Will exclusive vehicle lanes be barrier separated (Y/N)?	N
8.	Length of section in miles (including decimal places)?	30.0
9.	Number of interchanges along this section?	5
10.	Average road gradient along section (typical value = 0%)?	0%
11.	Average curvature along section (typical value = 2 deg.)?	2

Press Enter

Traffic Characteristics:

		Defaults	
12.	Current average daily traffic (ADT) (one direction)?		80000
13.	Average annual increase in ADT (one direction)?		3000
14.	Current peak-period volume/hr (3 hours/day)?	6667	0
15.	Future peak-period volume/hr in 10 years?	9167	0
16.	Current off-peak volume/hr (15 hours/day)?	4000	0
17.	Future off-peak volume/hr in 10 years?	5500	0
18.	Speed limit for LV along this section (mph)?	65	0
19.	Speed limit for SU and CV along this section (mph)?	55	65
20.	Current LV percentage of total ADT?	69.6%	0.0%
21.	Future LV percentage of ADT in 10 years?	63.0%	0.0%
22.	Current SU percentage of total ADT?	23.8%	0.0%
23.	Future SU percentage of ADT in 10 years?	29.8%	0.0%
24.	Current CV percentage of total ADT?	6.6%	0.0%
25.	Future CV percentage of ADT in 10 years?	7.3%	0.0%

ADT - Average Daily Traffic   SU - Single-Unit Vehicle   Press Enter
LV - Light Vehicle   CV - Combination Vehicle

Other Factors:

26.	Length of the analysis period (number of years)?	20
27.	How many years of this period are construction?	3
28.	Present value discount rate?	10.0%

Press Enter

Facility Construction and 4R Work Cost (in 10^3 dollars):

			Defaults	
29.	Construction cost per lane mile	(unseparated)?	$1,900	$0
30.	Construction cost per interchange	(unseparated)?	$500	$0
31.	Right-of-way acquisition cost/mile	(unseparated)?	$810	$0
32.	Construction cost per lane mile	(w/ barriers)?	$2,660	$0
33.	Construction cost per interchange	(w/ barriers)?	$700	$0
34.	Right-of-way acquisition cost/mile	(w/ barriers)?	$1,134	$0
35.	Average cost per lane mile for major resurfacing?		$108	$0
36.	PSI parameter (delta) (in million 18-kip ESALs)?		2.0	0
37.	PSI parameter (beta) used as the power exponent?		1.2	0
38.	Minimum allowable PSI (lower bound on PSI curve)?		1.5	0
39.	PSI at which resurfacing is desired (0-5 scale)?		2.5	0
40.	Average ESALs per light vehicle?		0.0003	0
41.	Average ESALs per single-unit vehicle?		0.06	0
42.	Average ESALs per combination vehicle?		1.5	0

Press Enter

TABLE 1 (*continued on next page*)

TABLE 1 (*continued*)

Value-of-Time and Accident Costs (in dollars):

	Defaults	
43. Light vehicle value-of-time per hour?	$5.00	$0.00
44. Single-unit vehicle value-of-time per hour?	$10.00	$0.00
45. Combination vehicle value-of-time per hour?	$15.00	$0.00
46. Light vehicle accident rate per LV MVM?	0.986	0.000
47. Single-Unit vehicle accident rate per SU MVM?	1.697	0.000
48. Combination vehicle accident rate per CV MVM?	1.555	0.000
49. Accident costs per fatality accident?	$226,800	$0
50. Accident costs per injury accident?	$9,288	$0
51. Accident costs per PDO accident?	$1,242	$0
52. Percent of total accidents blocking no lanes?	59%	0%
53. Percent of total accidents blocking one lane?	28%	0%
54. Percent of total accidents blocking two lanes?	13%	0%
55. Average minutes to clear non-truck involvements?	39	0
56. Average minutes to clear truck involvements?	63	0
57. Maximum queue length before diversion (miles)?	3.0	0.0

Press Enter

pacity on alternate routes in the traffic corridor in specifying future traffic volumes. Ideally, the prediction of travel demand should be brought into equilibrium with the levels of service supplied by all alternate routes in a travel corridor. However, EVFS would need to be integrated with a combined equilibrium assignment and elastic demand model in order to achieve that result. For example, Janson et al. (*4*) developed a network performance evaluation model for evaluating the impacts of adding high-occupancy-vehicle lanes to a transportation corridor that does equilibrate route volumes and travel costs with elastic demand.

The standard FHWA impedance function is used to calculate travel times from traffic volumes. Impedance is a function of a highway section's free-flow travel, which is assumed to equal the section length divided by the speed limit. Impedance is also a function of a section's practical capacity as measured in passenger car equivalents (PCEs) for the various vehicle types. On the basis of the description of the highway section provided by the user, the analysis program computes practical lane capacities for the highway section in the peak and off-peak hours of each year in the planning horizon. These lane capacities are calculated for an assumed lane width of 12 ft and an average vehicle mix. Lane capacities are calculated on the basis of the *1985 Highway Capacity Manual* (*3*). The capacity formula used in EVFS is

$$c = 2{,}000WT_{\mathrm{SU}}T_{\mathrm{CV}} \tag{1}$$

where

c = lane capacity (in vehicles per lane-hour),
W = lane width and clearance adjustment factor,
T_{SU} = truck adjustment factor for SU vehicles, and
T_{CV} = truck adjustment factor for combination vehicles.

$$T_{SU} = 100/[100 + (E_{\mathrm{SU}} - 1)P_{\mathrm{SU}}]$$

$$T_{\mathrm{CV}} = 100/[100 + (E_{\mathrm{CV}} - 1)P_{\mathrm{CV}}]$$

where

E_{SU} = PCE for SU vehicles,
E_{CV} = PCE for combination vehicles,
P_{SU} = percentage of SU vehicles in traffic flow, and
P_{CV} = percentage of combination vehicles in traffic flow.

The PCE values presented in Table 2 are used in the calculation of lane capacities according to the vehicle mix percentages and traffic volumes specified by the user. This set of passenger car equivalents was recommended for urban freeways by FHWA (*5*). EVFS computes the total volume of passenger car equivalents on the highway section based on the average percentages of single-unit and combination vehicles specified by the user. The PCE values are adjusted for hourly peak and off-peak traffic volumes in each year of the analysis period. The PCE values in Table 2 are also adjusted for the average gradient of the highway section based on the *1985 Highway Capacity Manual* (*3*).

For cases being analyzed in which there are both LV and MV lanes, the LV volume in the MV lanes is estimated by equating the volume-to-capacity (v/c) ratios of the LV and MV lanes. This estimate assumes that LV travelers will choose between the LV and MV lanes so as to satisfy the user equilibrium principle of equal travel times for LV travelers in both sets of lanes. This assumption of equal LV travel times does not account for other factors that may cause a different proportion of LV travelers to use the MV lanes, such as the perceived risk of traveling with heavy vehicles, and the uncertainty of egress options from both the LV and MV lanes. However, equating the LV travel times (or v/c ratios) does allow the PCE values used in calculating the practical capacity

TABLE 2 PASSENGER CAR EQUIVALENTS FOR URBAN FREEWAYS

Vehicles per Lane-Hour	Light Vehicles	Single-Unit Vehicles	Combination Vehicles
0-599	1.0	1.1	1.1
599-999	1.0	1.2	1.2
1000-1499	1.0	1.3	1.4
1500-1799	1.0	1.4	1.8
1800+	1.0	1.6	2.0

Source: Sequin et al. (1982). These values assume an average grade of less than 4% for single-unit vehicles, and less than 2% for combination vehicles.

of each set of lanes to depend on traffic volume, vehicle mix, and road gradient. The equation is as follows:

$$V_{LVLV}/C_{LV} = (V_{LVMV} + V_{SUMV} + V_{CVMV})/C_{MV} \qquad (2)$$

where

V_{LVLV} = LV volume per lane-hour in the LV lanes,
V_{LVMV} = LV volume per lane-hour in the MV lanes,
V_{SUMV} = SU volume per lane-hour in the MV lanes,
V_{CVMV} = CV volume per lane-hour in the MV lanes,
C_{LV} = vehicle capacity per lane-hour of LV lanes, and
C_{MV} = vehicle capacity per lane-hour of MV lanes.

Both V_{LVLV} and C_{LV} can be computed without any adjustments for the PCEs of other vehicles. However, the split of light vehicles between the LV and MV lanes between depends on the volume of trucks in the mixed-vehicle lanes. This means that the PCE values and vehicle mix percentages used to compute c_{MV} must be brought into balance with the volume of light vehicles in the mixed-vehicle lanes. Because of the rather large volume increments given by Table 2, the balance of light vehicles to use the MV lanes can be found within a few iterations of calculations and comparisons.

Vehicle travel times by vehicle and lane type are used to calculate the total value-of-time difference between cases of with and without the exclusive vehicle lanes, and these travel times are converted to speeds for running cost calculations. The running costs of light vehicles, SU trucks, and combination vehicles for different road grades and curves were obtained from AASHTO (*2*). These running costs are updated to 1985 dollars on the basis of the CPI, and are multiplied by the volumes of light, SU, and combination vehicles in each year of the analysis period. The value of time and running cost totals computed for each year are discounted and summed to 1985 present values on the basis of the specified discount rate.

Traffic flow conditions and travel speeds depend on the average mix of vehicles on a highway section. Vehicle mix percentages computed from statistics in which all counted vehicles do not travel the same distance must be computed on the basis of VMT. Accident rates and severities depend on the vehicle mix, and the total value of time computed for all vehicles must also account for the VMT mix of freight and passenger vehicles. The frequency of resurfacing, as affected by cumulative axle loadings, also depends on the vehicle mix. Default values of VMT mix obtained from FHWA (*6*) are presented in Table 3.

Values of time used as defaults in EVFS were used in a 1979 application of the FHWA Highway Investment Analysis Package (*7*). These values are \$3.20, \$7.00, and \$10.00 per hour for light vehicles, SU vehicles, and combination vehicles, respectively. Adjusting for price changes from 1979 to 1985 with a CPI of 1.482 increases these default values to roughly \$5, \$10, and \$15, respectively. The default value of time for light vehicles assumes an average occupancy of roughly 1.3 persons per vehicle. Because buses are included with light vehicles, the average occupancy may be higher for highways serving several bus routes that have a significant number of buses in the traffic stream. Highways leading to central business districts and large employment centers can also attract more car and van pools. Accounting for these factors, the user of EVFS must enter a value of time for light vehicles

TABLE 3 AVERAGE VMT MIX PERCENTAGES ON INTERSTATE HIGHWAYS

Area Type	Light Vehicles	Single-Unit Vehicles	Combination Vehicles
Rural	64.2%	28.6%	7.2%
Suburban	69.6%	23.8%	6.6%
Urban	75.0%	19.0%	6.0%

Source: Rural and urban values from FHWA (1988). Suburban values were computed here as the averages of the rural and urban values.

that corresponds to the average occupancy observed for a particular highway section.

CONSTRUCTION AND RESURFACING COSTS

Although benefits do not begin to accrue until after construction, all future benefits and costs are discounted to time 0 (i.e., the beginning of the first year), and all benefits and costs are calculated in 1985 dollars. With the assumption that inflation affects all goods at the same rate, discounted costs and benefits generated by EVFS can be inflated or deflated to an alternate year on the basis of the CPI without affecting the benefit-cost ratio of each alternative. The present value discount rate is assumed to be 10 percent according to Federal Circular 76 published by the U.S. Office of Management and Budget. Sensitivity of public investment analyses to the discount rate are usually performed with values of 8 and 12 percent.

Construction and right-of-way acquisition costs presented in Table 4 were obtained from the *1985 Characteristics of Urban Transportation Systems* (also referred to as the "CUTS manual"). Construction costs per lane-mile as given by the CUTS manual assume that average percentages of the highway section are elevated, at-grade, or depressed for rural, suburban, and urban areas, although these percentages are not documented in the CUTS manual.

The frequency and cost of 4R work (reconstruction, rehabilitation, resurfacing, or restoration) is affected by many site-specific factors such as roadway design, climate, soils, subbase, and axle loadings. Although highway pavements are usually designed to provide 20 years of service before reconstruction is required, greater than expected heavy-vehicle volumes can often make earlier 4R work necessary. When 4R work is needed, a trade-off exists between longer-lasting, more-costly remedial actions and less-durable, lower-cost actions. In EVFS, the estimation of 4R work costs over the analysis period is limited to periodic asphalt resurfacings. Some type of 4R work is required at various times of a road's life to maintain its pavement serviceability index (PSI) above a minimum acceptable level. The PSI gauges the functional performance of a road's pavement as it affects quality of ride and safety to the traveling public. The PSI is a weighted composite index of pavement distress observations collected by mechanical, visual, and photographic means.

The PSI of heavily traveled roads depends most significantly on the accumulation of equivalent single-axle loadings (ESALs) since it was last resurfaced. As such, the PSI is usually modeled as a function of ESALs, with an adjustment factor to normalize for road differences by functional class, pavement type, and location. The rate of PSI deterioration also depends on a road's age since last reconstruction caused by changes in the structural integrity of the underlying layers, but this effect is not considered in EVFS. Research performed at the Texas Transportation Institute (TTI) found that a modified version of the original AASHTO Road Test equation was superior for predicting PSI deterioration over time and generally had superior properties (*9*). Most notably, the TTI equation asymptotically approaches a minimum pavement condition, as pavement sections are observed to do, rather than degrade into negative values as the AASHTO equation does. The TTI equation defined as follows is an *S*-shaped function that ranges between 0 and 5:

$$\mathrm{PSI} = P_i - (P_i - P_f)\exp[-(\sigma/Q)^{\beta}] \qquad (3)$$

where

P_i = initial PSI of the pavement;
P_f = minimum acceptable PSI of the pavement;
Q = quantity of normalized load to pavement surface, usually expressed in millions of 18-kip ESALs;
σ = quantity of normalized load to pavement surface that reduces PSI from P_i to P_f; and
β = parameter affecting the *S*-shape of the PSI curve.

In the TTI equation, σ is a quantity of normalized load that is used to fit the equation, but σ does not equal the amount of load that reduces the PSI from PSI_i to PSI_f because it is

TABLE 4 CONSTRUCTION COSTS PER LANE-MILE FOR FREEWAY IMPROVEMENTS

	Rural	Suburban	Urban
New 4 Lane Freeway	1.11	1.49	1.88
New 6 Lane Freeway	1.22	1.73	2.24
Major Widening	1.50	1.90	2.30
Right-of-Way Costs	0.39	0.41	0.42
Cost per Interchange	0.40	0.50	0.60

Note: All values are in millions of 1983 dollars, which are multiplied by 1.08 for the 1983-1985 CPI change.

Source: Rural and urban values from UMTA (1985). Suburban values were computed here as averages of rural and urban values. Right-of-way costs are assumed equal to the cost difference per lane mile of new 4 lane freeway construction and major widening. Cost per interchange estimated from Roy Jorgensen (1975).

part of the exponential term. The TTI equation has been fit fairly closely to observed data using nonlinear regression to estimate the best fitting values of σ and β. A user of EVFS may alter any of the three parameters (σ, β, or P_f) that affect the shape of the PSI curve used to predict the frequency of pavement resurfacing.

Figure 1 shows a family of three TTI curves for asphalt overlays with σ and β equal to 2.0 and 1.2, respectively. These parameters were then estimated by Garcia-Diaz and Riggins (*9*) on the basis of 77 sample asphalt overlay sections. These three curves are for newly resurfaced roads with three different average annual loadings of 500,000, 700,000, and 900,000 ESALs. In each case, the pavement deteriorates to a PSI of 2.5 when the cumulative ESALs exceed 5 million. The average ESAL loading per vehicle of each type was estimated on the basis of values given by the Asphalt Institute (*10*) and Wright and Paquette (*11*) for concrete pavements. In EVFS, the default values of ESALs per vehicle that the user may override are 0.0003 ESALs per light vehicle, 0.06 ESALs per SU vehicle, and 1.5 ESALs per combination vehicle.

Uzarski and Darter (*12*) report average resurfacing costs (in 1983 dollars) for different road classes and PSI values when the overlay is performed. These costs were estimated for Interstates and urban freeways in ongoing research on the PAVER pavement management system. These costs are presented in Table 5 for PSI values between 1.0 and 4.0 for primary highways. These values exhibit an average resurfacing cost of about \$100,000 (in 1983 dollars) per lane-mile of 6-in. overlay to a highway with a 2.5 PSI, which generally agrees with other data sources, including the 1985 CUTS manual (*8*).

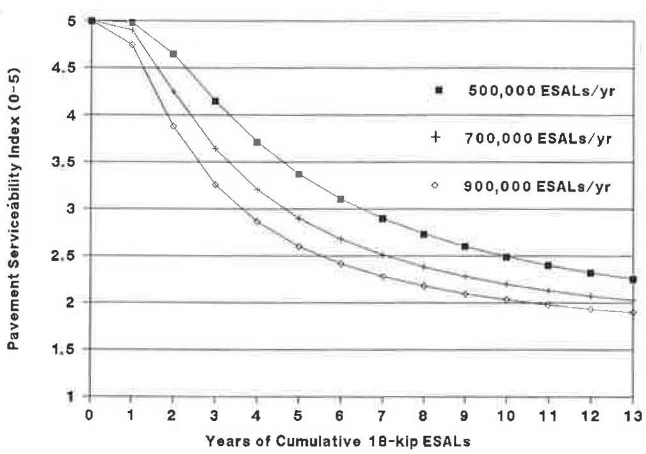

FIGURE 1 Pavement serviceability index for asphalt overlays.

A default resurfacing cost of \$108,000 (including an adjustment of 1.08 for the 1983 to 1985 CPI change) per lane-mile of highway with a PSI of 2.5 is used by EVFS to calculate resurfacing costs. This cost is adjusted for PSI values other than 2.5 in scale proportion to the costs exhibited in the 6-in. overlay column. The following example explains how EVFS estimates resurfacing costs for all lanes over the analysis period. An Interstate lane with an ADT of 20,000 distributed as 72 percent light vehicles, 20 percent SU vehicles and 8 percent combination vehicles will experience roughly 730,000 18-kip ESALs per year. At that loading rate, and the policy to resurface when the PSI reaches 2.5, the road will need to be resurfaced every 7 years, assuming no growth in traffic or change in the vehicle mix during that time.

After 20 to 30 years, most urban Interstates require extensive rehabilitation and reconstruction. In EVFS, it is assumed that all existing lanes will be resurfaced at the time that new lanes are added (i.e., all lanes begin the analysis period with a PSI of 5.0), and that the analysis period terminates before the next major reconstruction. This assumption can be removed by adding an average cost per lane-mile of reconstruction into the average resurfacing cost. The resurfacing frequency for non-barrier-separated lanes depends on which set of lanes requires it first, and all lanes are assumed to be resurfaced at that time. EVFS determines the frequency of resurfacing separately for each set of barrier-separated lanes, because the timing of resurfacing may vary between these sets of lanes depending on the ESALs. The cost of routine maintenance is not included by EVFS, because these activities will generally be the same regardless of lane use policies.

CALCULATIONS OF TOTAL ACCIDENT COSTS

Average accident rates are assumed to include the three standard accident categories: fatal, injury, and property damage only (PDO). Unfortunately, most compilations of accident data do not disaggregate the data by vehicle involvement type in the way that is needed to estimate the effects of separating light and heavy vehicles. For example, a recent study on twin-trailer trucks by TRB (*13*) reported fatal and injury accident rates for single-trailer and multitrailer trucks, but their rates

TABLE 5 RESURFACING COSTS PER LANE-MILE OF FREEWAY BY PSI

PSI	2" overlay	4" overlay	6" overlay
4.0	26822	53574	80397
3.5	27526	54278	81101
3.0	28934	55686	82509
2.5	46746	73427	100320
2.0	63782	90534	117357
1.5	75258	102010	128832
1.0	86662	113414	140237

Note: All values are in 1983 dollars, which are multiplied by 1.08 for the 1983-1985 CPI change.

of involvement with other vehicle types were not indicated. Studies that do distinguish between accidents involving light, SU, and combination vehicles (or similar categories) generally do not report the complete cross tabulation of that data.

The following relationship was developed for EVFS to predict the effects of separating light and heavy vehicles. The total number of accidents of all types equals the sum of nine terms representing single- and multiple-vehicle accidents within and between vehicle types according to the following equation.

$$\mathrm{ACC} = V_{LV}R_{LV1} + V_{LV}R_{LV2} + V_{SU}R_{SU1} + V_{SU}R_{SU2} + V_{CV}R_{CV1} + V_{CV}R_{CV2} + \frac{V_{LV}R_{LV3}V_{SU}R_{SU3}}{(V_{LV} + V_{SU})R_{LVSU}} + \frac{V_{LV}R_{LV4}V_{CV}R_{CV3}}{(V_{LV} + V_{CV})R_{LVCV}} + \frac{V_{SU}R_{SU4}V_{CV}R_{CV4}}{(V_{SU} + V_{CV})R_{SUCV}} \quad (4)$$

where

ACC = total number of accidents of all types,
V_{LV} = total light-vehicle million vehicle-miles (MVM),
V_{SU} = SU vehicle MVM,
V_{CV} = combination vehicle MVM,
R_{LV1} = single LV accident rate per LV MVM (0.199),
R_{LV2} = multiple LV accident rate per LV MVM (0.671),
R_{LV3} = LV with SU accident rate per LV MVM (0.020),
R_{LV4} = LV with CV accident rate per LV MVM (0.069),
R_{SU1} = single SU accident rate per SU MVM (0.061),
R_{SU2} = multiple SU accident rate per SU MVM (0.019),
R_{SU3} = SU with LV accident rate per SU MVM (0.566),
R_{SU4} = SU with CV accident rate per SU MVM (0.044),
R_{CV1} = single CV accident rate per CV MVM (0.099),
R_{CV2} = multiple CV accident rate per CV MVM (0.035),
R_{CV3} = CV with LV accident rate per CV MVM (0.849),
R_{CV4} = CV with SU accident rate per CV MVM (0.019),
R_{LVSU} = LV with SU accident rate per (LV + SU) MVM (0.019),
R_{LVCV} = LV with CV accident rate per (LV + CV) MVM (0.064), and
R_{SUCV} = SU with CV accident rate per (SU + CV) MVM (0.013).

A study by Goodell-Grivas (*14*) for FHWA reports accidents for these nine different types of vehicle interactions, and that data was converted into rates per MVM by vehicle type. These rates are shown in parentheses in the preceding list, and they result in a total accident rate of 0.876 per MVM of all vehicle types.

Implicit in the preceding equation is that all VMT values are generated on a given highway section within a certain time period. Hence, for a given highway section, more accidents are predicted to occur when greater traffic volumes or greater speeds generate greater VMT within a given period of time. The data in the Goodell-Grivas study (*14*) represented a relatively small sample along a specific section of freeway, so rates calculated from those data may not be generally applicable to other highway sections. Additional studies are needed to determine the transferability of accident rates in an equation of this form to predict accidents on other highway sections. A few recent studies, including Alassar (*15*) and Khasnabis and Al-Assar (*16*), have fitted alternative functional relationships to accident rates and traffic densities of different vehicle types on major highways.

Accident rates vary widely by the type of highway surroundings, and also by the study in which they are found. For example, accident rates from two different sources are presented in Table 6. Rates from Pigman et al. (*17*) are exhibited for Interstate sections with and without bridges and interchanges. Some of the variation between these rates is because of the classification of sample highway sections as freeways, expressways, or Interstates, and the criteria by which they were defined to be rural, suburban, or urban. Other differences in highway sections that affect accident rates are curvature, grade, vehicle mix, numbers of lanes, interchanges, bridges, and tunnels.

Meyers (*18*) compiled the accident data presented in Table 7 for controlled-access expressways for these three vehicle types and sorted by whether the accident caused fatalities, injuries, or property damage only. By comparison, a recent article by Giuliano (*19*) examining accidents on the I-10 freeway in Los Angeles, California, showed that 63 percent of all accidents involve no injuries, which agrees closely with the value of 67 percent computed on the basis of Meyers' (*18*) data. Among injury-causing accidents examined by Giuliano (*19*), 66 percent caused injuries to one person, 22 percent caused injuries to two persons, and 12 percent caused injuries to three or more persons. Average numbers of fatalities and

TABLE 6 TOTAL ACCIDENT RATES ON CONTROLLED-ACCESS HIGHWAY SECTIONS

Area Type	AASHTO (1977)	Pigman (1981)[a]	Pigman (1981)[b]
Rural	0.79	0.57	0.49
Suburban	1.07	0.77	0.61
Urban	1.43	3.05	2.07
Total	1.23	1.22	0.90

Note: Accident rates are per million vehicle miles, and include all accidents causing fatalities, injuries, and property damage only.

a) rates are with bridges and interchanges.

b) rates are without bridges and interchanges.

Sources: Shown by column headings.

TABLE 7 ACCIDENT RATES BY VEHICLE TYPE ON CONTROLLED-ACCESS EXPRESSWAYS

	Accident Type			
Vehicle Type	Fatal	Injury	PDO	Total
Passenger	0.013	0.373	0.748	1.134
Single-Unit	0.032	0.579	1.340	1.951
Combination	0.028	0.510	1.249	1.787

Note: Accident rates are per million vehicle miles, and include all accidents causing fatalities, injuries, and property damage only.

Source: Meyers (1981).

injuries per accident have already been factored into the costs presented in Table 8 by their sources such that these costs are given per accident.

EVFS applies the AASHTO (*2*) accident rates by area type and Meyers' (*18*) total accident rates by vehicle type to generate default values to Questions 46 to 48 that the user may override. Meyers' (*18*) accident rates, which are assumed to represent suburban highways, are multiplied by 0.79/1.07 for rural highways, and by 1.43/1.07 for urban highways. The Goodell-Grivas (*14*) rates listed earlier are then used to disaggregate the accident rates by vehicle involvement type. Other studies of accident rates may provide the analyst with alternative rates to be substituted as nonzero values for the default rates. In either case, the default rates, or their substitutes, are proportioned to accident types according to Table 7, and these rates are proportioned to the nine vehicle involvement types according to the values listed earlier from the Goodell-Grivas (*14*) study.

Average accident costs for each accident type (fatal, injury, and property damage only) are presented in Table 8 from a variety of sources such as NHTSA (*20*), the National Safety Council (NSC) (*21,22*), and the Highway Investment Analysis Package (HIAP) (*7*). Some of these accident costs are summarized by Fleischer (*23*). These valuations can vary widely depending on their source and application.

EVFS calculates total accident costs per MVM for mixed and exclusive vehicle lanes as follows. The 1985 NSC accident costs are multiplied by the accident rates per MVM just described by area, accident, and vehicle involvement type. The total accident cost of light-vehicle lanes equals the LV-only accident rate per LV MVM times the average LV accident cost. The total accident cost of mixed-vehicle lanes equals the sum of the products of the accident rates per MVM for the different vehicle involvement types times their respective average accident costs. The total accident cost for each heavy-vehicle lane is computed similarly to mixed-vehicle lanes except that only SU and combination vehicles are taken into account.

CALCULATIONS OF ACCIDENT QUEUING DELAYS

EVFS uses a deterministic queuing model to estimate the total delay caused by accidents predicted to occur on both mixed and exclusive vehicle facilities. Morales (*24*) found this type of queuing model to yield close estimates of accident delays on freeways in a study for FHWA. The total delay caused by an accident depends heavily on traffic volumes at the time of an accident, the number of blocked and unblocked lanes, the duration of lane blockage, and the number of route diversion options available to vehicles upstream from the accident scene. The study by Goodell-Grivas (*14*) concluded that travel time delays on urban freeways caused by truck accidents can cost more than twice the total fatality, injury, and property damage cost of those accidents.

An accident causes queuing and vehicle delays because the vehicle arrival rate (hourly vehicle volume) exceeds the vehicle service rate (unblocked lane capacity) during the accident clearing and queue dissipation stages of an incident. The accident-clearing stage is the time at which an accident first occurs to the time at which all accident wreckage and emergency equipment are cleared from blocking any lanes. The queue dissipation stage is the time at which the accident is cleared from blocking any lanes to the time at which the residual traffic queue disappears and normal freeway operations are restored. Figure 2 shows a graph of the queuing delays caused by a lane blocking accident as estimated by the deterministic queuing model.

The total delay time caused by an accident equals the shaded area shown in Figure 2. Lines *A* and *B* have slopes equal to the vehicle service rates of a highway during the accident clearing and queue dissipation stages, respectively. The accident clearing stage is from the time t_0 when the accident occurs (assumed to be time 0) to the time t_2 when all lanes are cleared. The queue dissipation stage is from the time t_2 to the time t_3 when the queue disappears. At time t_2, when

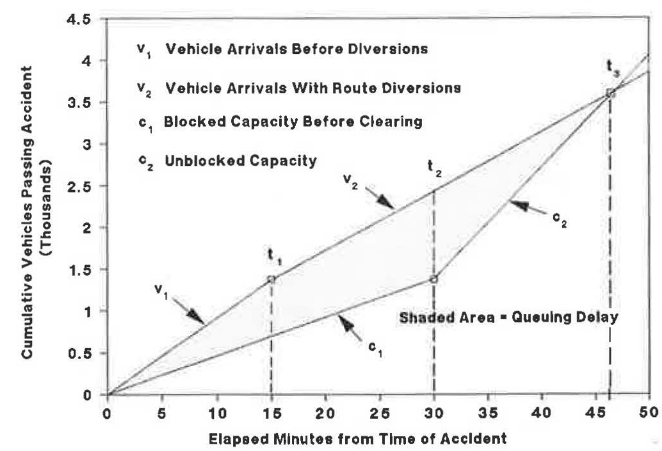

FIGURE 2 Deterministic queuing model of accident delays.

TABLE 8 ACCIDENT COSTS BY ACCIDENT TYPE

	Accident Costs				
	NHTSA (1975$)	NSC (1976$)	HIAP (1979$)	NSC (1983$)	NSC (1985$)
Fatal	287,175	125,000	122,000	210,000	226,800
Injury	3,185	4,700	7,550	8,600	9,288
PDO	520	670	600	1,150	1,242

Sources: Shown by column headings; 1985 NSC costs equal 1983 NSC costs updated to 1985 dollars with a CPI factor of 1.08.

the accident is cleared from blocking any lanes, the service rate returns to its preaccident level (denoted as C_2), which exceeds the current arrival rate, and the queue begins to dissipate. Morales (*24*) found that a highway may not return to its preaccident service rate at one time, and that short intermediate steps or piecewise linear segments between lines *A* and *B* can be used to represent certain accident clearing processes in more detail. However, most of the accidents reported by Morales (*24*) do not require this additional detail, and this additional detail altered the total delay by less than 10 percent in cases where it was used.

The vehicle service rate of unblocked lanes during the accident clearing stage (denoted as C_1) depends on the number of open lanes, plus other factors that affect vehicle flow such as smoke, debris, visible wreckage, and emergency equipment. This lower vehicle service rate can be estimated by adjusting the capacity of open lanes for the merging and caution exhibited by vehicles in passing an accident. The accident data reported by Goodell-Grivas (*14*) indicate that the open lanes beside accidents to have an average service rate of 80 percent of their usual capacity. For example, if only two of four lanes remain open (where the usual capacity of each lane is 2,000 veh/hr), the vehicle service rate of the open lanes will, on average, reduce to 3,200 veh/hr because of the effects of driving behavior near an accident scene.

With regard to vehicle arrival rates, the queuing model used in EVFS allows the arrival rate of vehicles at the rear of the queue to decrease at time t_1 during the accident clearing stage because of excessive queue length, route diversion options, and advanced warnings. In Figure 2, lines *C* and *D* have slopes equal to the vehicle arrival rates from time t_0 to time t_1 and from time t_1 to time t_3, respectively. The time t_1 at which the arrival rate decreases depends on how quickly the queue lengthens to the point at which drivers consider the route diversion options available to them. The EVFS assumes that the arrival rate will decrease when the queue length equals one-half the average distance between interchanges on the highway section being evaluated. The basis for this assumption is that the nearest upstream interchange at which drivers can divert to other routes will, on average, be one-half the average distance between interchanges if accidents are randomly distributed between interchanges.

Although travel time impacts on alternate routes are not estimated by EVFS, the extent of route diversion, which depends on the availability and reliability of alternate routes, affects the vehicle arrival rate into the queue. The arrival rate is expected to decrease prior to or at time t_2, because the queue begins to shorten after then. A reasonable assumption supported by data in Goodell-Grivas (*14*) is that the initial vehicle arrival rate V_1 will not decrease to a rate V_2 below the service rate C_1 of the unblocked lanes. The accident data reported by Goodell-Grivas (*14*) indicate an average reduction in the arrival rate at time t_1 equal to 33 percent of the difference between V_1 and C_1. This route diversion percentage will be greater on barrier-separated facilities where vehicles can divert to alternate lanes that are clear of the accident, but not exit the highway entirely.

Computationally, the total travel time delay of an accident is equal to the shaded area in Figure 2 as given by the following equation.

$$\begin{aligned}\text{Delay} &= 0.5[t_1^2(V_1 - C_1) - (t_2 - t_1)^2(C_2 - C_1)] \\ &\quad + 0.5(t_3 - t_1)[t_1(V_1 - C_1) + (t_2 - t_1)(C_2 - C_1)]\end{aligned} \tag{5}$$

where

- Delay = total vehicle queuing delay (hours—not weighted by vehicle differences in value of time or occupancy);
- N_l = number of highway section lanes (blocked or unblocked);
- L_q = length of queue (in miles) at which vehicle arrival rate decreases, assumed equal to one-half the average distance between interchanges unless analyst inputs a different value;
- t_1 = minimum $[t_2, (105.6\ N_lL_q)/(V_1 - C_1)]$ = hours after accident when vehicle arrival rate changes caused by queue length, diversion options, and advanced warnings—assumed to occur at t_1 or when the queue in all lanes N_l reaches length L_q, allowing 50 ft per vehicle in slow traffic;
- t_2 = hours after accident when all lanes are cleared (input);
- t_3 = $t_1 + [t_1(V_1 - C_1) + (t_2 - t_1)(C_2 - C_1)]/(C_2 - V_2)$ = hours after accident when queue disappears (calculated);
- V_1 = vehicle arrival rate per hour until time t_1—assumed equal to the hourly vehicle volume at the time of the accident;
- V_2 = vehicle arrival rate per hour from time t_1 to time t_3—assumed equal to $V_1 - 0.35(V_1 - C_1)$ for unseparated facilities, and equal to $V_1 - 0.70(V_1 - C_1)$ for barrier-separated facilities;
- C_1 = vehicle service rate per hour until t_2 when all lanes are cleared—assumed to equal 80 percent of the unblocked lane capacity weighted by PCEs for vehicle mix and volume; and
- C_2 = vehicle service rate per hour after t_2 when all lanes are cleared—assumed to equal the total lane capacity weighted by PCEs for vehicle mix and volume.

EVFS accounts for percentages of accidents that cause zero, one, or two lanes to be closed. A recent analysis of accidents on the I-10 Freeway in Los Angeles by Giuliano (*19*) indicated that 59 percent caused no lane closures, 28 percent caused one lane to be closed, and 13 percent caused two or more lanes to be closed. Although truck involvement also affects the severity of lane blockage, specific data on that relationship could not be found. An analysis of variance performed by Giuliano (*19*) did indicate that incident duration was significantly affected by truck involvement. The average incident duration of accidents involving trucks was 63 min, versus only 39 min for nontruck involvements. The incident duration variance for accidents involving trucks was also much greater than that for nontruck involvements. Incident duration was defined in the study as the time at which an accident is first reported to the time at which the accident is reported to be cleared. Incident duration by this definition does not include the queue dissipation time from t_2 to t_3 when normal traffic resumes.

Because most of the cases being analyzed with EVFS will involve mixes of lane types, certain lane use assumptions must be made to estimate the vehicle mix, volume, and queuing delay in the unblocked lanes because of a lane-blocking accident. The number of vehicles diverted into unblocked lanes depends on whether the two types of lanes are barrier separated, and also on the use of changeable message signs to direct lane use. If the two lane types are not barrier separated, then the assumption is made that all vehicle types will use the unblocked lanes to maneuver around the accident. However, if the two lane types are barrier separated, then it depends a great deal on how changeable message signs are used to divert traffic.

Total delay time is composed of delays both for light and for heavy vehicles, so vehicle mix is used to calculate a weighted value of delay time. The queuing calculations of travel time delay are only applied to lanes on the accident side of barrier-separated lanes, and no travel time adjustments are made for increased traffic on the other side of the barrier, because those impacts are assumed to be negligible. In all cases (both barrier-separated and unseparated), the vehicle mix in the lanes with an accident is held equal to the vehicle mix under normal operating conditions, despite diversions of some vehicles to other lanes or routes.

Accident rates may also vary by time of day because of traffic densities, speeds, and visibility conditions. Because data on this relationship for urban freeways were not available, EVFS assumes the same accident rates per MVM both for peak and for off-peak hours. As such, greater number of accidents per hour are predicted to occur during peak periods because of greater VMT per hour. EVFS does compute the number of accidents and queuing delays separately for both the peak and off-peak periods, and operating costs for vehicles caught in accident queues are adjusted for slower speeds. Last, clean-up and reporting costs are estimated to be $1,000, $5,000, and $10,000 per accident for light, SU, and combination vehicle accidents, respectively.

EXAMPLE APPLICATION OF EVFS

This section presents an example analysis of five alternative facility designs for a 30-mi highway section that currently has three mixed-vehicle lanes in each direction. The development of this example is based on the recent widening of US-59 that runs southwest from Houston to Richmond, Texas. This freeway is a major commuting artery feeding downtown Houston, and also a major truck route to and around Houston. The highway passes both through densely developed and less-constructed areas, so its location has been designated as suburban in the following analysis. Starting in 1987, parts of this highway section were widened from 3 to 5 MV lanes in each direction. In addition, a two-lane transitway was constructed in the median area of the highway that will carry buses, vanpools, and carpools. Traffic volumes on this highway section averaged about 80,000 vehicles per day in each direction in 1987, projected to increase to 110,000 vehicles per day in each direction in 10 years.

In addition to Case 0 (the base or do-nothing case), the four exclusive vehicle facilities considered in this example are as follows:

- Case 1: Designate one of three existing lanes for light vehicles only.
- Case 2: Widen from three to five MV lanes.
- Case 3: Widen from three MV lanes to two LV and three MV lanes.
- Case 4: Same as Case 3, except with LV and MV lanes barrier-separated.

Table 9 presents the general site information and traffic characteristics input to this EVFS example. The site information is exhibited for Case 4. The only differences in site information between cases are the number of future lanes of each type, number of new lanes of right-of-way to acquire, and whether or not the different lane types are barrier separated (Questions 3 to 7). Values for the current ADT and the annual increase in ADT were input to agree with the estimates just described, and the AASHTO division of ADT between peak and off-peak periods was accepted. The only change made to the default traffic characteristics was to increase the speed limit from 55 to 65 mph. All other factors including construction costs, values of time, and accident costs are the default values presented earlier in Table 1. The planning horizon was set to 20 years, with project completion after 3 years, and a discount rate of 10 percent.

Table 10 presents the EVFS results for the base case (Case 0) and the four alternative cases (Cases 1 to 4). Net benefits and net costs reported for Cases 1 to 4 are differences in benefits and costs from Case 0. Thus, for comparison purposes, net benefits and net costs equal zero for Case 0, and neither the net present value nor the benefit-cost ratio of Case 0 is relevant. Costs, benefits, and other performance measures are presented in more detail for each alternative case in Table 11, where vehicle operation costs are shown to be the most significant cost factor.

Table 10 presents the benefit-cost ratios and net present values of each facility alternative both with and without vehicle operating costs. Because of their many values, vehicle operating costs are the only costs read by EVFS from data files that cannot be modified by the spreadsheet user interface. A forthcoming revision of the AASHTO Red Book (*2*) will provide updated operating costs that revise these data files. The net present value of Case 1 is the same both with and without vehicle operating costs because traffic is predicted to operate at roughly the same speed in either case. Thus, without expanding the highway, travel times and costs will remain at high levels. The main benefit of Case 1 is lower accident costs because of vehicle separation.

The benefit-cost ratios of Cases 2 to 4 are only slightly greater than one when vehicle operating costs are included, but they are much greater than one without vehicle operating costs. The widening of this congested highway allows vehicles to travel at faster speeds, which results in greater vehicle operating costs per mile for both light and heavy vehicles. Both light and heavy vehicles achieve their lowest operating costs at speeds between 45 and 50 mph according to the AASHTO Red Book (*2*). Compared to Case 1, Cases 2 to 4

TABLE 9 SITE AND TRAFFIC CHARACTERISTICS INPUT TO EVFS (EXAMPLE)

General Site Information:

1.	Is this a rural, suburban, or urban highway section R/S/U?	S
2.	Current mixed-vehicle lanes in each direction (0-6)?	3
3.	Future mixed-vehicle lanes in each direction (0-6)?	3
4.	Future light-vehicle lanes in each direction (0-6)?	2
5.	Future heavy-vehicle lanes in each direction (0-4)?	0
6.	Number of new lanes of right-of-way to acquire (0-4)?	2
7.	Will exclusive vehicle lanes be barrier separated (Y/N)?	Y
8.	Length of section in miles (including decimal places)?	30.0
9.	Number of interchanges along this section?	5
10.	Average road gradient along section (typical value = 0%)?	0%
11.	Average curvature along section (typical value = 2 deg.)?	2

Traffic Characteristics:

		Defaults	
12.	Current average daily traffic (ADT) (one direction)?		80000
13.	Average annual increase in ADT (one direction)?		3000
14.	Current peak-period volume/hr (3 hours/day)?	6667	0
15.	Future peak-period volume/hr in 10 years?	9167	0
16.	Current off-peak volume/hr (15 hours/day)?	4000	0
17.	Future off-peak volume/hr in 10 years?	5500	0
18.	Speed limit for LV along this section (mph)?	65	0
19.	Speed limit for SU and CV along this section (mph)?	55	65
20.	Current LV percentage of total ADT?	69.6%	0.0%
21.	Future LV percentage of ADT in 10 years?	62.3%	0.0%
22.	Current SU percentage of total ADT?	23.8%	0.0%
23.	Future SU percentage of ADT in 10 years?	29.8%	0.0%
24.	Current CV percentage of total ADT?	6.0%	0.0%
25.	Future CV percentage of ADT in 10 years?	7.3%	0.0%

LV = Light Vehicle SU = Single-Unit Vehicle CV = Combination Vehicle

TABLE 10 SUMMARY OF THE EVFS EXAMPLE RESULTS

Results with vehicle operating costs

	Benefits	Costs		
Case 0	1796154	2390025		
	Net Benefits	Net Costs	Net Present Value	B/C Ratio
Case 1	64336	27156	37180	2.369
Case 2	518993	398391	120602	1.303
Case 3	551301	457605	93696	1.205
Case 4	552238	470031	82207	1.175

Results without vehicle operating costs

	Benefits	Costs		
Case 0	1796154	68529		
	Net Benefits	Net Costs	Net Present Value	B/C Ratio
Case 1	64336	27156	37180	2.369
Case 2	518993	139595	379398	3.718
Case 3	551301	198809	352491	2.773
Case 4	552238	211235	341003	2.614

Note: All values are shown in 1000's of dollars.
Costs include vehicle operating costs.

TABLE 11 DETAILED RESULTS FOR THE EVFS EXAMPLE

COST SUMMARY (in $1000s)

	Base Case	Case 1	Net	Case 2	Net
Resurfacing Lanes	$68529	$95685	$27156	$54894	-$13635
Vehicle Operation	$2321496	$2321496	-$0	$2580292	$258796
New Construction	$0	$0	$0	$104630	$104630
Right Of Way	$0	$0	$0	$48600	$48600
Total	$2390025	$2417181	$27156	$2788416	$398391

BENEFIT SUMMARY (in $1000s)

	Base Case	Case 1	Net	Case 2	Net
Travel Time	$1345819	$1345820	-$1	$1089779	$256040
Accident Costs	$172461	$151804	$20657	$172461	$0
Accident Delays	$277874	$234193	$43681	$14921	$262953
Total	$1796154	$1731818	$64336	$1277161	$518993

OTHER PERFORMANCE MEASURES

	Base Case	Case 1	Net	Case 2	Net
Total Accidents	44258	38590	-5668	44258	0
Avg. Accident Cost	$10094	$10019	-$75	$10094	$0
Avg. Delay Cost	$22841	$21767	-$1075	$1477	-$21364
Avg. Travel Speed	54.04	54.04	0.00	62.97	8.92

COST SUMMARY (in $1000s)

	Base Case	Case 3	Net	Case 4	Net
Resurfacing Lanes	$68529	$114108	$45579	$68465	-$64
Vehicle Operation	$2321496	$2580292	$258796	$2580292	$258796
New Construction	$0	$104630	$104630	$143259	$143259
Right Of Way	$0	$48600	$48600	$68040	$68040
Total	$2390025	$2847630	$457605	$2860056	$470031

BENEFIT SUMMARY (in $1000s)

	Base Case	Case 3	Net	Case 4	Net
Travel Time	$1345819	$1089779	$256040	$1089779	$256040
Accident Costs	$172461	$143765	$28696	$143765	$28696
Accident Delays	$277874	$11309	$266565	$10372	$267502
Total	$1796154	$1244853	$551301	$1243916	$552238

OTHER PERFORMANCE MEASURES

	Base Case	Case 3	Net	Case 4	Net
Total Accidents	44258	36384	-7873	36384	-7873
Avg. Accident Cost	$10094	$9973	-$121	$9973	-$121
Avg. Delay Cost	$22841	$1340	-$21501	$1205	-$21636
Avg. Travel Speed	54.04	62.97	8.93	62.97	8.93

Note: All costs and benefits are 1985 present value amounts.

have lower benefit-cost ratios but much greater net present values because of the low cost of Case 1. Case 2, which is to widen the highway with additional MV lanes, is the preferred alternative with the highest net present value. Cases 3 and 4 would be more competitive with Case 2 if the cost per accident fatality were increased to $500,000 or higher, or a longer planning horizon were used. Accident costs and delays for Cases 3 and 4 are much lower than for Case 2, but not enough to offset the higher cost of construction.

CONCLUSIONS

EVFS is a useful and flexible model for evaluating the economic feasibility of segregating vehicles on controlled-access highways by designating existing lanes and constructing new lanes to be used exclusively by light or heavy vehicles. EVFS can be used to perform sensitivity analyses of the critical points at which a particular exclusive vehicle facility becomes economically feasible, depending on (a) future traffic volumes on the highway, (b) existing and proposed number of lanes of each type, (c) percentages of heavy and light vehicles in the traffic stream, (d) costs of interchange and lane construction, (e) the pavement resurfacing cost, (f) vehicle operating costs, (g) person and freight values-of-time, and (h) accident rates, costs, and lane closures.

Several test analyses with EVFS similar to the previous example indicated that a few key factors were needed for barrier-separated facilities to be economically feasible. First, peak-hour volumes must exceed 1,800 vehicles per lane-hour, and off-peak volumes must exceed 1,200 vehicles per lane-hour. Second, heavy vehicles must exceed 30 percent of the vehicle mix. Exclusive facilities without barrier separation appear to be warranted for a wider range of traffic volumes and vehicle mixes depending on other site-specific characteristics. On congested highways, particularly during peak travel hours, designating one or two existing lanes exclusively for light vehicles can be a cost-effective traffic management strategy. The example of the previous section indicated this case to have a positive net present value. However, more rapid traffic growth and a longer analysis period will result in the addition of new unseparated lanes for light vehicles to have the greatest net present value.

These estimates of costs and benefits from EVFS should be viewed as midpoints within broad ranges because of the many assumptions needed to simplify numerous site-specific complexities. Relatively small differences between alternative cases of less than 5 percent may not be significant. However, the rankings of alternatives as determined by many test analyses for a given site are likely to be robust. EVFS could be improved by imbedding models for freeway simulation, route assignment, and elastic demand. Such enhancements are needed for improved modeling of route diversion alternatives during traffic accidents, and of traffic attracted from alternate routes because of added capacity. However, this expansion of EVFS would also require much more extensive data preparation on the part of the user. As currently designed, EVFS can be used to generate quick-response evaluations of many alternative facilities in just a few brief sessions.

ACKNOWLEDGMENTS

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Impact of Pavement Performance Consideration on Economic Evaluation of Pavement Strategies

T. F. Fwa and K. C. Sinha

The conventional practice of economic analysis of pavement strategies does not consider the differences in pavement performance levels among the alternatives analyzed. The impact of incorporating into the analysis pavement performance consideration that explicitly quantifies differences of pavement performance levels in monetary values is examined. Studies have indicated that there exist two components, namely the agency and the user values of pavement performance, that should be included when incorporating pavement performance consideration into economic evaluation of different pavement strategies. On the basis of recently available information and estimates of the agency and user values of pavement performance, it is found that these values are of the same order of importance as the cost items commonly considered in economic evaluation of pavements. Numerical examples illustrate the impact of including pavement performance consideration in the economic analysis. Significant changes to the results of conventional economic analysis are observed for the examples studied.

A common practice among highway agencies is to evaluate the relative merits of different pavement design, construction, and rehabilitation strategies on the basis of engineering economic analysis. Life-cycle cost analysis (*1*) and benefit-cost analysis (*2*) have been the two most widely used procedures for comparing highway pavement alternatives. Both highway agency costs and road user costs are usually considered in such analyses, although the specific cost items included may differ from agency to agency. In general, under the agency cost category, pavement construction, maintenance, and rehabilitation costs are considered. Under the road user cost category, vehicle operating costs and travel and delay time costs are the items most commonly included.

The current practice of economic analysis of pavement alternatives does not take into account differences in pavement performance among the strategies considered. The strategy selected on this basis may not be the most desirable to road users and the highway agency concerned. The need to consider pavement performance in economic analysis of different strategies, together with the usual agency and user considerations, has been discussed in detail by Fwa and Sinha (*3*). They suggested that there existed two distinct components of the value of pavement performance: one related to highway agencies and the other to road users. The order of magnitude of these two values of pavement performance is examined on the basis of the findings of two recently completed surveys. These values are then applied to economic analyses reported in the literature to demonstrate how the outcomes of these analyses would have been affected if pavement performance consideration were to be included.

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MAGNITUDE OF VALUE OF PAVEMENT PERFORMANCE

As the relative level of pavement performance has never been included as a decision parameter in economic analysis of pavements, little is known about the magnitudes and characteristics of agency and user values associated with it. Recently, two studies have been conducted to quantify the value of pavement performance. A study conducted in Indiana by Fwa and Sinha (*4*) was able to express agency and user values of pavement performance in monetary terms. Another study performed by Garg and Horowitz (*5*) in Wisconsin represented the value of pavement serviceability in terms of additional travel time. The findings of these two efforts are discussed in the following sections.

Agency Value of Pavement Performance

The agency value survey in the Indiana study included 30 highway officials whose work involved decision making concerning pavement design, construction, and rehabilitation. There were 9 highway officials from the state, 12 from counties, and 9 from cities. Each of the 30 officials was asked to classify pavement projects into three sizes according to the magnitude of project costs: large, medium, and small. For each project size, an official was to indicate the additional funds he was willing to commit for an alternative with better overall average pavement performance. A detailed description of the survey procedure and results was provided by Fwa and Sinha (*4*).

In analyzing the survey responses, a physical measure known as "pavement performance quality index" (PPQI), was introduced to quantify the overall performance level of a pavement over the entire analysis period. PPQI is defined as

$$(\text{PPQI})_n = \frac{1}{(\text{ESAL})_n}\int_0^{(\text{ESAL})_n} (\text{PSI})\, d(\text{ESAL}) \qquad (1)$$

where

ESAL = equivalent single-axle loads,

PSI = present serviceability index, and
n = analysis period over which the subscripted parameters are computed.

This definition is shown schematically in Figure 1. Each PPQI can be viewed as the overall average PSI level of the pavement performance history represented. Higher PPQI values are associated with better pavement performance.

The following findings were reported in the Indiana study:

1. The agency values of pavement performance differed among highway agency levels. Officials from state highway agencies valued pavement performance more than their counterparts in county and city highway agencies. The agency values awarded by city highway officials were the lowest.
2. The agency values varied with the overall pavement performance level. Higher agency values were associated with higher values of PPQI.
3. The agency values, expressed as percentage of total project cost, were not affected by the size of project.

Figure 2 shows the results of the study. The agency value for a given PPQI can be obtained from the plot for city, county, or state highway agencies. Expressed as a percentage of total project cost, each value represents the average additional fund that highway agencies are willing to spend to implement a strategy that will improve pavement performance from a PPQI level of 1.5 to the level indicated. In other words, it has been assumed that the agency value for pavement performance is zero at PPQI equal to 1.5. Between PPQI values of 2.5 and 4.5, the agency values ranged from 19 to 114 percent of project costs.

The agency value obtained from a plot such as Figure 2 can be incorporated into economic analysis of pavement alternatives by expressing it either as a form of agency benefits or as extra agency costs. If the benefits approach is adopted, the agency value for a given PPQI is obtained directly from Figure 2. In the extra agency costs approach, it is assumed that there are zero extra agency costs if a pavement strategy produces a PPQI value of 4.5. A PPQI value of 4.5 refers to a hypothetical situation where pavement PSI is maintained at 4.5, which is the PSI level of a newly constructed pavement, throughout the analysis period. Any pavement strategy that has PPQI less than 4.5 would incur an extra agency cost that can be computed from

$$(\Delta P)_k = (P)_{4.5} - (P)_k \tag{2}$$

where

$(\Delta P)_k$ = extra agency costs associated with PPQI value equal to k,
$(P)_{4.5}$ = agency value of pavement performance for PPQI equal to 4.5, and
$(P)_k$ = agency value of pavement performance for PPQI equal to k.

The values of $(P)_{4.5}$ and $(P)_k$ are obtained from Figure 2.

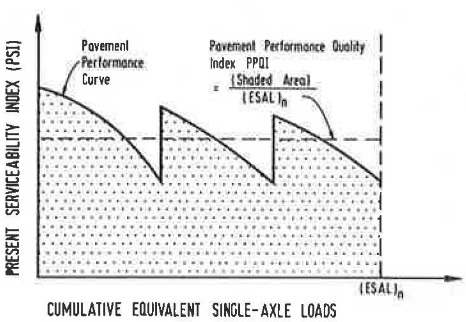

FIGURE 1 Pavement performance quality index as an overall measure of pavement performance (3).

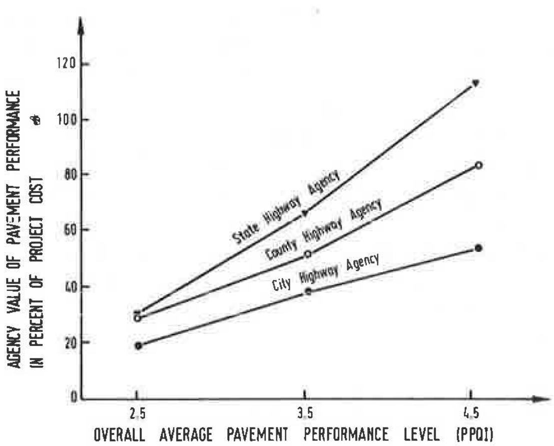

FIGURE 2 Agency value of pavement performance as a function of highway agency level and overall average pavement performance (4).

User Value of Pavement Performance

User values of pavement performance were addressed both by the Indiana (*4*) and by the Wisconsin (*5*) studies. Although the latter offered only an indirect assessment of the magnitude of these values, the former has provided monetary evaluation that can be used directly in an economic analyses.

In the Wisconsin study, test road sections with PSI ranging from about 4.0 to less than 1.5 were included. Participating road users were asked to estimate the amount of time they were willing to spend to avoid each test section, assuming they were to make a trip that lasted for 50 min. The survey results shown in Figure 3 are an assessment of user value in

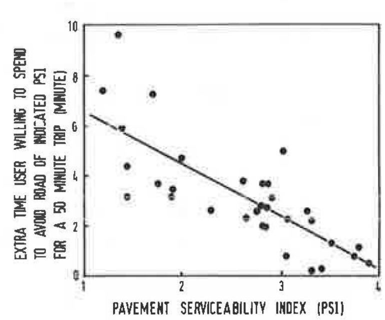

FIGURE 3 Relationship between road PSI and extra time user willing to spend to avoid a given road for a 50-min trip (5).

terms of travel time. The likely impact of pavement performance consideration in economic analysis can be judged by considering the expected travel time savings associated with various levels of pavement performance. Travel time savings are computed from estimated traffic speeds, a function of pavement condition. The relationships of PSI to average speed compiled by Haas and Hudson (*6*) are used for this purpose. For easy comparison, extra travel time is computed instead of travel time savings as shown in Figure 4. It is seen that user values of pavement performance are larger than user travel time costs for PSI values higher than 2.0. Because the PSI of typical pavements are higher than 2.0 for practically the entire length of their useful service lives, the comparison suggests that user values of pavement performance would be a significant factor in user costs analysis.

The user value survey of Indiana (*4*) determined how much users were willing to pay to travel on roads with better pavement serviceability. Ninety randomly selected road users of different occupational and educational background from Lafayette, Indiana, were included in the study. The results of the survey are shown in Figure 5. It was found that user values

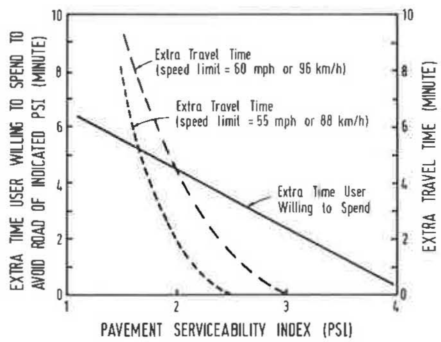

FIGURE 4 Indirect comparison in time between user travel time costs and costs user willing to pay for pavement serviceability.

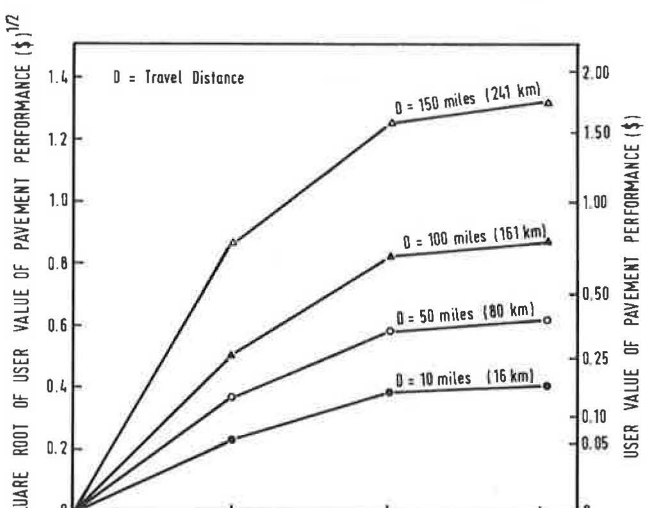

FIGURE 5 User value of pavement performance versus road condition as a function of travel distance (*4*).

varied with both travel distance and road condition. In general, user values increased with travel distance and with better pavement serviceability. The user values reported were obtained by taking the value at PSI = 1.5 as zero reference. The computed user values ranged from \$0.057 for travel distance of 10 mi and PSI of 2.5, to \$1.706 for travel distance of 150 mi and PSI of 4.5. The mean user value, expressed as monetary value per unit distance, ranged from 0.27 to 1.66 cents/mi above the reference value at PSI = 1.5. These values are comparable in their order of magnitude with those of other user cost items, such as vehicle operating costs and travel time saving costs, used in several recent pavement strategy evaluation studies (*7–9*).

For any pavement strategy, the time variation of user value of pavement performance can be derived from its time history of pavement performance. Relationships between PSI and user value of pavement performance such as those shown in Figure 5 provide the necessary information for the derivation. The total present worth of user value of pavement performance may then be calculated as follows:

$$(\mathrm{PW})_B = \int_0^T (S_t)(V_t)(F_t)\, dt \tag{3}$$

or

$$(\mathrm{PW})_C = \int_0^T (S - S_t)(V_t)(F_t)\, dt \tag{4}$$

where

$(\mathrm{PW})_B$ = present worth of pavement performance computed as user benefits,
$(\mathrm{PW})_C$ = present worth of pavement performance as extra user costs,
S = user value of pavement performance at PSI equal to 4.5,
S_t = user value of pavement performance at time t,
V_t = traffic volume at time t,
F_t = present worth factor, and
T = length of analysis period.

ECONOMIC ANALYSIS BASED ON AGENCY COSTS

Some highway agencies evaluate pavement alternatives on the basis of agency costs. The reasons for not considering user costs have been found to including the following (*10*): difficulty in obtaining reliable user cost data, lack of information on the relationships between pavement condition and variations of different user cost items, and the fact that user cost consideration does not have a direct link with the funding mechanism of road construction and maintenance. It is therefore relevant to examine how pavement performance consideration would affect the results of those economic analyses that include agency costs only. Two numerical examples from published literature are analyzed for illustration purposes in the following paragraphs.

Agency Cost-Based Analysis—Example 1

Figure 6 shows two design options originally analyzed by Kher et al. (*11*). The two options were compared over an analysis period of 30 years. The initial average daily traffic (ADT) was 10,000 vehicles. It was assumed to increase linearly to a magnitude of 25,000 vehicles per day at the end of the analysis period. Using a discount rate of 7 percent, the present worth of agency costs for Options I and II were computed to be \$291,100 and \$325,250, respectively. These costs included initial capital costs, resurfacing costs, maintenance costs, and salvage return values, but not values of pavement performance.

The PPQI value can be computed from Equation 1 by considering the time growth relationship of traffic loading and time variation of PSI, as follows:

$$(\mathrm{PPQI})_n = \frac{1}{(\mathrm{ESAL})} \int_0^{T_n} \mathrm{PSI}(t) d[\mathrm{ESAL}(t)] \qquad (5)$$

where T_n defines the length of analysis period. Numerical integration may be used in cases where PSI(t) and ESAL(t) cannot be expressed analytically.

Alternatively, a graphical method can be used to compute PPQI. This is achieved by first transforming the PSI-time plots of Figure 6 into PSI–ESAL plots as shown in Figure 1. This transformation can be easily performed because the time growth curve of traffic loading is known. The PPQI value may then be computed in accordance with the definition given in Equation 1.

Assuming that ESAL growth pattern is the same as the given traffic growth pattern, the PPQI values of Options I and II in Figure 6 can be shown to be 3.04 and 3.53, respectively. Using Equation 2 and the state highway agency curve of Figure 2, the extra agency costs for pavement performance are obtained as follows: \$291,000 × (1.14 − .503) = \$185,430 for design Option I, and \$325,250 × (1.14 − .683) = \$148,639 for design Option II. The total agency costs for Options I and II are therefore \$476,530 and \$473,889, respectively. Similar computations can be made if the highway authority were to be county or city highway agency. The results of these calculations are presented in Table 1.

Table 1 indicates that on the basis of conventional agency cost comparison, without considering agency values for pavement performance, Option I would be the preferred alternative. When agency values for pavement performance are included, a different conclusion could be obtained. Option II, instead of Option I, would now be selected by a state highway agency. Although a county or city highway agency would still choose Option I, the margins of difference between the two options have become smaller.

This example clearly illustrates that the outcome of economic analysis is influenced by individual agencies' values for pavement performance. The value a highway agency attaches to pavement performance represents an important feature of its pavement maintenance and management policy. Because pavement design and management policy varies from agency to agency, it is desirable for each agency to conduct its own evaluation to obtain a set of values for pavement performance that reflects its decision making and planning practices.

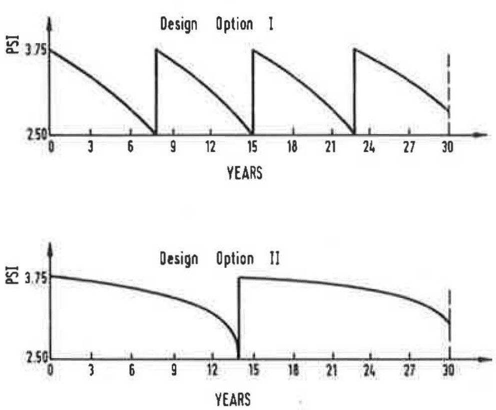

FIGURE 6 PSI versus time histories for design Options I and II considered in Example 1.

Agency Cost-Based Analysis—Example 2

In this example, a four-lane urban highway design analysis by the Maryland State Highway Administration involving comparison of eight strategies (*12*), is considered. The problem is shown graphically in Figure 7. The initial traffic was 12,000 veh/day in both directions with an annual growth rate of 5 percent. The same discount rate of 4 percent used in the original analysis (*12*) is also used in the current example.

Table 2 compares the present worth of agency costs computed with and without pavement performance consideration. The PPQI values have been calculated by assuming an ESAL growth rate equal to the traffic growth rate. Strategy 4 is the preferred choice of conventional analysis that considers construction, maintenance and rehabilitation costs, and salvage value of the pavement. When the extra agency costs associated with pavement performance are included, Strategy 1 becomes the most preferred option.

TABLE 1 SUMMARY OF RESULTS FOR EXAMPLE 1

Design Option	Agency Cost without Pavement Performance Consideration, in Present Worth	Agency Cost with Pavement Performance Consideration, in Present Worth						
		PPQI	State Highway Agency		County Highway Agency		City Highway Agency	
			Extra Cost	Total Cost	Extra Cost	Total Cost	Extra Cost	Total Cost
I	*\$291,100	3.04	\$185,430	\$476,530	\$124,591	*\$415,691	\$69,864	*\$360,964
II	\$325,250	3.53	\$148,639	*\$473,889	\$100,502	\$425,752	\$48,137	\$373,387

Note : Each entry marked with (*) represents the preferred option for the criterion indicated by corresponding column heading.

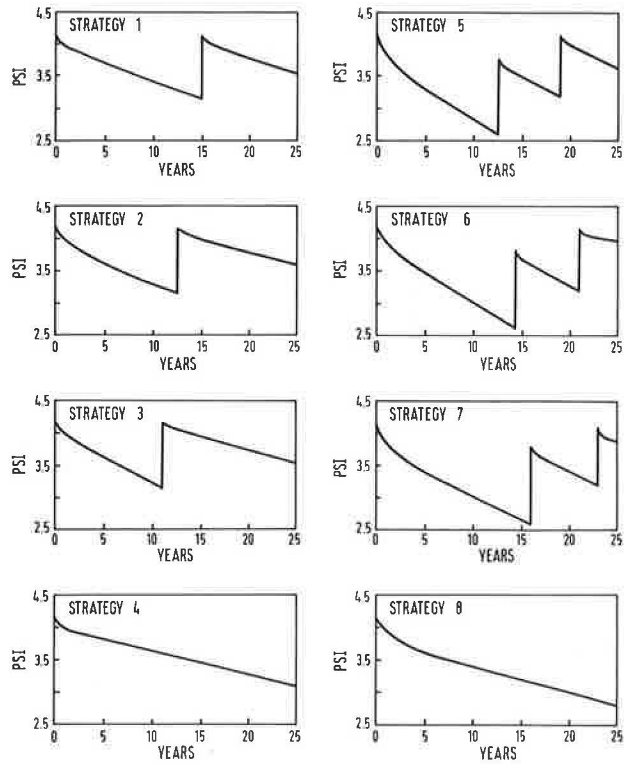

FIGURE 7 PSI versus time histories for different pavement strategies considered in Examples 2 and 4.

An examination of the relative ranking of the eight strategies in each case reveals some interesting trends and provides an insight into the significance of pavement performance consideration. Table 3 presents three lists of ranking in the order of preference according to (a) performance level (i.e., PPQI level); (b) conventional total agency cost without pavement performance consideration; and (c) total agency cost with pavement performance consideration, respectively. The comparison of the first two lists indicates that the relative ranking of Strategies 3, 2, 1, and 4 in List a becomes reversed in List b. The same also happens to Strategies 6, 5, 7, and 8. Strategy 3, which has the highest performance level, ranks last in List b. On the other hand, the strategy with the lowest performance level, Strategy 8, is the second most preferred alternative in List b.

This comparison tends to provide supporting evidence for several observations made by Fwa and Sinha (*3*). By examining the relationships between pavement performance and individual agency cost items, they have stated that (a) with given construction technology and standards, economic analysis based on construction or rehabilitation cost alone would generally favor strategies with lower pavement performance; (b) for a highway agency following a known maintenance policy, a strategy that requires low maintenance expenditure and yet is able to satisfy a minimum serviceability level over the analysis period would be selected on the basis of maintenance cost consideration; and that (c) better engineering and administrative effort helps ensure good pavement performance but requires more monetary imput. A selection criteria based on economy alone would not, therefore, favor a better pavement performance option.

The reasoning appears to be able to explain the ranking in List b of Table 3. However, this tendency to favor lower performance strategies in pavement evaluation may not be known to many engineers who use economic analysis based only on agency costs. Providing pavements with the highest possible performance level within available budget and resources is probably the foremost objective of a pavement engineer. Incorporating pavement performance consideration into economic evaluation of pavement strategies is consistent with this objective. The impact of this can be seen from the ranking in List c of Table 3. Comparison of Lists b and c indicates that some changes have taken place. High-performance strategies, such as Strategies 1, 2, and 3, now receive better preference. The ranking of Strategy 8 dropped from second to sixth position because of the relatively high extra agency costs associated with its low pavement performance level.

COMPARISON BASED ON ROAD USER COSTS

Few highway agencies, if any, would evaluate pavement alternatives on the basis of road user costs alone. However, to investigate how pavement performance consideration would affect the relative magnitude of the user costs under different

TABLE 2 SUMMARY OF RESULTS FOR EXAMPLE 2

Strategy	Agency Cost without Pavement Performance Consideration, in Present Worth	Agency Cost with Pavement Performance consideration, in Present Worth		
		PPQI	Extra agency cost	Total agency cost
1	$178,986	3.66	$70,699	*$249,685
2	$184,443	3.72	$67,322	$251,765
3	$198,566	3.75	$71,682	$270,248
4	*$173,923	3.52	$79,657	$253,580
5	$188,048	3.48	$88,759	$276,807
6	$194,568	3.51	$89,890	$284,458
7	$179,790	3.46	$86,299	$266,089
8	$177,505	3.26	$98,338	$275,843

Note: Each entry marked with (*) represents the preferred strategy for the criterion indicated by corresponding column heading.

TABLE 3 RELATIVE RANKING OF STRATEGIES CONSIDERED IN EXAMPLE 2

Rank	List (a) Ranking by Performance according to PPQI	List (b) Ranking by Agency Cost without Pavement performance consideration	List (c) Ranking by Agency Cost with Pavement performance consideration
1	Strategy 3	Strategy 4	Strategy 1
2	Strategy 2	Strategy 8	Strategy 2
3	Strategy 1	Strategy 1	Strategy 4
4	Strategy 4	Strategy 7	Strategy 7
5	Strategy 6	Strategy 2	Strategy 3
6	Strategy 5	Strategy 5	Strategy 8
7	Strategy 7	Strategy 6	Strategy 5
8	Strategy 8	Strategy 3	Strategy 6

Note : In each list, strategies are ranked in order of decreasing preference i.e. Rank 1 is the most preferred, while rank 8 is the least preferred.

pavement strategies is of interest because user costs often represent a significant share of total pavement costs. Two examples illustrate the impact of pavement performance consideration.

Road User Costs Comparison—Example 3

User costs of the two options shown in Figure 8 were analyzed by Zaniewski et al. (*8*). They reported a difference of only 1.2 percent in the vehicle operating costs of the two options.

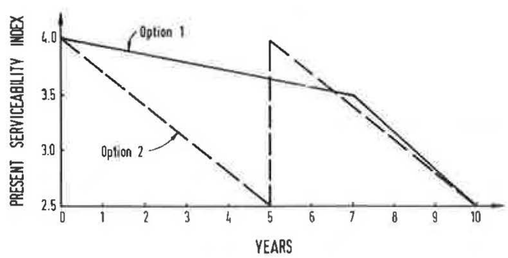

FIGURE 8 Pavement performance versus time relationship for Options 1 and 2 considered in Example 3.

The present worth of vehicle operating costs, including fuel, oil, tires, maintenance, and depreciation costs, was found to be $918,100 for Option I, and $929,200 for Option II. These were computed for an analysis period of 10 years at a discount rate of 3.75 percent, with an assumption that the daily traffic of 2,120 vehicles remained constant over the entire analysis period.

On the basis of the pavement performance data in Figure 8 and the given traffic volume information, the present worth of pavement performance can be derived using either Equations 3 or 4. Assuming the relationship of PSI to user value of pavement performance shown in Figure 5 is applicable, the present worth of pavement performance computed as extra user costs per mile for a 10-mi road segment is found to be $170,278 for Option I, and $353,723 for Option II. The total user costs, inclusive of user values for pavement performance, are $1,088,378 and $1,282,923 for Options I and II, respectively. The results, as presented in Table 4, now indicate a much more substantial difference of about 20 percent between the two options.

It should be noted that Zaniewski et al. (*8*) did not consider travel time and traffic delay costs in their calculations. These two cost items, if included, would have made Option I much more favorable than what they indicated. The inclusion of

TABLE 4 SUMMARY OF RESULTS FOR EXAMPLE 3

Pavement Option	User Costs without Pavement Performance Consideration, in Present Worth	User Costs including Pavement Performance Consideration, in Present Worth	
		Extra User Costs for Pavement performance	Total User Cost
I	*$918,100	$170,278	*$1,088,378
II	$929,200	$353,723	$1,282,923

Note : Entry marked with (*) represents the preferred option for the criterion indicated by corresponding column heading.

the user value of pavement performance, as demonstrated earlier, helps to further confirm the economic desirability of Option I.

Road User Costs Comparison—Example 4

Road user costs of the eight strategies described in Example 2 were also reported by Rada and Witczak (*12*). Two user cost strategies, namely running user costs and added user costs, were considered in the analysis. Running user costs were estimated for different PSI levels as a function of vehicle traveling speed. Added user costs are traffic delay costs caused by rehabilitation activities. The values of these two cost items for all the eight strategies are presented in Table 5. It was concluded that Strategy 1 had the lowest user cost.

Also presented in Table 5 are extra user costs associated with pavement performance levels, and the corresponding total user costs for each of the eight strategies. Strategy 1 is no longer the least cost option. It now falls behind Strategies 2 and 3, the two strategies with the highest PPQI values. The relative preference ranking of the remaining five strategies remains unchanged.

ECONOMIC ANALYSIS ON THE BASIS OF TOTAL COST

Life-Cycle Cost Analysis

The present worth value of agency and user costs, for the eight strategies described in Figure 7, have been computed in Examples 2 and 4, respectively. The life-cycle costs for each of the strategies, with and without pavement performance consideration, are presented in Table 6. Strategy 1 is the best strategy on the basis of the conventional analysis that does not include pavement performance consideration. Strategy 2 becomes slightly better than Strategy 1 in terms of life-cycle cost when agency and user values of pavement performance are included in the analysis.

TABLE 5 SUMMARY OF RESULTS FOR EXAMPLE 4

Strategy	User Cost without Pavement Performance Consideration, in Present Worth			User Cost with Pavement Performance Consideration, in Present Worth	
	Running Cost	Added User Cost	Total User Cost	Extra User Cost for Pavement Performance	Total User Cost
1	$693,356	$1,077	*$694,433	$78,999	$773,432
2	$697,955	$1,068	$699,023	$61,276	*$760,299
3	$707,155	$1,064	$708,219	$56,844	$765,063
4	$958,791	0	$958,791	$92,958	$1,051,749
5	$1,047,741	$1,965	$1,049,706	$127,459	$1,177,165
6	$1,136,997	$1,979	$1,138,976	$118,248	$1,257,224
7	$1,211,709	$1,990	$1,213,699	$129,874	$1,343,573
8	$1,289,186	0	$1,289,186	$147,708	$1,436,894

Note : Entry marked with (*) represents the preferred strategy for the criterion indicated by corresponding column heading

TABLE 6 SUMMARY OF LIFE-CYCLE COST ANALYSIS

Strategy	Life-Cycle Cost without Pavement Performance Consideration, in Present Worth			Life-Cycle Cost with Pavement Performance Consideration, in Present Worth		
	Agency Cost	User Cost	Total Cost	Agency Cost	User Cost	Total Cost
1	$178,986	*$644,433	*$873,419	*$249,685	$773,432	$1,023,117
2	$184,443	$699,023	$883,466	$251,765	*$760,299	*$1,012,064
3	$198,566	$708,219	$906,785	$270,248	$765,063	$1,035,311
4	*$173,923	$958,791	$1,132,714	$253,580	$1,051,749	$1,305,329
5	$188,048	$1,049,706	$1,237,754	$276,807	$1,177,165	$1,453,972
6	$194,568	$1,138,976	$1,333,544	$284,458	$1,257,224	$1,541,682
7	$179,790	$1,213,699	$1,393,489	$266,089	$1,343,573	$1,609,662
8	$177,505	$1,289,186	$1,466,691	$275,843	$1,436,894	$1,712,737

Note: Each Entry marked with (*)represents the preferred strategy for the criterion indicated by corresponding column heading

By arranging the results of Table 6 according to the order of preference, as is done in Table 7, the following observations can be made:

1. In the conventional analysis where pavement performance consideration is not included, drastic differences are found between the ranking list of agency cost-based solutions and that obtained from total cost-based solutions. For the analysis that includes pavement performance consideration, the corresponding differences are much less drastic.
2. User costs have a dominating influence on the results of total cost-based analysis. In the conventional analysis, the total cost-based ranking is identical to the user cost-based ranking. In the case of revised analysis with pavement performance consideration, some differences are found between the two corresponding rankings.

In general, considering agency and user values of pavement performance in project evaluation would achieve better agreement among agency cost-based, user cost-based, and total cost-based decisions. Realizing that "when all things are equal, the preference for better-performance pavements is common to both highway agencies and road users"(*3*), this agreement is not suprising.

Benefit-Cost Ratio Analysis

In this method, the ratio of the present worth of benefits to the corresponding worth of costs is computed to determine the economic desirability of the alternatives on the basis of an incremental pairwise comparison. The pairwise comparison is performed by taking alternatives into consideration in the order of increasing cost. The results of these analyses are presented in Table 8. The final conclusion concerning the most preferred strategy in each case is the same as that in life-cycle cost analysis.

CONCLUSIONS

Making use of recently available estimates of the agency and user values of pavement performance, it has been possible to (a) assess the order of magnitude of these values with respect to the major cost items commonly considered in economic analysis of pavement strategies, and (b) evaluate the impact of incorporating pavement performance consideration into these analyses.

It has been found that the agency and user values of pavement performance are of the same order of importance as the

TABLE 7 RANKING IN ORDER OF PREFERENCE ACCORDING TO LIFE-CYCLE COST ANALYSIS

Ranking in Order of Decreasing Preference	Life-Cycle Cost without Pavement Performance Consideration			Life-Cycle Cost with Pavement Performance Consideration		
	Agency Cost	User Cost	Total Cost	Agency Cost	User Cost	Total Cost
1	Strategy 4	Strategy 1	Strategy 1	Strategy 1	Strategy 2	Strategy 2
2	Strategy 8	Strategy 2	Strategy 2	Strategy 2	Strategy 3	Strategy 1
3	Strategy 1	Strategy 3	Strategy 3	Strategy 4	Strategy 1	Strategy 3
4	Strategy 7	Strategy 4	Strategy 4	Strategy 7	Strategy 4	Strategy 4
5	Strategy 2	Strategy 5	Strategy 5	Strategy 3	Strategy 5	Strategy 5
6	Strategy 5	Strategy 6	Strategy 6	Strategy 8	Strategy 6	Strategy 6
7	Strategy 6	Strategy 7	Strategy 7	Strategy 5	Strategy 7	Strategy 7
8	Strategy 3	Strategy 8	Strategy 8	Strategy 6	Strategy 8	Strategy 8

TABLE 8 SUMMARY OF BENEFIT-COST RATIO ANALYSIS

Analysis without Pavement Performance Consideration			Analysis with Pavement Performance Consideration		
Strategies Compared	Benefit/cost Ratio	Strategy Preferred	Strategies Compared	Benefit/cost Ratio	Strategy Preferred
4 vs. 8	Negative	Strategy 4	4 vs. 8	Negative	Strategy 4
4 vs. 1	Greater than 1	Strategy 1	4 vs. 1	Greater than 1	Strategy 1
1 vs. 7	Negative	Strategy 1	1 vs. 7	Negative	Strategy 1
1 vs 2	Negative	Strategy 1	1 vs. 2	Greater than 1	Strategy 2
1 vs. 5	Negative	Strategy 1	2 vs. 5	Negative	Strategy 2
1 vs. 6	Negative	Strategy 1	2 vs. 6	Negative	Strategy 2
1 vs. 3	Negative	Strategy 1	2 vs. 3	Negative	Strategy 2
Conclusion : Select strategy 1			Conclusion : Select strategy 2		

cost items in economic analysis of pavement. On the basis of the numerical examples presented, the following conclusions can be drawn. Conventional pavement evaluation relying solely on agency cost analysis tends to favor strategies with lower pavement performance levels. This bias can be corrected by including the agency value for pavement performance in the evaluation. Traditionally, very different recommendations could result from agency-cost based and user-cost based analyses. Better agreement would be achieved if both agency and user values for pavement performance are considered. This outcome is logical because good pavement performance is desirable to highway agencies and users alike. Agency and user values of pavement performance are important elements in economic analysis of pavement strategies because they can significantly influence the final outcome of the analysis.

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Employment and Income Impact of Expenditures for Bypass, Loop and Radial Highway Improvements

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Six multiple regression models are developed to estimate employment and income impacts of highway expenditures on bypass, loop and radial highway improvements. The regression models are of the single linear equation type. Three of the models are solved by the ordinary least squares method using 1-year cross-sectional data, and three of the models are solved by the ordinary least squares and pooled methods using 4-year combined cross-sectional and time series data. The before-versus-after construction approach is applied in the last three models. The economic impacts are estimated using the following dependent variables in the respective sets of equations: (a) number of manufacturing employees of an affected city, (b) number of employees of an affected county, and (c) total actual or real wages of an affected county. The research results indicate that the three economic impact variables are significantly affected by expenditures on the study highway improvements. The regression models developed from the combination cross-sectional and time series analysis exhibit these effects more clearly and are more accurate than those developed from the cross-sectional analysis. The results of this research can be used by highway planners in estimating the extent of the employment and income effects of expenditures on highway improvements like those studied.

Employment and income impacts of highway expenditures on specific highway improvements, such as bypass, loops, and radials, are analyzed. The majority of all the highway bypasses and loops constructed in the state are used in this analysis. Because of the difficulty of establishing the total cost of each of these improvements, actual dollar amounts are not used in developing the relationship between key economic development variables and highway expenditures. Alternatively, the key economic variables are related to other economic, locational, highway system, geographic, and time-related variables. The results indicate the average impact of a bypass, loop, or radial highway improvement on the key economic variables of a city or county having such improvements.

LITERATURE REVIEW

The literature review reveals several references that deal with the problem of establishing the relationship between highway construction expenditures and economic growth and development. Several studies indicate a significant link between economic development and highway expenditures (*1–3*). Other studies indicate a positive correlation between transportation expenditures and regional economic variables, such as employment growth rates, manufacturing activity, and population (*4,5*). There are studies that indicate that transportation costs and accessibility can affect the number of job seekers in a particular area and thus affect the size of the labor force available for hiring by interested firms (*1,6–9*). Even a significant relationship between highway expenditures and rural employment is established in one study (*1*). Large-scale models tend to indicate that positive relationships exist between economic activity and transportation expenditures (*1,10,11*).

Models and techniques used in estimating the overall and specific sector effects of changes in highway expenditures on U.S. output and employment are also reported in the literature (*7,10,11*). The Chase macroeconomic model and input-output models are examples (*10*). The Texas input-output model provides multipliers for estimating the impacts of highway construction on employment and income in Texas (*11*). Finally, the literature reports various studies that estimate the local effects of highway construction on employment, income, and land use (*12–17*).

Stephanedes and Eagle (*18*) do a good job discussing the various types of models used to estimate the impact of highway expenditures on employment and income. They analyze the following procedures: (a) input-output, (b) cross-sectional, (c) time series, and (d) pooled cross-sectional with time series. These researchers conclude that the input-output models produce mixed results; cross-sectional models only determine the correlation between highways and development; time series models differentiate the effects of highways on development from the effects of development on highways; and pooled cross-sectional and time series models determine the correlation between highways and development and also determine the effects of development on highways. These researchers prefer using the pooled model that is described in detail by Kmenta (*19*) and computerized by White and Horsman (*20*).

EVALUATION TECHNIQUES AND DATA BASE

Evaluation Techniques Applied

After a thorough examination of the existing models and techniques reported in the literature, two basic types of models are applied as evaluation techniques in this study as follows: (a) models using a cross-sectional data base, and (b) models using a combination time series and cross-sectional data base.

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Further, each model uses a single linear multiple regression equation and uses the ordinary least squares method to estimate it. Also, continuous and binary variables are used in each equation. The resulting equations show the statistically significant relationships between the selected economic impact variables and the various explanatory variables. No variable is used in these models to reflect general changes in the Texas economy over time. The models using only cross-sectional data do not need such a variable included to obtain results that can be used to make inferences with respect to highway expenditure impacts. Also, the results of models using 1-year cross-sectional data confirm the results of models using multiyear combined cross-sectional and time series data. Because the second set of models also use cross-sectionally based data, it does not seem critical to include a variable to reflect general economic conditions over time in the state.

The results generated by these models can be used to place an upper limit on estimates of the total economic impact resulting from expenditures for such highway improvements in a city or county. Also, these results can be compared with the estimates obtained by using multipliers generated by the Texas input-output model (*11*) with actual dollar amounts spent on such improvements.

Models Using Cross-Sectional Data

Models using cross-sectional data help to measure microrelationships between the key economic variables and the explanatory variables at one point in time. For example, it is helpful for the highway planner to know that the variable distance to equal or larger city explains a significant amount of variation in the employment of a county in which a major highway improvement is constructed, no matter which data year is used to estimate the model. In other words, this variable is not time related. However, the basic problem in using only cross-sectional data in these models is heteroskedasticity, a condition that violates the assumption that the error variances are constant (*19*). In such cases, the ordinary least squares estimation places more weight on observations with large error variances than on those with small error variances, keeping the variances of estimated parameters from being minimum variances. The resulting estimated parameters are still unbiased and consistent but not efficient. The extent of this problem can be measured with appropriate statistical tests.

Models Using Combination of Cross-Sectional and Time Series Data

Models based on a combination of cross-sectional and time series data help measure microrelationships and macrorelationships between the key economic variables and the explanatory variables, because they are based on multiyear data. Time series data are used primarily to develop macrorelationships. However, the use of time series data causes serial correlation, a condition that violates the assumption that the errors of the different observations are uncorrelated. Therefore, these models have to deal with both heteroskedasticity and serial condition. These problems are more pronounced in ordinary least squares models than in models using the pooling technique, because the pooling technique transforms the data before applying the ordinary least squares estimation. The transformation is made on each observation to adjust for heteroskedasticity and serial correlation. Again, the extent of these problems in a particular model can be measured with appropriate statistical tests.

The pooled model is a single multiple regression equation, as described by Kmenta (*19*), and is processed by SHAZAM, an economic computer program written by White and Horsman (*20*). The Kmenta model requires that all years of each cross section be arranged together in consecutive order, and SHAZAM, using the SAME option, restricts all cross sections to have the same autoregressive parameter, as described in the Kmenta model. As a result, the model yields regression residuals that are nonheteroskedastic and nonautoregressive. Therefore, the regression coefficients are efficient, consistent, and unbiased.

Data Base Developed

As indicated, the data base is designed to establish the statistical relationship between key economic variables and explanatory variables for specific types of highway improvements. The data base is restricted to major highway improvements, such as bypasses, loops, and radials. The data base contains 67 highway improvements that include 40 bypasses, 20 loops, and 7 radials. The criteria for selecting these highway improvements are as follows: (a) be improved with at least one segment completed after 1955 and before 1984, (b) be located in a city of over 4,000 population, and (c) be built on a new location.

The data base sources are the following: *Texas Almanacs*, U.S. Bureau of Census *County and City Data Books*, Texas Employment Commission quarterly reports, Texas directories of manufacturers, city maps, and SDHPT highway road and traffic maps.

To conduct a combination cross-sectional and time series analysis using an approach of before construction versus after, more than 1 year of data are required for each highway improvement studied. Therefore, the data base contains 4 years of data for each of the 67 highway improvements. The first year of data is 1954, which is selected as the first before-construction year of all 67 improvements. The last year of the study is 1988, which is at least 5 years after completion of each improvement. Also, data are collected for two interim years. The first interim year, 1961, is a before-construction year for some improvements and an after-construction year for others. The second interim year, the map year, is considered a before-construction year. It represents the year before the highway improvement is printed on the state highway map.

Some of the data for certain variables do not perfectly match one or more of the data years, but none are off more than 3 years. Where possible, the data is adjusted by extrapolating between two actual data years.

Table 1 presents a list of 34 basic variables that make up the data base. The variables are listed by type, name, and location on the left side of the table. Also, the primary functional relationship of each variable is indicated on the right side. There are 13 economic variables, 14 highway system

TABLE 1 VARIABLES USED IN CROSS-SECTIONAL AND COMBINED CROSS-SECTIONAL AND TIME SERIES ANALYSIS

Variable by Type Name and Location	Functional Relationship Dependent	Explanatory
Economic Development		
Population, county		X
Population, city		X
Firms, commercial, city	X	
Firms, manufacturing, city	X	
Employed, county	X	
Employed, city	X	
Employed, manufacturing, city	X	
Employed, manufacturing, old route, city	X	
Employed, manufacturing, new route, city	X	
Wages, ths. of dollars, county**		X
Bank deposits, ths. of dollars, county**		X
Oil produced, barrels, county		X
Vehicles registered, county		X
Highway System Description		
Hubs, city		X
Continuous highways, city		X
Terminal highways, city		X
State highways, city		X
U.S. highways, city		X
Interstate highways, city		X
ADT (1985), incoming highways, city		X
ADT (1985), new highway route, city		X
Type of new highway route, city		X
Shape of new route segments, city		X
Number of new route segments, city		X
Construction time, all new segments, city		X
Length, new route, city		X
Length, old route, city		X
Distance, between old and new routes, city		
Geographic and Time		
Distance to nearest major city, state		X
Distance to equal or larger city, state		X
Distance to Gulf coast, state		X
Age of first new route segment, city		X
Age of last new route segment, city		X
Before vs. after construction, city		X

**In actual dollars in cross-sectional analysis and in constant 1954 dollars in the combined cross-sectional and time-series analysis.

descriptive variables, and 7 geographic and time variables. Only those of the economic type are used as dependent variables, because they are considered more or less dependent on the other variables making up the data base. All but two of the variables are considered continuous. The other two categories are expanded into four binary or dummy variables. These are defined as follows:

Type of new highway route, city—expanded to

- Bypass = 1, otherwise = 0;
- Loop = 1, otherwise = 0; and
- Radial = 1, otherwise = 0.

Before versus after construction—expanded to

- After construction = 1, otherwise = 0.

Some of the other variables are combined in various ways or changed into log form and tried in one or more of the analyses or models.

Because the number of employees is one of the important measures of economic activity in a city or county, five employment variables are defined for this analysis. Also, because manufacturing firms can generate a significant amount of employment, three of these variables represent manufacturing employment. The other two variables represent total employment, including manufacturing employment. Another reason for defining variables representing only manufacturing employment is the likelihood that manufacturing firms may prefer one type of highway improvement over another.

RESULTS OF ANALYSES

The results of the cross-sectional analysis and the combined cross-sectional and time series analysis are presented separately in the following sections. The final models of each analysis are described and discussed in detail, including the amount of explained variation, level of statistical significance of each variable, and the appropriate test results. All inferences made from the results of the analysis are based on a comparison of *t*-ratios for each variable within or among models.

Cross-Sectional Analysis

The results of the cross-sectional analysis are presented separately for three selected economic variables, namely: (a) number of manufacturing employees in study city; (b) number of all employees in study county; and (c) total actual wages in study county. These three economic variables are considered the most feasible for indicating the employment and income impacts resulting from spending highway dollars to construct bypasses, loops, and radials. As is evident in the study cities and counties over the state, many businesses locate or relocate along these new highway improvements. In some cases, so many firms locate along these new transportation arteries that they cause traffic congestion on them in just a few years.

Number of Manufacturing Employees in City

Table 2 presents Model 1, which uses 1-year cross-sectional data to estimate the number of manufacturing employees in a city impacted by a highway improvement. For comparative purposes, the results are exhibited for two data years, 1954 and 1988. It should be recalled that 1954 is the true before-construction year and 1988 is the true after-construction year. Many combinations of variables are used in this model before deciding on the final sets presented in Table 2. Both of the data years have the same explanatory variables. Multiple collinearity is at a minimum, the signs of the regression coefficients are appropriate, and the variables used are expected to independently influence the variation in the number of manufacturing employees in a city with a highway improvement. The standard error of regression is at or near the minimum for both data years and the amount of explained variation is high, as indicated by the R^2 values and as confirmed by the high F values. However, the Durbin-Watson statistic is a little low, indicating that some serial correlation is present in the model. A Durbin-Watson statistic of about 2 would indicate the presence of no serial correlation. No correction is made for serial correlation because it is not a relevant problem for the 1-year cross-sectional analysis. No test is performed to determine if heteroskedasticity is a problem in this model, because such corrections are made in the combination or pooled analysis to be presented later.

Comparing the results of the two data years, Model 1 indicates that the building of a radial highway in a city does have a statistically significant positive influence on the number of manufacturing employees in that city. Also, the distance between the old and new routes has a statistically significant influence. As the distance between these routes increases, the number of manufacturing employees increases. In the case of the type of highway improvement, building a bypass has a positive but not statistically significant influence on the number of manufacturing employees. The extent of a loop highway's influence cannot be indicated explicitly in the model when the two other dummy variables describing the type of highway improvement are used as explanatory variables. Otherwise, the regression equation could not be solved. In this model, the influence of loops is included in the error term. Of the three, the loop dummy variable is the least correlated with the other independent variables in the different models. In many cases, it is not significantly related to the other independent variables. Therefore, its inclusion in

TABLE 2 MODEL 1: COEFFICIENTS FOR ESTIMATING NUMBER OF MANUFACTURING EMPLOYEES IN CITY, USING CROSS-SECTIONAL ANALYSIS

Explanatory Variable	1954 Data Base Regression Coefficient	1954 Data Base T-Ratio[a]	1988 Data Base Regression Coefficient	1988 Data Base T-Ratio[a]
Constant term	-1966	-0.92	-2098	-1.07
Number of U.S. highways	1792	2.95	1621	2.83
Number of State highways	1808	3.26	1404	2.68
Distance to equal or larger city[b]	-168.97	-10.89	-118.34	-7.87
Distance between old and new routes[b]	1124.49	1.52	1922.36	2.92
Population of City	0.1189	19.33	0.07622	35.66
Radial improvement	2977	0.62	6681	2.83
Bypass improvement	1597	1.01	544	0.37
R^2 statistic	0.98		0.99	
F statistic	341		736	
Durbin-Watson statistic	1.42		1.29	
Standard error of regression	4386		4147	

[a] T-ratios of 2.00 or greater are statistically significant 95% or more of time.

[b] In miles (00.00).

the error term should not result in an autocorrelated error term.

All of the other explanatory variables in Model 1 have a statistically significant influence on manufacturing employment. Two of these are highway related, namely, the number of U.S. highways and the number of state highways. As the number of these highways increases, the number of manufacturing employees increases. The distance to an equal or larger city has a negative influence on the number of manufacturing employees. Of all the explanatory variables in the model, the population of the city has the greatest statistically significant influence on manufacturing employment. Also, the city population explains more variation and helps the model to be more consistent than some of the other variables that are highly correlated with manufacturing employment.

Number of Employees in County

Table 3 presents Model 2, which estimates the number of employees in a county with two 1-year data bases. About the same results are obtained in Model 2 as in Model 1. The same explanatory variables are used to obtain the best statistical results. Model 2 explains a large amount of variation in the number of employees in a county containing one of these highway improvements, as evidenced by the high R^2 values and again confirmed by the high F values. About the same statistical relationships exist for Model 2 as exist for Model 1. The only exception is the change in the relationship between the two highway improvement variables and the number of employees in a county. In Model 2, a bypass improvement significantly affects the number of county employees; whereas in Model 1 radial improvements significantly affect the number of manufacturing employees in a city. This finding may indicate that manufacturing firms prefer radial highways over bypass highways, and that other types of businesses may prefer bypass highways over radial highways. Manufacturing firms may prefer radial highways because they provide more direct access to lower-income workers who live mostly within the city's core area. By contrast, the other types of businesses, mainly the retail and service types, may prefer bypass highways because they provide better access to a greater number of customers living in suburban areas of a city.

By comparing the results of the two data bases used for Model 2, several differences are observed. The first is the varied level of statistical significance of the two highway improvement variables. The 1988 data base produces more highly significant regression coefficients than does the 1954 data base, which is the expected result. Because none of the highway improvements had been built in 1954, the coefficients generated by the 1954 data base should not be statistically significant. However, one being significant may result partially from the anticipatory effects of a planned highway improvement. It usually takes several years to plan and build such highway improvements. As soon as businesses know the location of a planned bypass or loop around a city, some will purchase adjacent sites, build the facilities, and start operating before the highway improvement is built or opened for use, especially if the facility follows or intersects existing roads in the area. The second difference observed is the significantly higher standard error of regression obtained with the 1988 data base compared with that obtained with the 1954 data base. The standard errors of regression for both data bases in Model 1 are about the same. Such results would suggest that for various reasons the number of county employees fluctuated more between 1954 and 1988 than did the number of city manufacturing employees. Total employment in some counties apparently grew much faster than did manufacturing employment in the corresponding cities. The third difference observed is the statistically significant variable, number of U.S. highways, obtained only with the 1988 data base. Such a result indicates that U.S. numbered highways have become more attractive to businesses in recent years.

Total Actual Wages in County

Table 4 presents the Model 3 results from using 1-year cross-sectional data bases to estimate the total actual wages in a

TABLE 3 MODEL 2: COEFFICIENTS FOR ESTIMATING NUMBER OF EMPLOYEES IN COUNTY, USING CROSS-SECTIONAL ANALYSIS

Explanatory Variable	1954 Data Base: Regression Coefficient	1954 Data Base: T-Ratio[a]	1988 Data Base: Regression Coefficient	1988 Data Base: T-Ratio[a]
Constant term	-16614	-2.58	-134626	-5.49
Number of U.S. highways	2554	1.40	22476	3.12
Number of State highways	7500	4.50	37462	5.72
Distance to equal or larger city[b]	-306.99	-6.59	-837.64	-4.45
Distance between old and new routes[b]	2351.57	1.06	22973	2.78
Population of City	0.3581	19.39	0.6580	24.60
Radial improvement	-16742	-1.16	60452	1.20
Bypass improvement	10596	2.24	52059	2.80
R^2 statistic	0.97		0.98	
F statistic	277		377	
Durbin-Watson statistic	1.53		1.35	
Standard error of regression	13170		51889	

[a] T-ratios of 2.00 or greater are statistically significant 95% or more of time.
[b] In miles (00.00).

TABLE 4 MODEL 3: COEFFICIENTS FOR ESTIMATING TOTAL ACTUAL WAGES IN COUNTY, USING CROSS-SECTIONAL ANALYSIS

Explanatory Variable	1954 Data Base Regression Coefficient	1954 Data Base T-Ratio[a]	1988 Data Base Regression Coefficient	1988 Data Base T-Ratio[a]
Constant term	-65974	-2.13	-3568511	-4.89
Number of U.S. highways	12276	1.41	516093	2.42
Number of State highways	33608	4.21	1104246	5.66
Distance to equal or larger city[b]	-1597	-7.15	23544.51	-4.20
Distance between old and new routes[b]	10756.84	1.01	464529.64	1.89
Population of City	1.4319	16.18	16.4995	20.72
Radial improvement	-86500	-1.25	-43264	-0.03
Bypass improvement	45344	2.00	1495349	2.70
R^2 statistic	0.96		0.97	
F statistic	191		244	
Durbin-Watson statistic	1.49		1.45	
Standard error of regression	63123		1545318	

[a] T-ratios of 2.00 or greater are statistically significant 95% or more of time.
[b] In miles (00.00).

county. Once again, the same explanatory variables, as used in Models 1 and 2, are also the most feasible to use in Model 3. Generally, the same results are obtained in Model 3, as in both the other models, especially in Model 2. The only exception is the fact that the regression coefficient for the variable distance between the old and new routes in Model 3 is not quite statistically significant using the 1988 data base compared to Model 1.

The effects of the highway improvement are not as clear-cut in Model 3 as in the other two models. It takes the combined cross-sectional and time series analysis to clarify the effects of these types of highway improvements on the three economic impact variables.

Combined Cross-Sectional and Time Series Analysis

As previously discussed, the combined cross-sectional and time series analysis is performed by using a multiple regression technique described by Kmenta (*19*) and executed with a computer program written by White and Horsman (*20*). Also, it should be recalled that the data base has 4 years of data, each year having 67 observations, resulting in a combined data base of 268 observations.

The same economic impact variables used in the cross-sectional analysis are also used in this analysis. The same explanatory variables listed in Table 1 are tried out in this analysis, except for adding the dummy variable that indicates the general before- versus after-construction effects. For comparative purposes, the analysis is run also on an ordinary (nonpooled) least squares basis. The results of the three economic impact variables are presented separately in the following paragraphs.

Number of Manufacturing Employees in City

The results of Model 4, which estimates the number of manufacturing employees in a city, are presented in Table 5. All but two of the explanatory variables used in this model are used in Models 1, 2, and 3, and because time-series data are also included in the Model 4 data base, a before- versus after-construction variable is added. Again, many combinations of explanatory variables (approximately 30) were used in this analysis before obtaining the best overall sets for this model. Also, the dependent variable and several explanatory variables were tried in log form. In addition, several explanatory variables were combined. For example, the number of U.S. highways was combined with the number of state highways, and the average daily traffic (ADT) on incoming highways on one side of the city was combined with the same on the other side of the city. Multiple collinearity is at or near a minimum; the standard errors of estimate are near a minimum; and the amounts of explained variation are relatively high, as evidenced by the R^2 and confirmed by the F values.

Table 3 presents the results of the ordinary least squares approach as well as the pooled approach. Compared with the ordinary least squares approach, the pooled analysis yields lower R^2 and F values. However, the Durbin-Watson statistic is much higher for the pooled analysis, which properly corrects for serial correlation in the error term. Therefore, the regression coefficients of the pooled approach are more efficient, consistent, and unbiased than those of the other approach.

The results of Model 4 generally confirm the results of Model 1 by indicating that manufacturing employment in an affected city is positively affected by highway improvements, such as those included in the study. Even though it is not statistically significant, the before- versus after-construction variable is positively related to manufacturing employment. Also, the other variables directly related to the highway improvement are positively related to manufacturing employment, and two are statistically significant. As has already been suggested, radial highway improvements may influence manufacturing employment more than do bypass improvements, because some manufacturing firms may prefer to locate along new routes leading directly into the core area of city where many of the low-income employees live. This is not to say that manufacturing firms don't locate along bypasses or loops.

TABLE 5 MODEL 4: COEFFICIENTS FOR ESTIMATING MANUFACTURING EMPLOYMENT IN CITY, USING COMBINED CROSS-SECTIONAL AND TIME SERIES ANALYSIS

Explanatory Variable	Ordinary Least Squares Regression Coefficient	T-Ratio[a]	Pooled Regression Coefficient	T-Ratio[a]
Constant term	-3818	-2.34	-685	-0.98
Distance to equal or larger city[b]	-166.83	-13.48	-101.64	-9.15
Distance between old and new routes[b]	4979.20	10.05	2541.20	6.91
Before versus after construction	-1097	-1.10	210	1.19
Bypass improvement	3441	2.66	763	1.75
Radial improvement	26101	8.64	23467	7.49
Population of city	0.07793	31.35	0.0722	20.13
R^2 statistic	0.95		0.88	
F statistic	798		323	
Durbin-Watson statistic	1.11		1.72	
Standard error of regression	7268		0.84	

[a] T-ratios of 2.00 or greater are statistically significant 95% or more of time.
[b] In miles (00.00).

In fact, some do. Also, other types of firms do locate along radial improvements, but such firms are more attracted to bypasses and loops. The distances between the old and new routes significantly influence manufacturing employment in a positive way, which tends to confirm that manufacturing firms like to locate along all three types of improvements.

Finally, the regression coefficients of Model 4's pooled approach are more efficient, consistent, and unbiased than those of Model 1, because correction is made for heteroskedasticity and autocorrelation. Also, the Model 4 results, as presented in Table 5, yield more definite indications of the positive effects of such highway improvements on the number of manufacturing employees in an affected city than those indicated in Model 1, as indicated in Table 2. For example, the explanatory variables distance between old and new routes and radial improvement are more highly significant in Model 4 than in Model 1. Also, the explanatory variable bypass improvement is almost statistically significant in Model 4, whereas in Model 1, this variable is not statistically significant.

Number of Employees in County

Table 6 presents the results of Model 5, which estimates the number of employees in a county by using the ordinary least squares analysis and combined or pooled analysis with a 4-year data base. Again, the same explanatory variables are used in this model as used in Model 4. About the same results are obtained for the two analyses. Even though the R^2 and F values are not quite as high, the pooled analysis yields more efficient and accurate regression coefficients than the ordinary least squares analysis. The critical before- versus after-construction variable of Model 5 is highly significant and indicates that a highway improvement, such as one of those

TABLE 6 MODEL 5: COEFFICIENTS FOR ESTIMATING NUMBER OF EMPLOYEES IN COUNTY, USING COMBINED CROSS-SECTIONAL AND TIME SERIES ANALYSIS

Explanatory Variable	Ordinary Least Squares Regression Coefficient	T-Ratio[a]	Pooled Regression Coefficient	T-Ratio[a]
Constant term	-13662	-0.88	2249	0.26
Distance to equal or larger city[b]	-302.89	-2.58	-328.11	-4.05
Distance between old and new routes[b]	-5572.10	-1.18	-4090.90	-1.45
Before versus after construction	48812	5.18	11619	4.22
Bypass improvement	18857	1.53	12290	2.02
Radial improvement	-116990	-4.07	-171710	-4.32
Population of city	0.67218	28.46	0.7156	16.12
R^2 statistic	0.88		0.83	
F statistic	326		218	
Durbin-Watson statistic	1.65		1.80	
Standard error of regression	69045		0.61	

[a] T-ratios of 2.00 or greater are statistically significant 95% or more of time.
[b] In miles (00.00).

studied, positively impacts employment in the affected county. The results of Model 5 also show that bypass improvements have a statistically significant and positive effect on county employment, whereas, radial improvements have the opposite effect. Bypass improvements are usually longer and further away from congested downtown areas, thus providing access to new shopping centers and other developments on large and less expensive sites. On the other hand, radial improvements are probably the least desirable of the three types of improvements to attract county employment. However, the authors cannot explain why radial improvements would reduce total county employment.

When the results of Models 4 and 5 are compared, the effects of the two highway improvement variables are shown to be different for city manufacturing employment than for county employment. Also, this difference is supported by a change in the distance between old and new routes variable, which is positively related to manufacturing employment and negatively related to general county employment. Firms other than those of the manufacturing type prefer to locate on highway improvements that are not so far removed from the old centers of business activity in a county. However, both manufacturing and other types of employment are negatively affected by the distance to an equal or larger city.

Again, the Model 5 pooled analysis, using a 4-year data base, presents additional indications of the impact of new highway improvements on county employment not presented by the Model 2 ordinary least squares analysis, using a 1-year data base. Model 5 indicates that radial improvements are significantly and negatively related to county employment, whereas Model 2 indicates insignificant and mixed results for this variable. Also, the Durbin-Watson statistic is higher for Model 5 than for Model 2. Therefore, the Model 5 regression coefficients are more efficient than those of Model 2, being more free of heteroskedasticity and serial correlation.

Total Real Wages in County

Table 7 presents the Model 6 results of estimating total real wages in a county by using the ordinary least squares analysis and pooled analysis, both with a 4-year data base. This final model uses the same explanatory variables as used by Models 4 and 5. The R^2 and F values of this model are somewhat lower than those obtained for the two previous models. The Durbin-Watson statistic for the pooled analysis of this model is the highest of the three models, indicating that its regression coefficients are the most efficient. In other words, all heteroskedasticity and serial correlation are removed. Model 6 also exhibits the same relationships for the variables used to estimate real wages as exhibited by Model 5, which estimates the number of county employees. Because county wages are highly correlated with county employment, the same relationships among the explanatory variables are expected to exist. Model 6 indicates that the distance between the old and new routes variable is statistically significant, but Model 5 indicates it to be insignificant. Also, Model 6 indicates that the bypass improvement variable is not significant, whereas Model 5 indicates this variable to be significant.

About the same results are obtained by the ordinary least squares analysis as obtained by the pooled analysis, with both using the same explanatory variables. The R^2 and F statistics are lower for the pooled analysis, but the Durbin-Watson statistic is larger, even approaching 2.00, which indicates a full correction for serial correlation and heteroskedasticity. Using the 4-year data base is superior to using a 1-year data base, because it allows for a before- versus after-construction analysis and for a pooled cross-sectional and time series analysis, which yields regression coefficients that are nonheteroskedastic and nonautocorrelated. One reason for the difference in results may be caused by the use of total actual wages in the 1-year data base model and total real wages in the 4-year data base model.

SUMMARY AND CONCLUSIONS

In an attempt to estimate the impact of highway expenditures on highway bypass, loop, and radial improvements, two evaluation techniques are applied as follows: (a) regression models using a cross-sectional data base; and (b) regression models

TABLE 7 MODEL 6: COEFFICIENTS FOR ESTIMATING TOTAL OF REAL WAGES IN COUNTY, USING COMBINED CROSS-SECTIONAL AND TIME SERIES ANALYSIS

Explanatory Variable	Ordinary Least Squares Regression Coefficient	T-Ratio[a]	Pooled Regression Coefficient	T-Ratio[a]
Constant term	-37236	-0.39	37100	0.68
Distance to equal or larger city[b]	-1779.30	-2.42	-1818.30	-3.30
Distance between old and new routes[b]	-58966	-2.01	-44576	-2.35
Before versus after construction	262530	4.46	55438	3.64
Bypass improvement construction	107770	1.40	70134	1.82
Radial improvement	-915230	-5.11	-1404600	-5.35
Population of city	3.7186	25.22	4.1724	14.17
R^2 statistic	0.84		0.74	
F statistic	228		126	
Durbin-Watson statistic	1.56		1.90	
Standard error of regression	430960		0.64	

[a] T-ratios of 2.00 or greater are statistically significant 95% or more of time.
[b] In miles (00.00).

using a combination cross-sectional and time series data base. The data base developed to conduct this evaluation contains several economic variables that can be impacted by highway expenditures. It also contains highway system, geographic, and time variables that can independently impact these economic variables. The three economic variables chosen for detailed study are as follows: (a) number of manufacturing employees in a study city, (b) number of employees in a study county, and (c) the total actual or real wages in a study county.

The regression models used in the analysis are of the single linear equation type and are solved by the ordinary least squares method or the pooling method. Models 1, 2, and 3 estimate the preceding three economic variables and use a 1-year cross-sectional data base. Models 4, 5, and 6 also estimate the three economic variables, but they each use a four-year combination cross-sectional and time series data base that is applied on a before- versus after-construction basis.

Briefly, the results of the study indicate: (a) that the preceding three economic impact variables are impacted significantly by expenditures for the highway improvements studied; (b) that the regression models developed from the combination cross-sectional and time series analysis exhibit these effects more clearly and accurately than those developed from the cross-sectional analysis, because a before- versus after-construction approach is used; and (c) that although the before- versus after-construction explanatory variable may capture other effects in addition to those of the highway improvement, it still can be reasonably inferred that a major portion of the effects are caused by the highway improvement.

The following conclusions are derived from the above analysis:

1. Models based on a combined cross-sectional and time series data base produce more efficient and consistent estimates of highway expenditure impacts on employment and wages in a study city or county than models based on a 1-year data base.
2. Highway expenditures for bypass, loop, and radial improvements produce statistically significant impacts on employment and wages in the affected city or county.

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Developing the Finnish Main Road Network: The Planning Process

JUHANI TERVALA

A new round of planning of Finland's main road network began in summer 1989 with the publication of the report *Developing the Main Highway Network in Finland—A Basis for Reassessment.* The aim of the planning work was to redefine the length of the main road network and to provide new quality standards for the main roads. An effort has been made to carry out the planning work for the main highway network in a completely new way. The planning work is based in its entirety on an open, interactive, participative planning process that recognizes local conditions and needs. The work has been carried out open to public inspection. The planning process has aimed to reduce the conflicts between professional planning and its clients. The planning of development actions aims at correct timing of projects, in a wide area over a sufficiently long time span. The plan includes comprehensive investigations of effects. The plan is dynamic. It is easy to revise if the starting assumptions change. Thus a durable basis for decision making has been obtained. The choices can be made on an informed basis. The planning of the main road network was extended in the beginning of 1990 to include all public roads. The planning of ROAD 2010 was begun because of the main road network and because the whole financing of road maintenance and its various priorities are interlinked to a considerable extent. The ROAD 2010 report will be published in summer 1991. The plan includes a new draft proposal for the main highway network. The plan will then be sent to be dealt with by the Ministry of Transport and Communications. The process is a continuous one.

The aim has been to carry out the planning of the development of the main highway network in a completely new way (see Figure 1). The planning work is based in its entirety on an open, interactive, participative planning process recognizing local conditions and needs. In the planning, an attempt has been made to take into consideration the trend towards openness in public administration that is characteristic of the present era. Publicity belongs to the nature of the work.

In addition, it was desired to see the clients' point of view in the planning and give weight to it. The main highway network will serve the whole of Finland and promote its affluence. By means of an open, interactive, and participative planning process, an attempt has been made to reduce the conflicts between professional planning and its clients, i.e., other planners and road users and inhabitants. These conflicts are as follows:

- Difficulty in understanding plans,
- Differences of opinion in the content of the plans, and
- Lack of confidence.

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EXPECTATIONS OF SOCIETY

In general, all planning activities provide the society of the moment with the framework, frontiers, and expectations. As regards the planning of the main highway network in today's society, points of emphasis include the planning of the entire transport system, demands for the balanced development of the country, common visions, green values, and demands for clarity in respect of the plans.

The Transport System

The Finnish National Road Administration has until now, like the other sector administrations, operated within the confines of its own sector. However, today's society is increasingly seeking to find solutions that transcend sector boundaries. There is a need to develop a common basic understanding regarding the country's transport system. The National Road Administration for its part must participate actively in this work both by putting forward its own views and also by assessing the views put forward by others.

In the National Road Administration, an effort has been made to raise the planning of the road transport system from the project-planning level to the level of planning the entire transport system. From consideration of the effects of individual projects, the level of discussion and planning must be raised to consideration of the effects of the entire transport system.

The Balanced Development of the Country

Balanced development of the country requires that the Finland of the future shall be developed increasingly around regional centers. In order to prosper in an expanding Europe, there should be increased interaction between these regional centers, with the metropolitan region, and internationally. This process requires good communications. All Finns must be ready for a united Europe.

A Common Vision

In Finland, road transport is the principal mode of transport. The planning of road traffic is not just a highway engineering design process. Limitations of resources require a common vision of the future in which all forms of transport must be considered at the same time. New forms of finance must be

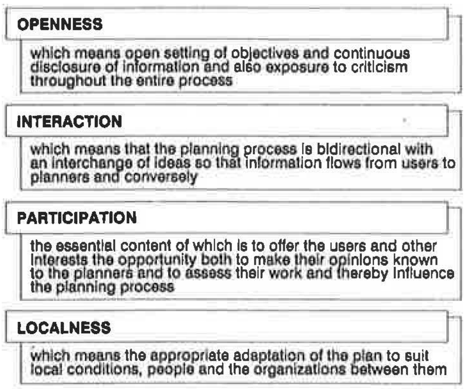

FIGURE 1 The aims of the planning process.

actively sought. Traffic planning is in part also a political process. The task of the National Road Administration is to participate in this ongoing process as an expert authority.

Green Values

Consideration of the environment in all activities is a starting point of planning. A wide view of the consequences of different actions should be taken. Proposed measures should have an overall beneficial effect on the natural environment. The principle of lasting development should be a starting point in our activities.

Clarity in Planning

In all fields, the limitations of resources require the establishment of priorities and setting of limits. By means of planning, it is possible to allocate resources correctly and time them right. The improvements proposed should be realistic. Ideal solutions that are based on traffic considerations do not solve the whole problem.

The appearance of a road must tell the driver how to behave, on the basis of the knowledge of safety risks. This knowledge of human behavior must be a basic starting point of planning. The appearance of a road must take into account the communications function of the road, the surrounding land use, and the classification of the road.

STARTING ASSUMPTIONS FOR PLANNING OF THE MAIN HIGHWAY NETWORK

In Summer 1989, the Finnish National Road Administration initiated a discussion on the development of Finland's highway network. The aim was to redefine both the length and the quality standard of the main road network.

The principal reasons for initiating planning of the main highway network were as follows:

- The rapid increase in the number of sections of main highway subject to congestion and traffic jams and the rapid deterioration in traffic conditions. Additional capacity is required.
- The growth in the number of traffic accidents. By developing the main highway network, it would be possible to improve traffic safety.
- The seriously deteriorating condition of the roads. A period of extensive major repairs to the main roads was becoming inevitable.
- Support for regional structure. Development of the main road network is an effective means of influencing regional land use development.
- Providing for future needs. The planning of motorways should be comprehensive. The provisions for motorways (for the years 2010 to 2030) must be examined very critically.

As a basis of planning, new forecasts of traffic volumes and numbers of vehicles for 1989 to 2010 are used. It is assumed that the proportion of the total traffic carried by the different forms of transport will remain approximately as at present and also that in the near future there will not be major changes in the weights and dimensions of vehicles. It is assumed that measures to limit demand for transport will not be implemented except in city centers. Increased emphasis on the environment is also a starting point.

STAGES OF THE PLANNING PROCESS

The planning of the development of the main highway network is based entirely on an open, interactive, participative planning process recognizing local conditions and needs. The planning process is continuous. The stages of the planning process are shown in Figure 2.

In the report *Developing The Main Highway Network In Finland—A Basis For Reassessment*, June 1989, two development alternatives are put forward for the main highway network: a regionally more extensive Network A, and a Network B designed almost entirely on the basis of traffic considerations. The length of Network A was approximately 4,700 km and that of Network B approximately 2,600 km.

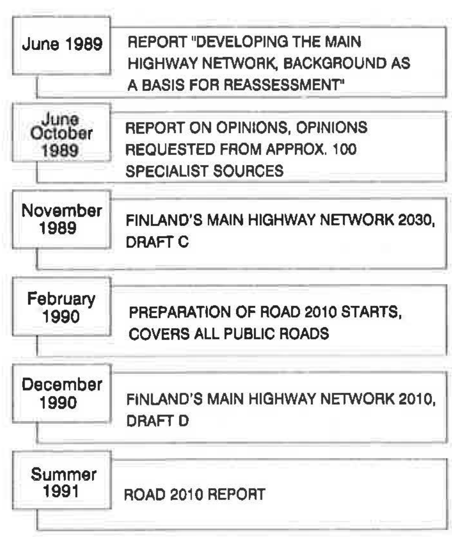

FIGURE 2 Stages of the planning process.

Opinions on the Report

Opinions on the report were requested from road districts, regional planning authorities, provincial federations, county administrative boards, central administrative boards, and certain associations. In total, 85 opinions were received.

The majority of the opinions stated that additions should be made even to the more extensive Network A. The most serious deficiency was considered to be the lack of a main highway running across the country in an east-west direction in central Finland.

It was generally considered to be a good thing that discussion of the development of main roads had begun. The development of the main highways and comprehensive planning were also considered important. The most criticized item was that the development of other forms of transport, above all rail transport, had not been dealt with in the report. The opinions also held that environmental effects should have been examined more closely.

Finland's Main Highway Network for 2030, Draft C

On the basis of the opinions, a new draft proposal for Finland's main highway network was produced in Autumn 1989 (draft 29 November 1989). The draft comprised a total of 7,000 km of main highways, of which 2,800 km were motorways. The main roads now covered all the higher road classes.

On the basis of this draft, full-scale planning work was begun on the effects of the main highway network, on its justification, and also on the procurement projects involved. The draft was subjected to strong criticism by the press.

Preparation of ROAD 2020 Starts, February 1990

The problems that emerged during the planning of the main highway network played a part in accelerating the long-term planning of the entire road network. The planning of the main highway network became an essential part of the planning of highway network maintenance as a whole. ROAD 2010 comprises seven separate subprojects, as shown in Figure 3.

Finland's Main Highway Network for 2010, Draft D, December 1990

On the basis of the investigations of effects, the negotiations, and other assessments, it has been decided to produce a new proposal for the main highway network (Draft *D*, see Figure 4). The main highway network comprises 7,100 km, of which approximately 1,200 km are motorways. The draft together with its justification will be sent out for extensive consideration by public interest groups at the end of 1990.

ROAD 2010 Plan, Summer 1991

The ROAD 2010 report will be published in summer 1991. The report will then be sent to be dealt with by the Ministry of Transport and Communications.

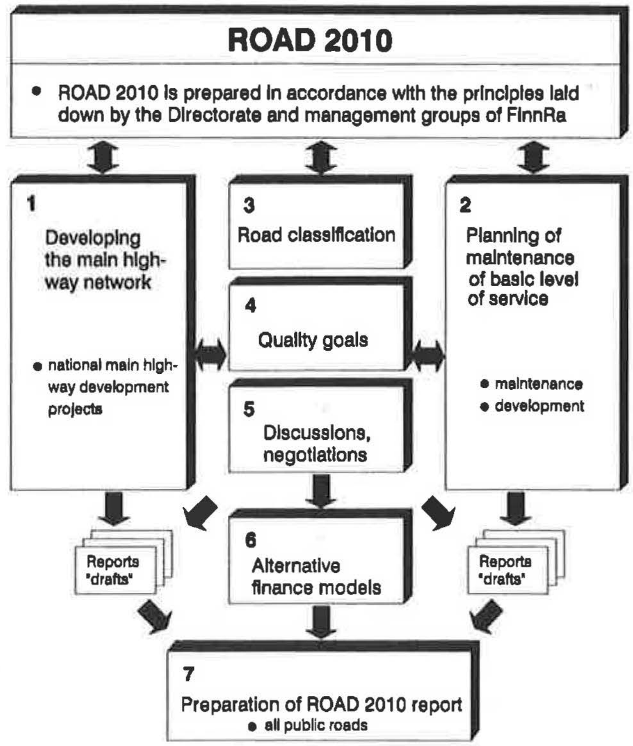

FIGURE 3 ROAD 2010 subprojects.

CONTENT OF THE PLAN FOR THE MAIN HIGHWAY NETWORK

The principal contents of the report on developing the main highway network in Finland are as follows:

- Defining the length and quality standard of the main highway network,
- Formulating projects and allocation of priorities,
- Preparing the development program,
- Investigating effects (other forms of transport, regional and social structure, economic effects, traffic, safety, driving costs, environmental effects).

Length of the Main Highway Network

The main highway network currently denotes the part of the public road network that consists of trunk highways and other main highways comprising altogether over 11 400 km of road. Of this amount, almost 7 500 km are trunk highway.

The development plan for the trunk highway network being prepared is for a highway network of revised length (excluding the Helsinki metropolitan region inside Ring Road III), the length of which in the draft is approximately 7 100 km (Figure 4). The definition of the network is based on the following factors.

Regional and Social Factors

The main highway network

- Covers the entire country,

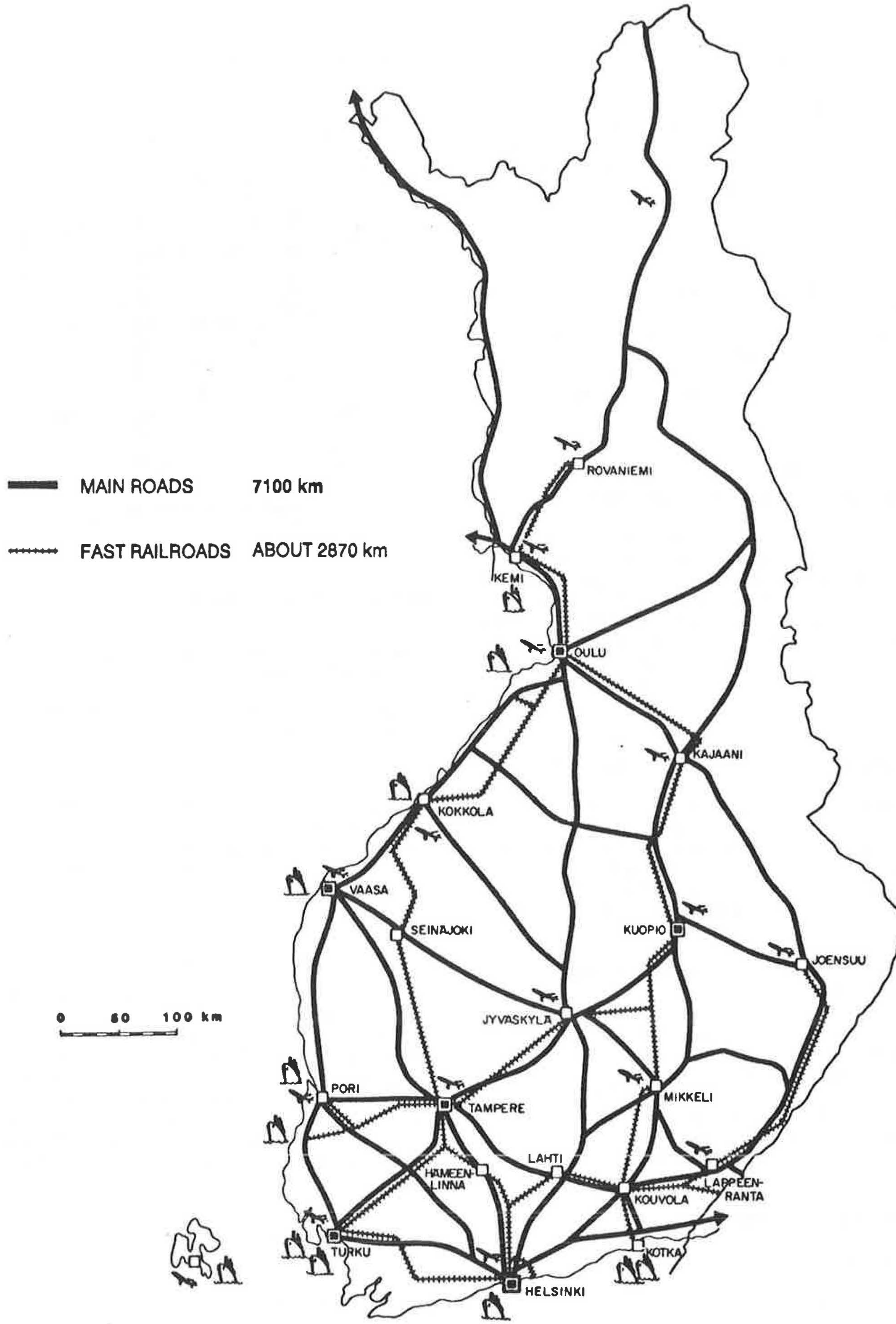

FIGURE 4 Finland's main road network, Draft D.

- Supports regional structure and its development, and
- Bypasses built-up areas (as a general rule).

Road Network Factors

The main highway network

- Is a fully connected network consisting of long, unbroken stretches of road;
- Connects Finland to its neighboring countries and to the rest of Europe;
- Includes the European (E) roads; and
- Provides road connections to the vicinity of passenger and goods terminals for other forms of transport.

Road Quality Factors

The main highway network

- Includes motorways, semimotorways and high-grade trunk highways with two or more lanes, and
- Comprises the highest class in the highway classification system.

Qualitative Targets For Main Highways

Targets have been set for travel speeds and road width.

Speed Level

For the main highway network, the aim is for the highest permissible speeds and a technical quality standard of the road such that it is possible to drive safely at these speeds. The speed limit guidelines used as a starting point in planning are as follows:

Road Class	*Speed Limit (km/hr)*
Motorway	120
Semimotorway	100
Main road in general	100

For safety and environmental reasons, speeds may be 20 km/hr lower in built-up areas and at intersections. In towns, speeds below 80 km/hr and traffic lights are possible, but only where absolutely essential or as a temporary solution. In each case, the speed limit is determined according to conditions either on the basis of safety or to achieve the desired environmental effects. On motorways and semimotorways, the use of variable speed limit signs is a possibility in the future.

Width of Road

The width of the road has a significant effect on driving behavior and thus also on traffic safety. As a starting point, the following cross section values have been used as a guide in combination with the average daily traffic (ADT) volumes given by the traffic prediction for the year 2010.

ADT Volume, 2010	*Cross Section (m)*
< 3,000	9
3,000 to 10,000	10.5
10,000 to 12,000	Considered individually
> 12,000	Motorway, semimotorway, or dual-carriageway trunk road

To a minor extent, roads with width of 12.5 m have been constructed on which traffic of all classes is permitted. This type of cross section is being discontinued. Its use is possible only in special cases as a stage in the ultimate construction of a motorway. It is intended that the use of overtaking lanes shall be increased considerably, with the road having three lanes periodically. Main roads having four or more lanes and dual carriageways come into question in built-up areas.

Other Qualitative Factors

Other qualitative guidelines for main highways are not laid down, but are determined in the detailed design of each individual project, taking into consideration the conditions and what is reasonable.

Classification of Developmental Measures

The measures required for the road network under examination and in different parts of the country vary greatly. The classification of developmental measures that is used is as follows:

1. Addition to network of a new main road connection,
2. Construction of motorway,
3. Construction of semimotorway,
4. Upgrading of semimotorway to motorway,
5. Construction of bypass for built-up area or special arrangements in built-up area,
6. Major improvement of existing road,
7. Minor improvement of existing road,
8. Major bridges and grade-separated intersections,
9. Right-of-way reserve, and
10. No need for developmental measures.

Selection Criteria for the Groups of Measures and the Formulation of Development Projects

The selection of the right measure is based above all on the present standard of the road, on the volume and nature of the traffic, and on their predicted development. The selection of the measure is likewise affected by factors connected with regional and social structures and by environmental factors in the vicinity of the road. The selection criteria for the various groups of measures are explained in the following paragraphs.

1. Addition to Network of New Trunk Road Connection. This group comprises only one project; the development and construction of an east-west link (between Jyväskylä and Vaasa) to the main highway standard. The lack of road links in this group is illustrative of the nature of the development of the trunk road network. The links of the network already exist,

but relative to the standard of the roads already have many shortcomings, and more are anticipated in the future.

2. Construction of Motorway. The need for a motorway is based on high traffic volume. In this work, the guideline threshold value has been increased so that 12,000 veh/day on an existing road requires additional traffic-carrying capacity. Regional and social factors and road network factors together with the volume of traffic to be carried ultimately decide whether a motorway, semimotorway, or four-lane trunk road should be built. The traffic volume for a motorway should be at least 10,000 veh/day for the solution to be justified.

3. Construction of Semimotorway. A semimotorway comes into the question

- As the first stage in the construction of a motorway,
- When the maximum volume of traffic to be carried is forecast to remain below 10,000 veh/day, or
- As a transitional link from a motorway to the ordinary trunk road environment.

Other factors are similar to those relating to motorways.

4. Upgrading of Semimotorway to Motorway. The upgrading of a semimotorway to a motorway, i.e., the construction of a second carriageway, is justified at the stage when the traffic volume on the road exceeds 12,000 veh/day.

5. Construction of Bypasses for Built-up Areas or Special Arrangements in Built-up Areas. In this group of measures, the starting point is naturally that the existing road passes through a built-up area. This condition generally causes numerous problems for traffic (flow and safety) and social structure (continuous effect). The environmental effects are negative (emissions, noise, and urban image). The construction of a bypass around the built-up area is not always justified. Depending on the circumstances, a more efficient solution may be to resolve the conflicts between the road, traffic, and environment while preserving the existing road routing.

6. Major Improvement to an Existing Road. This measure comes into question when the existing road has multiple shortcomings. If a road simultaneously has poor geometry, is narrow with numerous intersections, and additionally has structural weaknesses, then the road must be rebuilt. In this case, the road must be built either entirely or partly to a new site. The upgrading of a road to four lanes is also classified as belonging in this group.

7. Minor Improvement to an Existing Road. This group of measures covers the largest number of road-kilometers in the planned network. The main shortcoming is narrowness, i.e., the road lacks hard shoulders. This condition affects the structural durability of the road, safety (and particularly conditions for pedestrians and cyclists), and also driving comfort. The development measures can be carried out for the most part while retaining the existing road siting. In connection with widening of the road, it is appropriate at the same time to carry out the measures required to protect the ground water (as is also done in connection with major road improvements).

8. Major Bridges and Grade-Separated Intersections. The projects in this group of measures, which apply to points on the network, serve to improve traffic safety and traffic flow.

9. Advance Right-of-Way Reservation. The time span of the program for the implementation of the development plan for the trunk road network extends to the year 2010. By that time the basic growth of traffic will be substantially complete (the number of vehicles will not grow significantly and there will be no further increase in the number of people holding a driving license). On the other hand, regional or social factors may still give rise to even considerable growth of traffic locally or on particular sections of road. Projects that may become topical after the year 2010, and for which it is desirable to make site reservations at the various stages of land-use planning, have been classified as reservations. Advance right-of-way reservations are generally associated with stretches of semimotorway for their future upgrade, and also with built-up environments in which socioeconomic development is to be expected. Projects, the approval of which is subject to dispute and unsettled, have also been classified as reservations.

10. No Need for Developmental Measures. Part of the trunk road network has already been constructed or improved to a standard corresponding to the targets. Minor measures are not considered as development, but are instead carried out as part of basic road maintenance.

Quantitative Data by Developmental Measure Group

On the basis of the survey of needs, the approximate quantities in the different groups of developmental measures are as follows:

Category	*Quantity*	*Cost (FIM)*
1	62 km	0.3
2	480 km	10.8
3	330 km	5.1
4	220 km	2.4
5	400 km	3.8
6	1 050 km	4.0
7	3 080 km	5.0
8	6 + 33	1.1
9	625 km	–
10	1 200 km	–

The same stretch of road or connecting link may be the subject of action in more than one group of measures during the time span under consideration, so that the above lengths cannot be added together directly.

Order of Implementation of Projects Within Each Group of Measures

For purposes of scheduling, the projects within each group of measures are arranged in order of relative importance. In the following, the criteria used are explained for each group of measures.

1. Addition to Network of New Main Road Connection. There is only one project in this group (link between Jyväskylä and Vaasa). It has been decided that the project will be implemented on the basis of the decision made in 1984 by the Ministry of Transport and Communications.

2 and 3. Construction of Motorway and Construction of Semimotorway. Motorways and semimotorways have been placed in a special position in road and traffic legislation. As part of the trunk road network, they provide carrying capacity for high traffic volumes economically and safely. In the long term, they have a significant effect on regional structure and the local social structure.

The order of implementation of motorways is affected by the following:

- Volume of Traffic in Built-Up Environments. From the point of view of the functioning of the entire trunk road network, it is important to avoid congestion of the major concentrations of traffic in urban areas. The environmental effects are generally favorable.
- Volume and Nature of Traffic in Rural Areas. The traffic volumes vary on the network links for which a motorway is a justifiable solution.
- Factors Related to Service Level of the Existing Road. These also affect the choice of development path for the stretch of road in question, should improvements be made first to the existing road before construction of a motorway.
- Formation of Continuous Motorway Links. This factor comes into the question mainly when considering the need for motorway reservations on the basis of road network and regional structure factors.

4. Upgrading of Semimotorway to Motorway. The existing semimotorways have been designed and constructed so that they can be upgraded to full motorways in the second phase of the implementation. The need to do this will arise in the near future. The criteria are in principle the same as those given in connection with motorways. The service life of an existing semi-motorway, however, can be prolonged to a limited extent in rural conditions by making more effective use both of the parallel road and of the semimotorway, and also by providing the semimotorway with a clearly marked system of overtaking lanes.

5. Construction of Bypass for a Built-Up Area or Special Arrangements in Built-up Areas. The order of implementation in this group of actions is affected above all by the seriousness of the conflicts between the road traffic and the environment. Top priority should be given to solving the problems that arise when the trunk road traffic is carried by the street network or passes through the urban area. Generally, the location of the road in the community is decisive. Other factors taken into account are traffic safety, the volume and nature of the traffic, and the seriousness of the nuisance caused by the traffic.

6. Major Improvement of an Existing Road. The order of implementation of the projects in this group of actions is affected by the level of service that the road offers to traffic. The international classification of the level of service *A* to *F* (*F* represents a completely congested state during peak traffic hours) simultaneously takes into account both quantitative and qualitative highway engineering and traffic factors. Poor traffic safety or poor structural condition of the road may increase the priority for implementation of the project.

7. Minor Improvement of an Existing Road. Inadequate width of the road in relation to the composition and volume of traffic establishes the order of priority for projects in this group. Stretches of roads running near houses and with a more than average number of accidents should be improved before more remote sections.

8. Major Bridges and Grade-Separated Intersections. Weight and headroom restrictions cannot be tolerated on bridges on the trunk road network. These points should be dealt with at the earliest opportunity. The order of priority for grade-separated intersections is based on traffic safety and traffic flow considerations and on the location of the point in the road network and in the community structure.

9. Advance Right-of-way Reservations. Reservations are not arranged in any order of priority in this connection. By following the development of society and traffic growth, establish the importance of the land and the rate at which the existing reservations being abandoned and new ones planned to the extent required.

Program of Measures, 1991 to 2010

The development plan for the main highway network is being formed into a program of measures for four 5-year periods covering the time interval 1991 to 2010. The content of the program is affected by the weightings of transport policy, highway policy, economic policy, and environmental policy and by the corresponding opportunities to obtain funding. In turn, the program can affect the development of the regional and social structure of Finland.

The program of measures has been drawn up in connection with this work on the basis of need and keeping the goals in view.

Projects from the different group of measures have been included in the program in order of effectiveness. In the whole program, emphasis has been given to conditions in urban areas, traffic safety, and traffic economy. If funding does not correspond to the need, then it will be necessary to decide what shall be left undone, or what shall be postponed until a later date.

The length of the main road network in the draft is approximately 7 100 km. For reasons of regional structure, it includes road sections that differ widely in their importance to traffic. Largely as a factor in structuring the program of measures, the especially important roads in the main highway network have been defined. These highways connect the major regional centers to the metropolitan region and provide road links to Sweden and the Soviet Union (see Figure 5). The projects for the construction and improvement of these

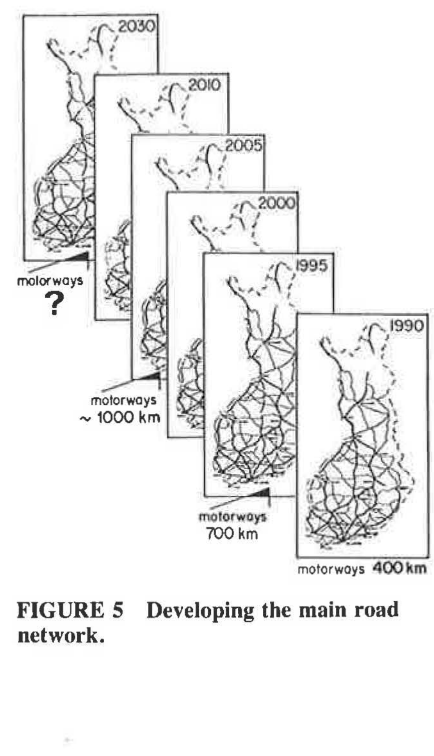

FIGURE 5 Developing the main road network.

roads are scheduled so that they will be completed by the year 2005, i.e., over the next 15 years.

Around 2010, Finland's network of main highways should appear near the state shown in Figure 6.

Investigations of Effects

The development of the main highway network to a state that corresponds to the targets and needs will cost approximately FIM 33 billion. In order to ensure an adequate return on the investment and the achievement of the targets set, the plan includes comprehensive investigations of the effects. These investigations concern the effects of development on

- Traffic safety,
- Noise emissions and exhaust emissions from traffic,
- Fuel consumption by traffic,
- National economy and transport economy in particular,
- Regional and social structure, and
- The division of labor between different forms of transport.

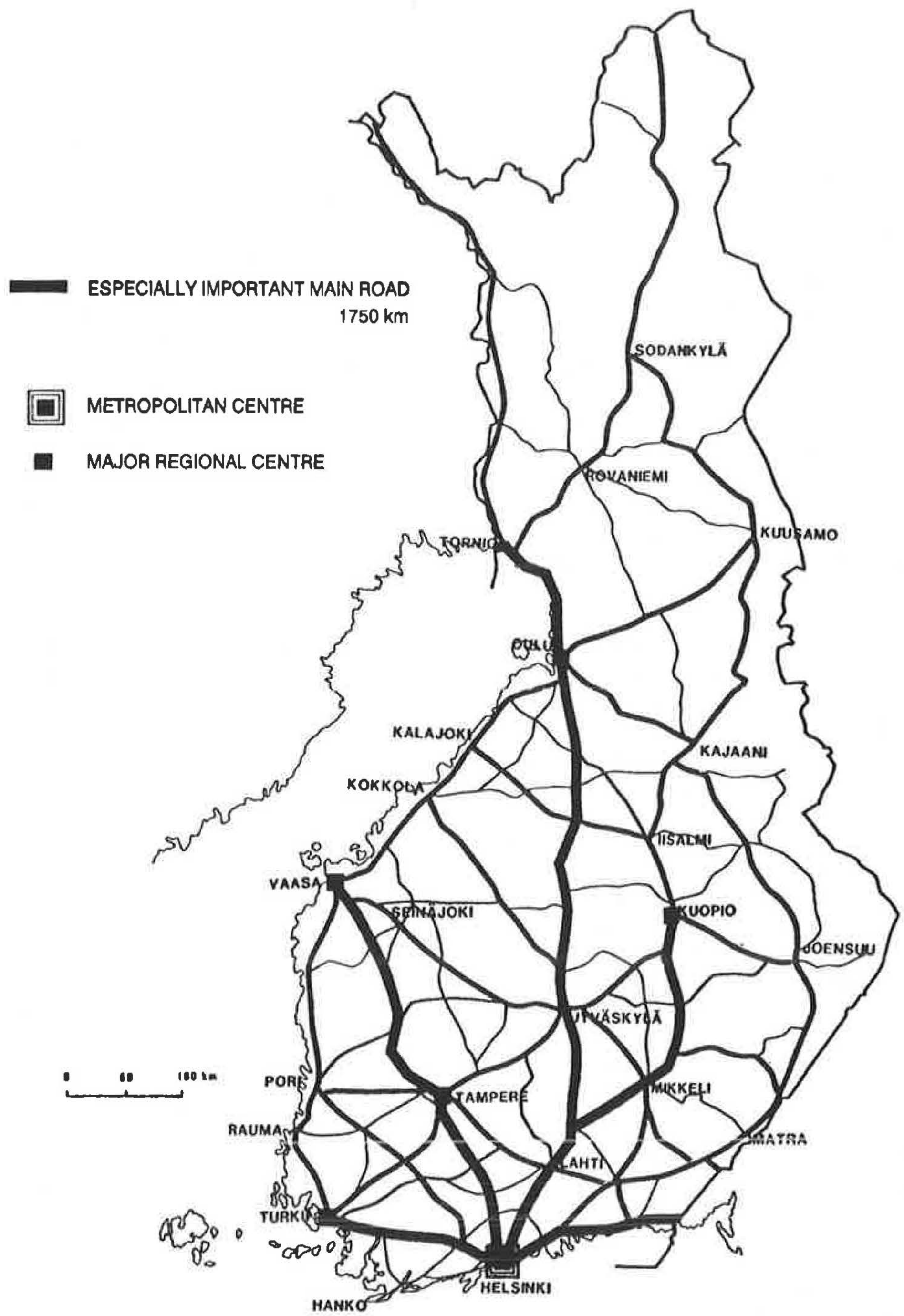

FIGURE 6 Finland's main road network around year 2010.

EFFECTS OF DEVELOPMENT ACCOUNT

The development of the main highway network should result in favorable development and prevent or reduce negative effects. In this connection the following targets have been set. The development of the trunk road network should

- Make a positive contribution to development of the national economy,
- Safeguard the reliability of transport and the operating conditions for commerce and industry in the different regions of the country,
- Maintain and improve the service level offered to road users,
- Promote traffic economy,
- Improve traffic safety,
- Reduce the growth of fuel consumption and emissions by road traffic, and
- Localize problems so as to cause less nuisance.

The targets set in planning the development measures mean that the requirements set for both the natural and man-made environments and also for the economic effects will be taken into account as a whole.

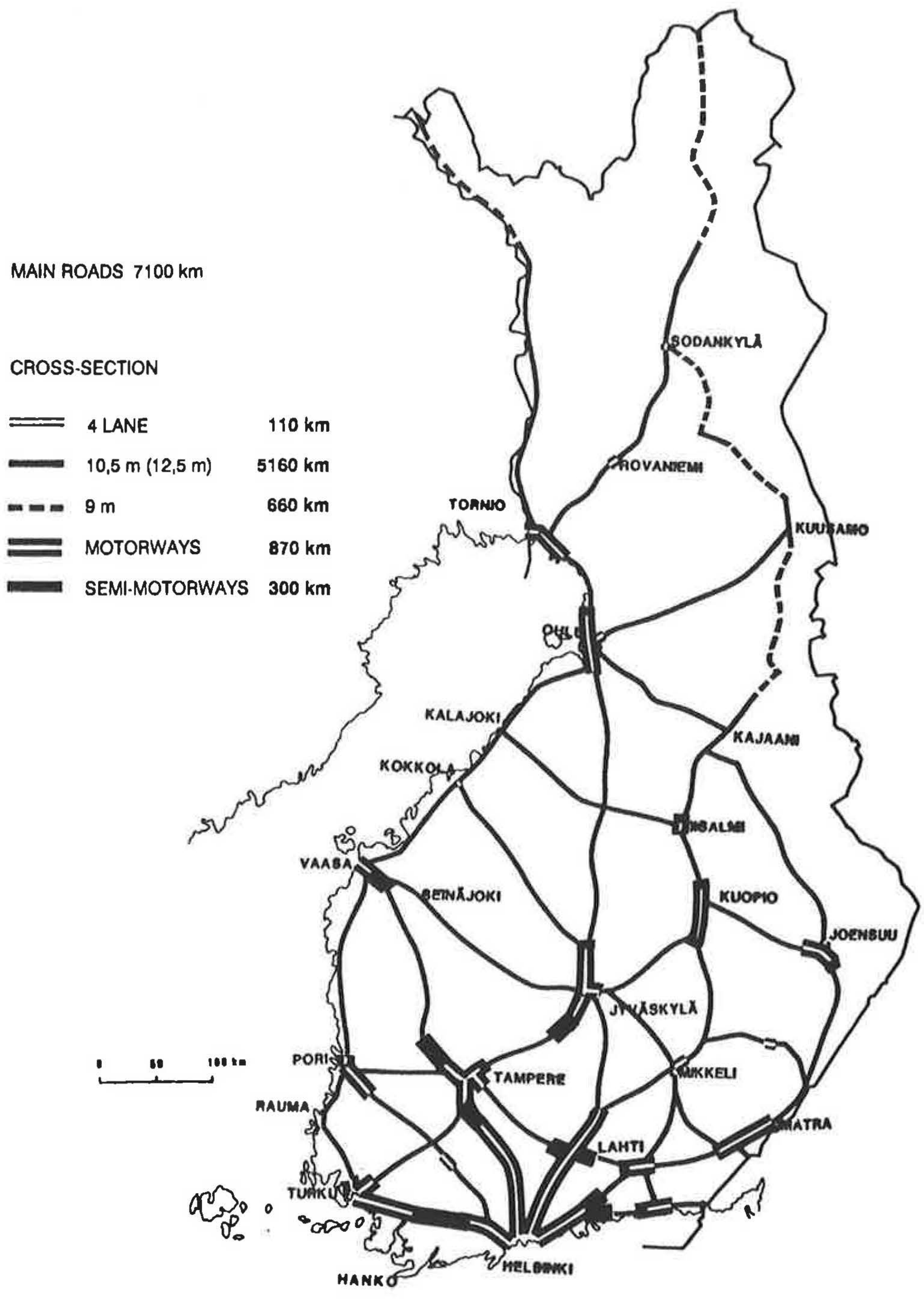

FIGURE 7 Finland's main road network—cross sections after year 2010.

ASSESSMENT OF THE PLANNING PROCESS

The development plan for the main highway network is a network level plan that creates a basis for more detailed project planning. Only by the investigation of the project need and the various stages of physical planning can a project proceed to implementation.

The development plan for the main highway network is being prepared by an open and interactive planning process. At the end of 1990, the draft plan will be presented for consideration by public interest groups. The reactions and opinions received will, as far as possible, be taken into account together with the results of the import assessment in drawing up the proposal of the Finnish National Road Administration, which is to be submitted to the Ministry of Transport and Communications in May 1991.

In the planning work, an effort has been made to take into account publicity, the points of view of the different parties, discussions, opinions, etc. The plan has changed during the work. It has proved possible to partly reduce conflicts between professional planning and its clients.

Some of the principal observations of the planning process include the following:

- The draft proposals presented were misunderstood. They were seen as final proposals. There have been problems in providing information about the process.
- The proposed changes to the present situation have been feared "hysterically." It appears difficult to perceive the system as a whole; there was a tendency to see isolated details as being problematic.
- The planning of the entire road maintenance function (ROAD 2010) was begun more forcibly during the planning process.
- Far fewer motorways should be proposed than originally assumed.
- The weighting of traffic considerations should be more flexible than before (more technical alternatives, and local problems must be taken into account).
- It has been possible to develop the planning process during the course of the work. The views of different interests have been put forward at an opportune time.

Figure 7 shows a map of the main Finnish road network as it should appear after the year 2010.

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Programming Route Improvements to the National Highway Network

BRUCE N. JANSON, L. SCOTT BUCKELS, AND BRUCE E. PETERSON

A network design approach to the selection and programming of strategic route improvements to the U.S. national highway network of Interstates, four-lane urban highways, and rural principal arterials is described. Alternative route improvement strategies are defined as mutually exclusive sets of link improvements that can be programmed for construction within any decade of a multidecade planning horizon. Two improvement strategies considered for each route are (a) to make every link median divided with controlled access and at least four lanes, or (b) to make every link at least four lanes, but without any changes to median division or access control. Route improvement strategies programmed for each decade are constrained by 10-year funding allocations. A trip distribution model is used to distribute commodity shipments forecasted for each decade among regions. The example evaluates 536 potential improvements to 289 major highway routes between adjacent Bureau of Economic Analysis regions, or nearly two improvement strategies per route. Route improvement benefits are computed as changes in the value of the objective function, which is the total discounted interregional shipment cost for all years of the planning horizon. Because different routes and interregional shipments can share common links, a rank-add-and-swap heuristic solution procedure was developed and applied that accounts for the interdependent costs and benefits of route improvements. Implications of this network design approach for strategic planning of the national highway network are discussed.

A variety of network design models have been developed and applied to discrete decision problems concerning adjustments to facilities or services in network-based systems. Combined models of network design and travel demand forecasting have been described for the planning and evaluation of multimodal regional transportation systems for both person and freight travel. Heuristic solution approaches have been found to obtain good solutions for many applications to the degree of optimality required. Additionally, applications of network design models to transportation have been facilitated in recent years by their integration with geographic information systems and microcomputer data bases.

The problem of planning long-range strategic improvements to competing routes or corridors of an interregional highway network is addressed. A network improvement programming formulation and heuristic solution approach are described in which route improvement strategies are candidates for inclusion in 10-year periods of a 30- to 50-year planning horizon. Alternative investment strategies for each route are specified as mutually exclusive sets of link improvements in successive decades, where each set is treated as a separate project candidate in a project programming framework. The two improvement strategies considered for each route are to make all necessary upgrades so that (a) every link is median divided with controlled access and at least four lanes, or that (b) every link is at least four lanes, but without any changes to median division or access control.

In an example application, alternative improvements to 289 major highway routes between adjacent Bureau of Economic Analysis (BEA) regions in the 48 contiguous states of the United States are considered. These routes connect the geographic population centroids (as of 1985) of 181 BEA regions (as defined in 1989), and are composed of Interstates, four-lane urban highways, and rural principal arterials, some of which have only two lanes. Routes without any two-lane links have only one improvement strategy option. One improvement strategy is considered for 42 routes with no two-lane links, and two improvement strategies are considered for the other 247 routes. Each strategy for each route can be programmed in any of three decades (1991 to 2000, 2001 to 2010, and 2010 to 2020), resulting in a total of 1,608 possible route, strategy, and decade combinations. The full network to which these routes belong contains 7,775 bidirectional links and 5,620 nodes.

The benefit of a route improvement at any point in the solution process is its reduction to the total interregional commodity shipment cost for the entire planning horizon, which is the objective function of these problems. The strategy programming criterion is the ratio of objective function reduction per unit of construction cost for a given route improvement, which is an effective gradient measure used in solving zero-one integer programming problems. The total construction cost of route improvements must be feasible within the funds allocated for each decade. All costs and benefits are discounted to present values according to an assumed discount rate to calculate the benefit-cost ratio and budget feasibility of each route improvement strategy.

Two problem formulations are presented for fixed versus variable interregional shipment distributions. The first problem assumes fixed interregional shipment matrices that vary by decade, but not because of network changes. The second problem incorporates a typical trip distribution model to redistribute interregional shipments in each decade on the basis of path cost changes caused by network improvements. Because different routes and interregional shipments can share common links, a rank-add-and-swap heuristic solution procedure was designed to account for the interdependent costs and benefits of alternative route improvements. Optimal and near-optimal solutions to other network design and project

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programming problems have been obtained by using this same basic heuristic solution approach, even when the number of network improvements made per iteration of the algorithm is increased from one to many. Ways of using this modeling approach for planning future expansions and improvements to the Interstate highway system are discussed.

BACKGROUND

The basic network design problem is to determine a set of link additions or improvements that are feasible within the resource constraints specified so that the performance of the network is improved by the maximum amount. Performance of the network is usually approximated by some system-wide objective function, such as the total travel cost of all person trips or commodity shipments. Link additions usually represent new roads or transit routes, whereas link improvements represent upgrades to existing facilities or services. Service level reductions for some routes can also be evaluated by adding traffic restrictions or reducing transit services. For directed networks in which bidirectional links are coded as directed arc pairs, network changes that only affect one direction of flow can also be evaluated. The example in this paper only considers symmetrical link improvements for both directions of flow.

The unit shipment cost of each link will be assumed to be fixed regardless of flow volume. For networks with fixed-link travel costs, the optimal routing of shipments is by shortest paths. Link flows are determined in the first problem (NIP1) by assigning a fixed region-to-region shipment matrix for each decade to shortest paths of the network with improvements made in the current and previous decades. In the second problem (NIP2), a gravity-type distribution model is used to recalculate an interregional shipment matrix for each decade according to shortest-path costs. Link flows are determined in NIP2 by assigning the variable shipment matrices to the minimum cost routes of each 10-year network plan. The forecasted origin and destination shipment totals for each region in each decade are held fixed in all cases.

Other researchers, such as LeBlanc (*1*), Boyce and Janson (*2*), Poorzahedy and Turnquist (*3*), and LeBlanc and Boyce (*4*), have developed formulations and solution algorithms to network design problems in which travel costs are dependent on link flows. While these formulations are more representative of the supply constraints that affect travel costs on congested networks, they are not generally applicable to interregional network improvement analyses in which congestion is not a major factor. Furthermore, a network design problem in which the objective is to minimize total user cost, but which also assigns traffic to routes on the basis of user equilibrium criteria, may contain several local optima that are inferior to the global optimum. Network design problems with variable costs in which traffic is assigned in a system-optimal manner do not have the same difficulty, but formulations and test problems of that type are not examined in this paper.

Magnanti and Wong (*5*) review several types of network design problems for transportation planning, and they summarize reported experiences with various optimization and heuristic solution techniques. A primary consideration in the development and use of these or any models is the level of effort required for the degree of useful results obtained. Because model results serve as only one factor in the overall decision-making process, a model's development cost and computational burden is often a deterrent to its implementation. Furthermore, many forms of deterministic optimization models are not well suited to the qualitative considerations and quantitative uncertainties inherent in many actual design settings. In situations where knowledge of actual costs and benefits is rather approximate and a clearly dominant design choice is not apparent, a cost-effective procedure must be used to identify good and perhaps near-optimal designs.

Complete enumeration of all feasible and infeasible solutions to a combinatorial problem with N candidate projects would require the evaluation of 2^N solutions. However, the imposition of a single budget constraint greatly reduces the number of feasible solutions that need to be examined. For example, given a funding constraint of F and an average cost $\bar{c}$ for N candidate projects, then a random subset of R projects would have a total cost of about F, where $R = F/\bar{c}$. Because there are $N!/R!(N - R)!$ subsets of N projects containing exactly R projects, this number serves as an approximate upper bound to the number of solutions that any reasonably efficient search process would need to examine in order to obtain optimality. Bounding rules can be incorporated into branch-and-bound procedures, such as those described by Balas (*6*) and Geoffrion (*7,8*) to reduce the number of subsets requiring examination even further without violating optimality. On the other hand, the heuristic solution procedure requires that just kN networks be examined, where k is a constant that can be specified or at least estimated before executing the heuristic, and k never needs to exceed R.

A NETWORK IMPROVEMENT PROBLEM INVOLVING FIXED SHIPMENTS (NIP1)

All commodity shipments will be assumed to originate and terminate at nodal centroids of the 181 BEA regions covering the 48 contiguous states. The first network design problem examined here is one in which shipments between each pair of regions are known and fixed. These shipments are denoted by the matrix S, where each S_{ij}^d element equals the average annual commodity units shipped from Region i to Region j in Decade d. An optimal network design problem with fixed shipments, fixed link shipment costs, and a single period funding constraint on construction costs is referred by Magnanti and Wong (*5*) as a budget design problem with fixed costs and travel demands. The problem defined by Equations 1–5 extends this single-period problem to a multiperiod planning horizon.

$$\text{NIP1:} \qquad \min Z(G) = \sum_{d \in D} \sum_{i \in E} \sum_{j \in E} S_{ij}^d \, u_{ij}^d \, v^d \tag{1}$$

subject to:

$$\sum_{r \in R} \sum_{p \in P} c_{rp}^d \, x_{rp}^d \leq F^d \qquad \text{for all } d \in D \tag{2}$$

$$\sum_{d \in D} \sum_{p \in P} x_{rp}^d \leq 1 \qquad \text{for all } r \in R \tag{3}$$

$$x_{rp}^d = (0,1) \qquad \text{for all } r \in R,\ p \in P,\ d \in D \tag{4}$$

$$G = \{x_{rp}^d = 1 \qquad \text{for all } r \in R,\ p \in P,\ d \in D\} \tag{5}$$

where

- R = set of candidate improvement routes;
- P = set of candidate route improvement strategies, indexed from 1 to the maximum number of strategies defined for any given route;
- D = set of decades (10-year periods) in the planning horizon;
- E = set of 181 BEA regions as of 1989;
- G = set of route improvements programmed for each decade of the planning horizon;
- $Z(G)$ = total present value shipment cost of all interregional commodity shipments over minimum paths in G, which NIP1 seeks to minimize;
- S_{ij}^d = average annual commodity units shipped from Region i to Region j in Decade d (fixed in NIP1);
- u_{ij}^d = minimum path unit shipment cost from Region i to Region j over the improved Network G in Decade d (variable);
- v^d = present value discount factor that converts and sums annual shipment costs for Decade d into a single present value at Time 0 (fixed);
- x_{rp}^d = 1 if Strategy p is programmed for Route r in Decade d; 0 otherwise (variable);
- c_{rp}^d = construction cost of Strategy p for Route r in Decade d, expressed in present value dollars at Time 0 (fixed); and
- F^d = total funding available for route improvements in Decade d, expressed in present value dollars at Time 0 (fixed).

In this notation, each subscript pair rp denotes a set of link improvements for a given Route r and Strategy p, where Strategy 1 for Route 1 can be different from Strategy 1 for Route 2. Constraint Equation 2 ensures that construction costs for all programmed improvements are feasible within the funding constraints of all decades, and Equation 3 ensures that no more than one mutually exclusive route improvement strategy is included in the solution for each route. Alternative route improvement strategies for the same route are also mutually excluded from being programmed for more than one decade. Equation 5 defines a network improvement program G as a particular set of route improvements in each decade, and the expression for u_{ij}^d defines the minimum interregional shipment costs for a given network improvement program G.

A NETWORK IMPROVEMENT PROBLEM INVOLVING VARIABLE SHIPMENTS (NIP2)

The program given by NIP1 is to find the network improvement program G^* that is feasible within funding constraints and that minimizes the total present value cost of interregional commodity shipments carried over minimum cost paths. NIP2 is formulated in the same manner as NIP1 except that S_{ij}^d is variable instead of fixed. Cost-dependent shipments can be modeled within NIP2 by one of several alternative trip distribution forms, each being the solution to a nonlinear programming problem in which the objective is to maximize the statistical likelihood of the distribution matrix (given by the entropy function) subject to shipment production and attraction constraints at regions, and an average shipment cost constraint between regions (*9,10*). Equation 6 indicates the form of the origin-constrained shipment distribution used in the example presented later.

$$S_{ij}^d = A_i^d\, O_i^d\, D_j^d\, (u_{ij}^d)^{-\beta} \qquad \text{for all } i \in E,\ j \in E \tag{6}$$

where

- $A_i^d = \left[\sum_{j \in E} D_j^d\, (u_{ij}^d)^{-\beta}\right]^{-1}$ for all $i \in E$, $d \in D$;
- S_{ij}^d = average annual commodity units shipped from Region i to Region j in Decade d (variable in NIP2);
- O_i^d = average annual units shipped from Region i in Decade d (fixed); and
- D_j^d = total population of BEA Region j in 1985 (fixed).

Each balancing factor A_i^d causes Row i of S^d to sum properly, and results from the Lagrange multiplier on shipment productions from Region i in the maximum entropy trip distribution problem. The deterrence parameter β relates interregional shipment costs to shipment frequencies, and equals the Lagrange multiplier on average shipment cost in this problem. Shipments are assigned to minimum cost paths, but not all shipments from any origin are routed to their least cost destination. The power function form of the cost deterrence function is used here, rather than a negative exponential function. The power function results from replacing u_{ij}^d by $\ln u_{ij}^d$ in Wilson's maximum entropy formulation of this problem. In Equation 6, u_{ij}^d is raised to a negative power instead of being in the negative exponent itself. Interregional commodity shipment distributions using this power function form of the deterrence function have been shown to adequately fit survey data (*11*).

In the later example, each row total of S^d (denoted as O_i^d) equals total dollars of manufactured shipments and agricultural production from each BEA region as reported by the 1988 County and City Data Book (*12*). Because estimates of total shipments to each BEA region were not available from any known data source, the distribution of shipments to each BEA region was weighted on the basis of 1985 populations. The U.S. Bureau of Census is administering a 1989 survey of national commodity movements called the National Transportation Activity and Commodity Survey (NTACS) that will provide improved estimates both of origin and of destination shipment totals by county for 15 major industrial classes with which alternative forms of the shipment distribution model can be calibrated that are industry-specific. Although a commodity flow model for national network design should account for more industry specific factors affecting shipments between regions, the use of Equation 6 is sufficient to approximate changes in commodity shipments with network design.

For a given value of β in Equation 6, the total shipment cost will vary between alternative networks, which is the objective of network design problems NIP1 and NIP2 to minimize. The solution to NIP2 is a network that is optimal in the following sense: given that shipments S are calculated on the basis of Equation 6 for each network improvement program G, where each u_{ij}^d is the minimum path cost for each (i,j) pair and β is fixed, no other network improvement program results in a distribution with a lower transportation cost than the optimal network G^*. Boyce and Soberanes (*13*) formulate a problem similar to NIP2 in which the objective is to find the network with maximum distribution entropy subject to a mean shipment cost. Although this formulation has an appealing interpretation, it requires the calibration of β for each alternative network. Moreover, requiring average shipment cost to be constant in a network design problem for which the objective is to minimize this value presents a conflict. Hence, β was held constant in the example. If origin-destination data are available for multiple commodity types, then the distribution model can be generalized by commodity type with values of β specific to the cost-deterrence relationships of different commodity shipment patterns.

RANK-ADD-AND-SWAP HEURISTIC SOLUTION PROCEDURE (RASH)

Ranking and selection procedures are often used to determine project priorities on the basis of many considerations including project severities, geographical funding distributions, and benefit-cost analyses. For network design problems in which candidate improvements to a network have independent benefits, a once-through ranking and selection process might perform well as a heuristic solution technique. In network design problems of the type formulated earlier, an improvement to one route may affect the benefits of improving other routes, and some routes may overlap. Hence, this ranking and selection process must be performed sequentially and iteratively, recalculating the rankings of all remaining candidate route improvements after one or more changes to the network have been made in each iteration.

Several researchers (*14–17*) have described and tested branch-and-bound algorithms for solving discrete network design problems. Many of these algorithms are reviewed in the survey article by Magnanti and Wong (*5*). The number of networks to be examined by these branch-and-bound algorithms is quite large, because the bounding rules are generally weak and do not greatly reduce the computational burden of the search in problems that do not have clearly dominant choices. Only in cases where certain link additions are essential to creating shorter minimum paths is it found that the bounding rules achieve a significant reduction in search effort. On the other hand, heuristic solution approaches can considerably reduce the number of network evaluations required to obtain a good or near-optimal solution, particularly in problems with many closely competitive and near-optimal solutions.

Problems such as NIP1 and NIP2 are classic knapsack problems for cases in which the objective function and cost constraints are strictly linear, such that the impacts of all route improvements are independent of each other. A heuristic method of solving a knapsack problem with one cost constraint is to first rank the candidate items according to their benefit-cost ratios, and then to accept items into the solution from the best on down until no more items can fit within the single cost constraint. Integer programming algorithms designed to solve knapsack problems often use this approach to generate a good initial feasible solution from which to search for further improvements. Quite often, this initial solution is either an optimal solution or a close competitor. Moreover, any improvements to this initial solution often achieve only a small percentage improvement in the value of the objective function.

A benefit-cost or return-expense ratio is often used as an effective gradient measure in algorithms for solving zero-one programming problems (*18*). This ratio is simply a means of ranking alternative project candidates in each iteration after adjusting their costs and benefits to present values. Janson and Husaini (*19*) and Janson (*20*) successfully demonstrate the use of this ranking criterion in several heuristic algorithms for network design, and for regional highway programming problems in which projects have alternative start times subject to yearly budget and regional funding constraints.

In the rank-add-and-swap heuristic (RASH) solution procedure described next, route improvement strategies are ranked and added to the solution according to their ratios of benefit present value (BPV) to cost present value (CPV). BPV is the discounted reduction in the total shipment cost caused by a route improvement, and CPV is the discounted construction cost of a route improvement. Thus, any decrease in the value of the objective function corresponds to positive benefits, and any increase in the value of the objective function corresponds to negative benefits. An equivalent ranking criterion is NPV/CPV, where NPV is the net present value equal to BPV − CPV. Because NPV/CPV = (BPV/CPV) − 1, both ratios always yield identical rankings.

For adding a given improvement with indices (r,p,d) to the current solution G^n at Iteration n of the solution procedure, this benefit-cost ranking ratio is defined by

$$\mathrm{BCR}_{rp}^{dn} = [Z(G^n) - Z(G^{n+})]/c_{rp}^{d} \tag{7}$$

where

$Z(G^n)$ = objective function value of current solution G, expressed in present value dollars at Time 0.
$Z(G^{n+})$ = objective function value of current solution G plus route improvement (r,p,d), expressed in present value dollars at Time 0.
c_{rp}^{d} = construction cost of Strategy p for Route r in Decade d, expressed in present value dollars at Time 0.

In each iteration of RASH, recalculating the benefit-cost ratio for each route improvement candidate requires updating all interregional minimum path shipment costs for each improvement considered in NIP1, and redistributing the commodity shipments among regions because of shipment cost changes in NIP2, in each decade. Then, changes to the objective function in each decade are discounted to Time 0.

If RASH were to add only one new route improvement to the current solution in each iteration, it would be excessively tedious for large problems or problems in which the evaluation of each route improvement requires a significant amount of computational effort, such as for shortest path and shipment distribution routines. Hence, RASH is designed to take a larger step towards the final solution in each iteration by adding several new route improvements to the current solution in each execution of Step 5. However, the larger step size may allow route improvements with interdependent costs and benefits to be added in the same iteration. Because interdependent candidates may not be as important to the solution in combination with others, a method is needed to delete some route improvement strategies from the current solution so that others can be added.

RASH allows the current solution to expand by several route improvements in each iteration, and also allows previously included improvements with inferior benefit-cost ratios to be deleted or switched with new improvements with superior ratios at that point in the solution process. Alternative improvements for routes that already have improvements in the current solution can also be substituted or switched for each other. Each iteration results in a new solution comprised of top-ranked budget-feasible improvements with respect to the previous solution subject to both "net" and "gross" step size limitations on the increment of total funding allowed to be programmed in each iteration.

In order to determine the composition of the new solution in each iteration, the RASH procedure computes changes in the objective function for each possible improvement addition or deletion as follows:

1. If an improvement strategy for Route r is not in the current solution G^n, then compute the decrease in the value of $Z(G^n)$ for each alternative improvement to Route r when added to G^n.
2. If an improvement strategy for Route r is in the current solution G^n, then compute the decrease in the value of $Z(G^{n-})$ for each alternative improvement to Route r when added to G^{n-}, where G^{n-} is equal to G^n without the current improvement to Route r.

Note that G^{n-} is defined as the current solution minus a particular route improvement strategy, whereas G^{n+} is defined for Equation 7 as the current solution plus a particular route improvement strategy. The difference is made solely to describe the conditions correctly. The second condition is worded to cover the evaluation of each already included route improvement strategy when removed from the current solution, because RASH allows deletions of improvements from the current solution so that other improvements can be added.

As stated earlier, increases and decreases in the value of the objective function correspond to negative and positive benefits, respectively. Because improvement deletions (or disimprovements) have negative construction costs, the benefit-cost ratio given by Equation 7 will always be positive for both improvements and disimprovements so long as route improvements never increase the total shipment cost and disimprovements never decrease the total shipment cost. This property must be true of any improvement or disimprovement to a network for problems NIP1 and NIP2 to be convex. This property may not be true of a network design problem with user equilibrium assignment, or in problem NIP2 if β is allowed to vary during the solution process.

The RASH procedure limits the number of route improvements added per iteration to the current solution with a net step size equal to some fraction of the total undiscounted construction funds initially allocated for the entire planning horizon. For example, if \$10 billion were allocated for each of three decades, a net step size of \$3 billion would allow the route improvements added in each iteration to have a total undiscounted cost of up to 1⁄10 of the initially allocated funds. This net step size would enable a final solution to be found in about 10 iterations. A gross step size, which might typically be set to twice the net step size, is also used to limit the amount that the current solution can depart from the previous solution because of improvement switching. However, the gross step size will only affect the solution process in cases where alternative route improvements have highly interdependent impacts on the costs and benefits of each other. The gross step size limit was never found to affect the solution process or the final solution in the example of this paper.

As a preview to the RASH procedure, candidate route improvements are ranked in descending order of their benefit-cost ratios, and the highest ranked feasible improvements are added to the current solution subject to the net and gross step size limitations and the available funds in each decade. The term "budget-feasible" means that a given route improvement strategy (r,p,d) can fit within the remaining funds available for Decade d when it is considered for addition to the current solution. The term "step-size-feasible" means that a given route improvement strategy (r,p,d) can fit within both the remaining net and gross step sizes of undiscounted funds when considered for addition to the current solution.

STEPS OF THE RASH SOLUTION PROCEDURE

1. Let G^n be the current subset of programmed route improvement strategies at Iteration n of this solution procedure. Discard any route improvement strategy (r,p,d) that is not budget-feasible within the funds allocated for Decade d (using unspent funds from previous decades if allowed). Begin with no route improvements such that G^0 is the existing network, and $x_{rp}^{dn} = 0$ for all (r,p,d) combinations. Specify the allowable net and gross step sizes per iteration (denoted as k and K, respectively) as portions of the total undiscounted initially allocated funds in all decades such that the final solution will be obtained within a reasonable number of iterations. Initialize n to 0, and go to Step 2.
2. Increment the iteration counter n to $n + 1$. Set the cumulative step size limit nk for Iteration n equal to the net step size k times the iteration counter. Reset the gross step size K to its original value defined in Step 1. Go to Step 3.
3. For each not-yet-improved route, compute the benefit-cost ratio BCR_{rp}^{dn} of each alternative route improvement strategy (r,p,d) if individually added to the current solution G^n as the change in the value of $Z(G^n)$ divided by the candidate's present value cost. For each already-improved Route r, evaluate the ratio of each alternative improvement to Route r as the change in the value of $Z(G^{n-})$ divided by the candidate's present value cost, where G^{n-} is equal to G^n minus the current improvement to Route r. All possible route improvements are considered to be budget-feasible in this step. Go to Step 4.
4. Rank all route improvement candidates evaluated in Step 3 in descending order of their benefit-cost ratios. An improvement strategy for a given route in a later decade is only ranked higher than an improvement strategy for the same route in an earlier decade if the later strategy has both a higher ranking ratio and a greater NPV. Go to Step 5.
5. If the rank-ordered list of route improvement candidates is empty, then STOP. Else, go to Step 6.

6. If the top-ranked route improvement candidates is budget feasible (using unspent funds from previous decades if allowed) and no other improvement has been included for this same Route r in this current iteration, then go to Step 7. Else, remove this candidate from the rank-ordered list, and return to Step 5.

7. If the top-ranked route improvement candidate is feasible within both the amounts of cumulative and gross step sizes remaining (nk and K), then go to Step 8. Else, return to Step 2.

8. Include the top-ranked route improvement candidate in the current solution G^n by setting its value of x_{rp}^{dn} to 1, and remove this candidate from the rank-ordered list. Subtract the undiscounted cost of this route improvement strategy from the cumulative step size nk, and also from the gross step size K if this candidate was not in the solution of the previous iteration. Update the remaining funds in Decade d, and return to Step 5.

Table 1 indicates how alternative route improvement strategies are ranked and added to solutions of the RASH procedure for the first two iterations, where the decade of construction is disregarded for example purposes. With a net step size of $400 million, eight route improvements could be included in the first iteration. These same route improvements are included in the second iteration, although with slightly different ranks because of interdependent costs and benefits. The second iteration includes 15 route improvements within the cumulative step size of $800 million for two iterations. Note that two route improvement strategies were passed over because improvements for these routes had already been included in the solution of this iteration.

The RASH procedure does not require an individual route improvement strategy to have an economically acceptable benefit-cost (B/C) ratio as a condition of acceptance for two reasons. First, with interdependent effects, individual route improvements with B/C ratios below one when evaluated individually may have B/C ratios above one when evaluated with other route improvements. Second, a full accounting of all costs and benefits may not be possible within the context of the analysis, and the purpose of the analysis is to determine a best design for the costs and benefits that are recognized, allowing that benefits may be underestimated. Problems NIP1 and NIP2 as formulated do not include any benefits to personal travel, impacts on business development, or any other economic or environmental effects.

EXAMPLE APPLICATIONS OF RASH TO AN NIP2 PROBLEM

An example is presented of applying the strategic network improvement planning approach described earlier to potential improvements of 289 major highway routes between adjacent BEA regions that cover the 48 contiguous states of the United States. These routes connect the geographic population centroids (as of 1985) of 181 BEA regions (as defined in 1989), and are mostly composed of Interstates, four-lane urban highways, and rural principal arterials.

The National Highway Planning Network connecting these regions was developed at Oak Ridge National Laboratory to support a wide variety of national transportation analyses, primarily for the U.S. Departments of Energy, Defense, and Transportation. The full network (as of 1989) contains approximately 370,000 mi of roads to varying degrees of accuracy in both its geographic and attribute data, and is currently used by the Office of Transportation Systems, FHWA, for analytical modeling and forecasting purposes. In addition to the $X-Y$ coordinate pairs needed to describe each link's geographical location and alignment, the network data base has 17 other attributes defined for each link as follows:

1. Link ID,
2. Sign route,

TABLE 1 EXAMPLE OF ROUTE IMPROVEMENT RANKINGS AND SELECTION

			Cost	Iteration #1					Cost	Iteration #2	
r	p	Cost	Sum*	Ratio	In/Out	r	p	Cost	Sum*	Ratio	In/Out
15	2	32	32	2.571	In	14	1	92	92	2.493	In
14	1	92	124	2.494	In	15	2	32	124	2.424	In
2	1	71	195	2.364	In	6	1	11	135	2.326	In
16	2	91	286	2.321	In	2	1	71	206	2.220	In
6	1	11	297	2.290	In	3	1	32	238	2.189	In
3	1	32	329	2.252	In	16	2	91	329	2.172	In
19	2	27	356	2.202	In	19	2	27	356	2.079	In
17	1	27	383	2.183	In	17	1	27	383	2.042	In
5	1	39	---	2.027	Out	5	1	39	422	1.842	In
8	1	19	---	1.834	Out	4	2	57	479	1.661	In
11	1	76	---	1.776	Out	8	1	19	498	1.623	In
4	2	57	---	1.750	Out	11	1	76	574	1.579	In
6	2	92	---	1.587	Out	6	2	92	---	1.512	Out
2	2	84	---	1.579	Out	2	2	84	---	1.413	Out
12	2	53	---	1.377	Out	12	2	53	627	1.278	In
18	1	72	---	1.365	Out	18	1	72	699	1.170	In
13	1	47	---	1.231	Out	13	1	47	746	1.162	In
8	2	84	---	1.132	Out	8	2	84	---	1.061	Out
4	1	29	---	1.044	Out	15	1	62	---	0.907	Out
1	1	40	---	0.969	Out	4	1	29	---	0.896	Out
15	1	62	---	0.917	Out	1	1	40	---	0.855	Out

* All costs are in millions of dollars. The cost sum is the running total cost for included route improvement strategies.

3. Length,
4. Heading,
5. Urban flag,
6. One-way flag,
7. Median division,
8. Access control,
9. Number of lanes,
10. Traffic restriction identifier,
11. Toll flag,
12. STAA truck route flag,
13. Principal highway extension,
14. Pavement type,
15. Administrative class,
16. Functional class, and
17. Existing or proposed link.

The geographical coordinates of links and nodes in the highway network data base were obtained primarily from a set of road maps digitized by the U.S. Geological Survey (USGS) from 1:2,000,000 scale plates of the National Atlas. Additional maps ranging in scale from 1:100,000 to 1:250,000 obtained from state highway agencies and other departments were also used to supplement the development of this network. Approximate percentages of road mileage by functional class in the full network of 370,000 mi are as follows:

Percentage	*Road Category*
5.7	Interstates (rural, urban, and rural/urban)
21.9	Rural or rural-urban principal arterials
31.8	Urban principal arterials and other arterials
9.0	Collectors and other minor arterials
31.6	Unknown or unclassified in the network

The entire U.S. highway network data base contains roughly 42,000 links and 27,000 nodes. For this network improvement analysis, a subnetwork of major intercity highways was extracted from the full network, including all links in the first two functional class groupings listed, plus some from the third group. Links in the extracted network were combined into longer links over which attributes important to this analysis did not vary. These attributes were

- Number of lanes,
- Whether or not opposing lanes of traffic are divided by a median strip or barrier, and
- Whether or not access to the lanes is controlled by entrance and exit ramps.

This network extraction and condensing process resulted in a subnetwork of 137,338 mi (or 37.1 percent of the full network mileage) with 7,775 links and 5,620 nodes. This subnetwork, shown in Figure 1, referred to as the "analysis network," was used in all test runs of the RASH procedure, including those for the following example.

Figure 2 shows the boundaries of the 181 BEA regions as they were defined in 1989. Figure 3 shows an enlarged portion of Figure 2 for three BEA regions in southern Texas with the analysis network of Interstates, four-lane urban highways, and rural principal arterials crossing these regions. Highlighted in bolder lines is the initial minimum-cost path between the 1985 population centroids of the Corpus Christi and Brownsville-McAllen-Harlingen BEA regions.

In Figure 3, the width of the initial minimum-cost path from Corpus Christi to Brownsville corresponds to the number of existing lanes along each segment of this route. Table 2 presents the link characteristics of this route for its existing status and with each improvement strategy. The two improvement strategies considered for each route are to make all necessary

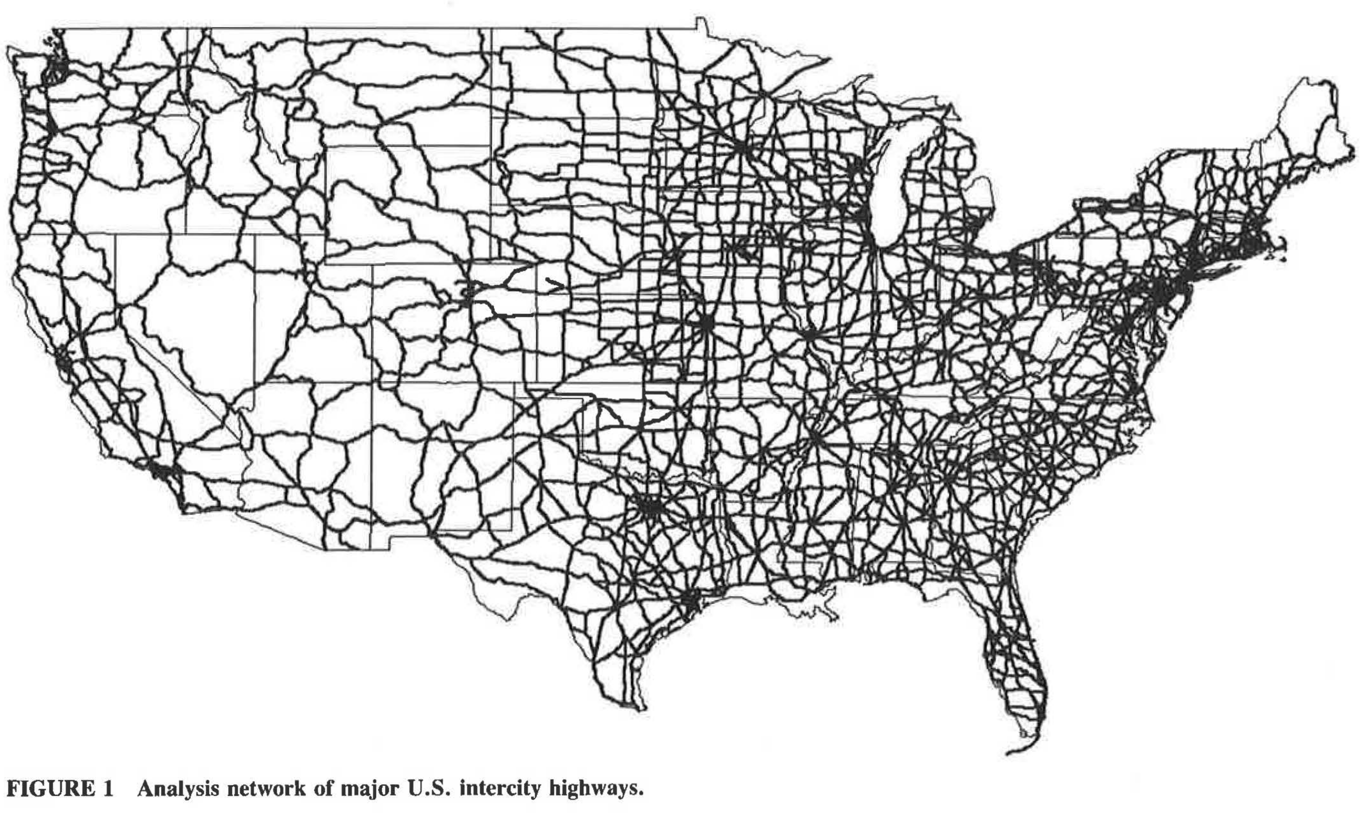

FIGURE 1 Analysis network of major U.S. intercity highways.

FIGURE 2 The 181 BEA regions in the 48 contiguous states of the United States.

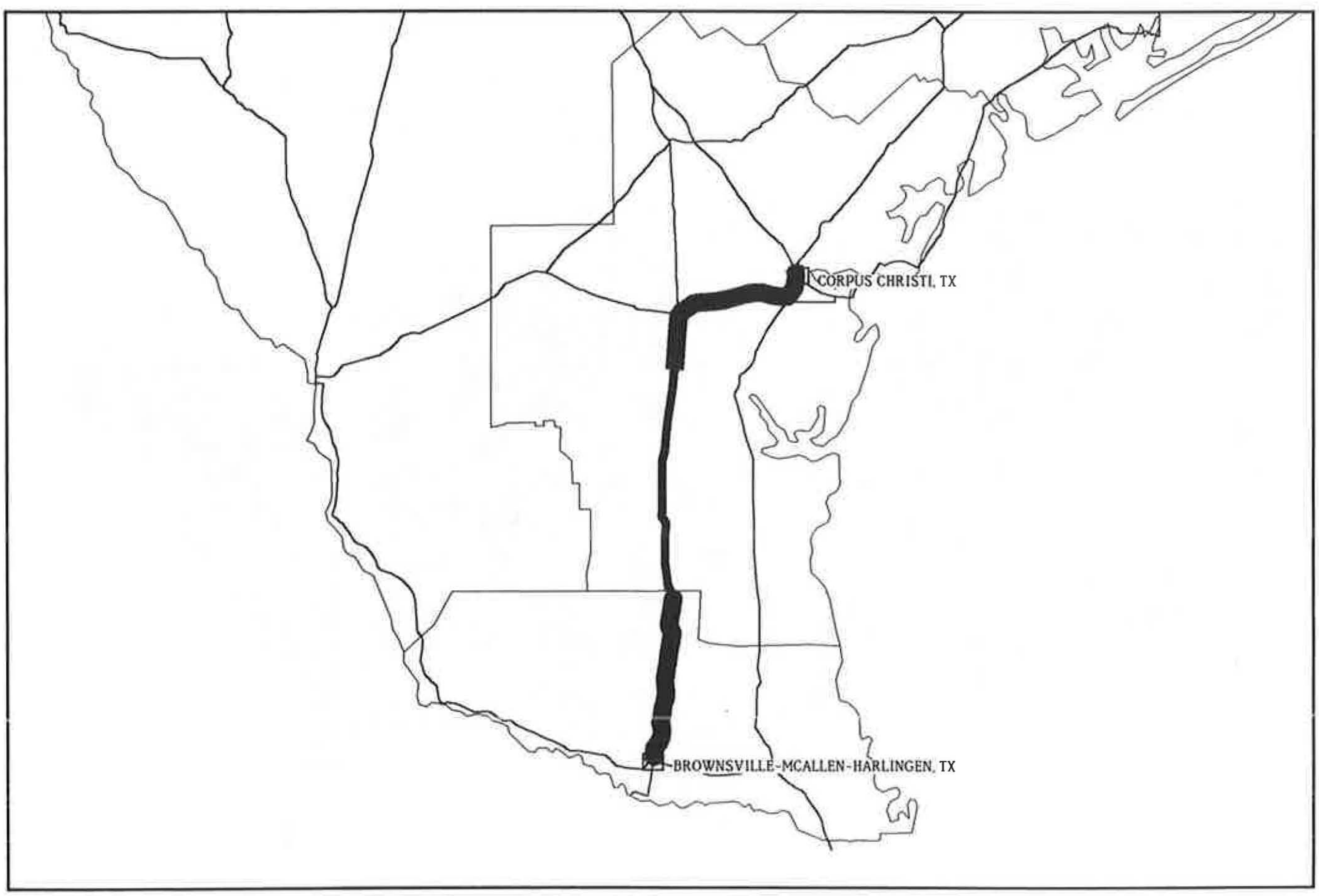

FIGURE 3 A candidate improvement route in the analysis network—minimum-cost path from Corpus Christi to Brownsville, Texas.

TABLE 2 LINK ATTRIBUTES OF THE CANDIDATE IMPROVEMENT ROUTE

Existing Attributes

Link ID	# of Lanes	Divided Median	Access Control	Speed (mph)	Length (miles)	Travel Time (min)
1	4	No	No	37.5	5.8	9.3
2	4	Yes	No	37.5	27.1	43.4
3	4	Yes	No	37.5	13.4	21.4
4	2	No	No	26.9	54.9	122.3
5	4	Yes	No	37.5	15.0	24.0
6	4	Yes	No	37.5	25.2	40.3
				32.5	141.4	260.7

Improvement Strategy 1 (undiscounted cost = $1134.5 x 10^6)

Link ID	# of Lanes	Divided Median	Access Control	Speed (mph)	Length (miles)	Travel Time (min)
1	4	Yes	Yes	65.0	5.8	5.4
2	4	Yes	Yes	65.0	27.1	25.0
3	4	Yes	Yes	65.0	13.4	12.4
4	4	Yes	Yes	65.0	54.9	50.7
5	4	Yes	Yes	65.0	15.0	13.8
6	4	Yes	Yes	65.0	25.2	23.3
				65.0	141.4	130.6

Improvement Strategy 2 (undiscounted cost = $219.6 x 10^6)

Link ID	# of Lanes	Divided Median	Access Control	Speed (mph)	Length (miles)	Travel Time (min)
1	4	No	No	37.5	5.8	9.3
2	4	Yes	No	37.5	27.1	43.4
3	4	Yes	No	37.5	13.4	21.4
4	4	No	No	37.5	54.9	87.8
5	4	Yes	No	37.5	15.0	24.0
6	4	Yes	No	37.5	25.2	40.3
				37.5	141.4	226.2

Note: Average (not total) route speed shown below speed column.

upgrades so that (a) every link is median divided with controlled access and at least four lanes, or that (b) every link is at least four lanes, but without any changes to median division or access control.

Table 3 presents link attributes and mileages of all 289 routes considered for improvement. These routes comprise 64,444.8 mi of the 137,338 mi (or 47 percent), and 3,309 links of the 7,775 links (or 43 percent), of the entire analysis network. Because Strategy 2 is only applicable to routes with two-lane links, there are 536 possible route improvements (289 of Strategy 1, and 247 of Strategy 2). Table 3 presents the road mileages of all 289 routes by their link attributes for three extreme cases: (a) no improvements, (b) all 247 Strategy 2 improvements, or (c) all 289 Strategy 1 improvements.

Unit shipment costs were assumed to be directly proportional to route travel times. Link travel times were computed

TABLE 3 SUMMARY OF ALL POSSIBLE ROUTE IMPROVEMENTS BY STRATEGY TYPE

# of Lanes	Divided Median	Access Control	Speed (mph)	Road Mileages by Link Type: Existing Routes	All 2nd Strategy	All 1st Strategy
2	No	No	26.9	20556.9	0.0	0.0
2	No	Yes	45.5	223.1	0.0	0.0
4	No	No	37.5	432.7	20989.6	0.0
4	No	Yes	65.0	2.1	225.2	0.0
4	Yes	No	37.5	7364.2	7364.2	0.0
4	Yes	Yes	65.0	35534.4	35534.4	64113.4
>4	Yes	Yes	65.0	331.4	331.4	331.4
			totals =	64444.8	64444.8	64444.8

Total undiscounted cost of all strategy 1 improvements = $275,789 x 10^6
Total undiscounted cost of all strategy 2 improvements = $83,566 x 10^6

as over-the-road distances divided by average travel speeds as reported by FHWA for functional road classes. Link travel times were then increased by 20 percent for roads with uncontrolled or partially controlled access because of intersection delays, and by another 10 percent for two-lane roads because of slow vehicle impedances. In order to compute shipment costs, the link travel times were multiplied by a fixed value per minute of travel time saved per million dollars of goods being shipped. For the type of shipment distribution function used in this example, the value of time will not affect the selection of route improvement strategies because its value will not alter the shipment distribution or relative sizes of benefit-cost ratios used to rank alternative route improvements during the solution process.

This example is for a 30-year planning horizon beginning in 1990 in which total commodity shipments to and from each region are forecasted for each year of each decade. Route improvements can be programmed for construction in any decade, but the total construction cost of all route improvements programmed must be within the 10-year funding allocation of each decade. Route improvement construction costs were computed on a lane-mile basis according to recently reported costs for road widening. Construction costs were assumed to be the same in each decade for each project in terms of undiscounted 1990 dollars, and the same level of funding in undiscounted 1990 dollars was used as the budget constraint in each decade.

Forecasts of shipment origins from each region in each year of the planning horizon were made on the basis of economic activity data for the counties of each region obtained from the 1988 County and City Data Book (*12*). The total value of shipments from each region was assumed to be proportional to the dollar value of manufactured goods shipped from each region plus the dollar value of farm production in each region, which is less than 7 percent of these two values combined for the nation as a whole. These two product groups account for roughly 80 percent of all U.S. truck vehicle-miles of travel when such ambiguous goods as building products are defined as manufactured goods.

The 1988 estimated shipments from each region were assumed to grow at a rate of 3 percent per year over the entire planning horizon. Thus, shipment estimates for 1991 were already greater than the 1988 estimates by more than 9 percent with compounding. The 1985 population of each region was then used to weight the total value of shipment destinations to each region. The population of each BEA region was assumed to increase at a uniform rate for all regions in every year of the planning horizon.

The value of time for commodity shipments was assumed to be the same per dollar of good shipped regardless of product type. Other carrier costs for labor and equipment were not included in the analysis, because these varied with fleet and vehicle size. The commodity shipment data in this example are only intended to represent surrogate measures of shipment generation and attraction rates that are realistically proportional to the actual magnitudes of shipments between regions.

A discount rate of 10 percent per annum was applied both to the costs and to the benefits of all network improvement strategies. All improvement strategy costs and funding allocations were averaged over each decade as uniform series. Uniform series discount factors were applied to these cost and funding streams in order to express all amounts in 1990 present value dollars. The total shipment cost reduction in each year brought about by a given improvement was discounted to 1990 dollars, and the reductions for each year were summed to equal the total present value of improvement benefits.

In this example, a budget constraint of $27,579 million (undiscounted) was allocated for route improvements in each decade, which equals 10 percent of the total undiscounted cost of all 289 Strategy 1 improvements to all routes. Table 4 presents the road mileage changes over time in the RASH solution to this example by the attributes listed because of the route improvements made in each decade. Table 5 indicates that a total of 9,050 mi of highway are to be improved by Strategy 1, and 839 mi of highway are to be improved by Strategy 2.

Table 6 presents the benefit-cost ratio for each decade of route improvements in the RASH solution to this example and for the entire planning horizon. The freight shipment costs exhibited are estimated on the basis of total travel time required. The freight shipment costs represent estimated travel time costs assuming an average commodity shipment value of $10,000 per truck and an average truck value-of-time of $15 per hour. The values labeled as being without improvements indicate how much worse the freight shipment costs would have been had these route improvements not been made and no other improvements substituted for them. Table 6 indicates an average truck trip travel time decrease of 14.5 min because of all route improvements. This average travel time savings is for all truck trips, not just those using improved routes.

The discounted benefit-cost ratio increases in each successive decade because of the 3 percent annual growth rate in total shipment value. In computing this ratio, both route improvement costs and shipment cost savings are discounted by the same annual discount factor, where the route improve-

TABLE 4 ROAD MILEAGE IMPROVEMENTS IN THE RASH SOLUTION

			Road Mileages by Link Type			
# of Lanes	Divided Median	Access Control	Existing Routes	End of Decade 1	End of Decade 2	End of Decade 3
2	No	No	20556.9	18847.5	16866.1	14980.7
2	No	Yes	223.1	119.4	107.5	72.3
4	No	No	432.7	716.4	1057.5	990.0
4	No	Yes	2.1	97.4	97.4	97.4
4	Yes	No	7364.2	5723.8	4383.7	3388.3
4	Yes	Yes	35534.4	38608.9	41601.2	44584.7
>4	Yes	Yes	331.4	331.4	331.4	331.4
		totals =	64444.8	64444.8	64444.8	64444.8

TABLE 5 SUMMARY OF ROUTE IMPROVEMENTS IN THE RASH SOLUTION

	Strategy 1	Strategy 2	Total
Decade 1			
1) miles improved	3075	477	3551
2) number of routes	56	14	70
3) undiscounted cost	25571	2001	27572
Decade 2			
1) miles improved	2992	363	3355
2) number of routes	43	6	49
3) undiscounted cost	26126	1451	27577
Decade 3			
1) miles improved	2984	0	2984
2) number of routes	28	0	28
3) undiscounted cost	27569	0	27569
All Decades			
1) miles improved	9050	839	9890
2) number of routes	127	20	147
3) undiscounted cost	79266	3452	82718

Note: All costs are in millions of undiscounted 1990 dollars.

TABLE 6 BENEFIT-COST COMPARISON OF THE RASH SOLUTION

	Decade 1	Decade 2	Decade 3	Total
Undiscounted Values				
Total shipment value	22790762	30628878	41162651	94582291
Total shipment cost				
1) without improvements	503973	677298	910231	2091502
2) with improvements	498070	666121	892868	2057059
3) reduction (= benefits)	5903	11177	17363	34443
Average shipment travel time with improvements (minutes) (884.5 without improvements)	874	870	868	870
Total strategy cost	27572	27577	27569	82718
Discounted Values				
Total shipment cost				
1) without improvements	302622	156800	81244	540666
2) with improvements	299078	154212	79694	532984
3) reduction (= benefits)	3544	2588	1550	7682
Total strategy cost	16942	6533	2518	25993
Total benefit/cost ratio	0.209	0.396	0.616	0.296

Note: All costs, benefits, and shipments are in millions of dollars.

ment costs are assumed to be spread uniformly over each decade. Although the end of the planning horizon truncates the benefit stream for each improvement, the relative rankings of projects in a common decade will be unaffected by the end of the planning horizon. Hence, using a finite or infinite planning horizon will have little impact on the RASH solution to this example.

CONCLUSIONS

A heuristic network design procedure for the selection and programming of major route improvements to the national highway network has been presented. The solution outcome of this procedure relies heavily on the suitable definition and assessment of the net benefits and costs of alternative system design plans. Beyond the simplified treatment of benefits and costs used in this paper, system benefits should also include accident reductions, access improvements, economic development impacts, environmental effects, and energy considerations. System costs must be made more specific as to the design and construction requirements of alternative strategies for different routes, because construction costs can be several times greater than the average for sites with different terrain or environmental complications.

These requirements are indeed burdensome for large problems that may, in fact, possess several good solutions, any one of which is not so difficult for a heuristic to reliably obtain. In cases where several good solutions satisfy the desired goals of a broader decision making process, the heuristic solution procedure can be used to investigate the sensitivity of competing solutions to different cost and benefit assumptions at moderate computational expense. Then, both human and computer resources can be focused on the generation and evaluation of alternative problem specifications, which are critical to completeness of the overall design process.

The results of this study show that a relatively straightforward and computationally less burdensome heuristic solution approach can be successfully applied to evaluate alternative highway network improvement programs for several future decades. The integration of this approach with geographic data bases, network link files, and highway information management systems facilitates the preparation and execution of alternative travel demand forecasts and funding scenarios. Although codes for the heuristic solution approaches described herein can be developed and implemented easily on microcomputer workstations, it would be difficult to solve these same problems with integer programming optimization packages.

The imposition of a budget constraint on highway expenditures in each decade can be relaxed to determine the funds needed to achieve desired benefit levels over the planning horizon. Equity constraints in the form of regional funding requirements or net present value constraints can also be added to the model that require each region to receive a given amount of funds in each decade (*20*). In the presence of such equity constraints, route improvements are selected within regions so as to achieve maximum net present value for the entire system subject to these constraints.

Additional data are needed, particularly by commodity type, to improve the form and implementation of the shipment distribution model used in the example of this paper. The U.S. Bureau of Census is currently administering NTACS for 1989, which will provide better estimates of both origin and destination shipment totals of tons and dollar values by 15 major industrial classifications. The NTACS data may allow alternative forms of the distribution model to be calibrated and tested for use in this network improvement programming process. Other data sources must be garnered for better carrier and shipper cost data in relation to highway improvements.

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Computerized Methodology for Highway Deficiency and Project Development Studies

JAISUNG CHOI, JOHN M. CORBIN, JEONG KIM, AND WILLIAM D. BERG

Datalog technology has made information about roadway geometry available in digital form. The Highway Project Development Program (HPDP) is a software package that reconstructs vertical and horizontal roadway alignments from datalog files and evaluates existing and proposed alignments on the basis of sight distances, curve speeds, vehicle speeds, accident rates, and user costs. A case study was performed to apply HPDP to a project currently being designed by the Wisconsin Department of Transportation. Most problems encountered while applying HPDP during the case study were solved, although some still remain. Extensive package testing should continue and should use more comprehensive case studies. New software capable of generating datalog information would enhance the package's flexibility in simulating possible improvements. Interactive software to produce the necessary input files, and computer-based menus for applying HPDP would also prove useful. Finally, HPDP could also be integrated within a geographic information system environment to facilitate its application.

The Wisconsin Department of Transportation (WisDOT) has instrumented its photolog vehicle to record bearing, grade, and cross-slope data at 0.01-mi intervals. The data are stored in lines of text, each line constituting a datalog record for a specific point identified by its odometer reading. Each record includes the following information: route and county name, odometer reading, roadway grade (percent), roadway transverse slope (decimal), and roadway compass bearing (degrees). Previous research had developed software to convert the datalog information into a highway alignment data base that included horizontal and vertical curve data, as well as the location of segments not meeting stopping and passing sight distance criteria (*1*).

Related research had also been conducted for WisDOT to update the road user cost estimation methodology found in the Highway Investment Analysis Package (HIAP) software available from FHWA (*2*). The potential for incorporating the HIAP user-cost and benefit-cost analysis algorithms with the datalog processing software was viewed as offering a new integrated capability for conducting highway deficiency and preliminary project development studies. With the cooperation and financial support of WisDOT, research was undertaken to develop such a software package. The current status of the resulting Highway Project Development Program (HPDP) is described, and recommendations regarding future work in this area are recommended (*3*).

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OVERVIEW OF THE SOFTWARE

The HPDP consists of FORTRAN programs MAIN, RECAL, and BOVERC. All files used as input and produced as output by HPDP are text files that are easily read and manipulated by the user with any text editor. The files must be assigned to appropriate FORTRAN logical units before execution of HPDP. Table 1 lists the files used in HPDP.

The HPDP software initially interprets user input and datalog information to reconstruct vertical and horizontal highway alignment. Alignment is then evaluated on the basis of stopping and passing sight distances, horizontal curve design speeds, speed profile characteristics, accident rates, travel time, and vehicle operating costs. User input is provided in the form of a global data file, which identifies the following:

- The analyzed highway segment limits,
- Traffic parameters,
- Local area and highway type description data,
- Optional railroad crossing data,
- Optional controlled intersection data,
- Parameters used in defining deficient sections,
- Switches used to control program execution, and
- Data used in the benefit-cost analysis.

Sight distances along a highway are constrained by interference between curve crests and the sight line, and by obstructions located along the inside of a horizontal curve. Sections of the highway along which sight distance is deficient are determined by HPDP for both the horizontal and vertical cases. The deficient sections are then combined where identified limits overlap. Separate analyses are performed using stopping sight distance and passing sight distance criteria.

Leisch's speed profile methodology is incorporated in the HPDP methodology to assist in identifying potentially hazardous locations (*4*). Free-flow automobile speed profiles are constructed on the basis of constraints imposed by horizontal alignment. Truck speeds are similarly determined, but are further affected by changes in vertical alignment. The truck speeds established by horizontal and vertical alignment constraints are then combined to form an aggregate truck speed profile. Deficient speed sections are identified when the automobile running speed is more than 10 mph below a selected design speed, or when truck speeds are more than 10 mph lower than automobile speeds.

Accident rates are evaluated using a 0.10-mi analysis section moved by 0.01-mi increments along the study segment. The

TABLE 1 HPDP FILE NAMES AND DESCRIPTIONS

File Name	Descriptive File Name
ACCDNT.DAT	Accident Data File
BOVC.DAT	User Cost Data File
BOVC.OUT	Benefit-Cost Analysis Results File
CURVE.DAT	Highway Alignment Improvement Data File
DEFILE.DAT	Highway Deficiency Analysis Result File
ELVOD.DAT	Elevation and Odometer Data File
FGRP.DAT	Traffic Volume Distribution File
GLOBAL.DAT	Global Data File
HORZCRV.DAT	Horizontal Curve Data File
LOG.DAT	Datalog File
MOE.DAT	Highway Alignment Summary File
NEW.DAT	Alternative Highway Alignment Data File
NEWPVT.DAT	Alternative Vertical Curve Parameter File
PVCPVT.OUT	Vertical Curve Parameter File
PROFILE.PLT	Vertical Profile Plot
SPEED.PLT	Speed Profile Plot
VCLCRV.DAT	Vertical Curve Data File

	Input Files	Program	Output Files
		([E] indicates required user editing of files)	
1.		"Profile Plotting Run"	
	GLOBAL.DAT [E] LOG.DAT	MAIN	PROFILE.PLT
2.		"Existing Alignment Run" (Base Year)	
	GLOBAL.DAT [E] LOG.DAT VCLCRV.DAT [E] ACCDNT.DAT [E] FGRP.DAT [E] (optional)	MAIN	ELVOD.DAT BOVC.DAT = >rename DEFILE.DAT SPEED.PLT PROFILE.PLT HORZCRV.DAT PVCPVT.OUT
3.		"Existing Alignment Run" (Design Year) (Same as 2 with design year AADT in GLOBAL.DAT)	
4.		"Proposed Alignment Development Run"	
	GLOBAL.DAT [E] ELVOD.DAT PVCPVT.OUT HORZCRV.DAT CURVE.DAT [E]	RECAL	NEWPVT.DAT MOE.DAT NEW.DAT
5.		"Proposed Alignment Run" (Base Year)	
	GLOBAL.DAT [E] LOG.DAT VCLCRV.DAT [E] ACCDNT.DAT FGRP.DAT (optional) NEW.DAT NEWPVT.DAT	MAIN	ELVOD.DAT BOVC.DAT = >rename DEFILE.DAT SPEED.PLT PROFILE.PLT HORZCRV.DAT PVCPVT.OUT
6.		"Proposed Alignment Run" (Design Year) (Same as 5 with design year AADT in GLOBAL.DAT)	
7.		"Benefit-Cost Analysis Run"	
	GLOBAL.DAT [E] (BOVC.DAT from 2,3,5,6)	BOVERC	BOVC.OUT

FIGURE 1 HPDP application procedure.

accident rate within the 0.10-mi segment is compared to a critical accident rate determined for locations having similar characteristics. Sections in which the existing accident rate exceeds the critical accident rate are defined as deficient.

Travel time is defined by the average running speed and encountered delays. The average running speed is a function of the volume-to-capacity ratio and is independent of the speed profile analysis discussed previously. Delays result from controlled intersections and railroad crossings within the study segment. HPDP can accommodate a study segment containing, at most, one controlled intersection and one railroad crossing.

User costs include running costs adjusted for grade and horizontal curvature. User costs also include excess costs of speed change cycles, stop cycles, and idling resulting from intersection and railroad crossing delays. User costs are established for each vehicle type for several congestion conditions occurring during a typical year.

Analysis of an Existing Alignment Run

The general procedure followed in applying HPDP is shown in Figure 1. The global data file is initially used to run MAIN to plot the vertical profile. This profile plotting run provides a plot of the vertical alignment (profile.plt), which is then used to manually construct the vertical curve data file (vclcrv.dat). The vertical curve data file contains the odometer reading of the point of vertical curvature (PVC) and the point of vertical tangency (PVT) for each vertical curve identified. Attempts to develop methodology to automate this step were not successful because of the inherent variance in the grade data collected by the photolog vehicle. A similarly constructed accident data file (accdnt.dat) consists of a listing of accident locations for a selected study duration. The odometer reading and number of accidents are included for each accident location.

HPDP models several annual traffic volume distributions. Each distribution consists of six periods of the year in which the traffic volume is assumed constant. The six durations cover the total number of hours in 1 year. A user may develop a unique annual traffic volume distribution by constructing a traffic volume distribution file (fgrp.dat) specifying six levels of traffic volume as a percentage of average daily traffic. Each level specified must also include the total hourly duration of the condition.

The global data file, the datalog file, the vertical curve data file, the accident data file and the traffic volume distribution file are then used as input to MAIN for the existing alignment run. The existing alignment run generates various reports and data files. Generated reports include a speed profile plot (speed.plt) of both auto and truck speeds as constrained by geometrics, for the length of the study segment. The highway deficiency analysis result file (defile.dat) presents vertical and horizontal alignment data as well as summaries of segment deficiencies.

Output data files include the user cost data file (bovc.dat) containing data for the benefit-cost analysis performed later by BOVERC. The vertical curve parameter file (pvcpvt.out), the horizontal curve data file (horzcrv.dat), and the elevation and odometer data file (elvod.dat) contain alignment data that may be used in the development of a new alignment with RECAL. A profile plot can also be generated during the existing alignment run to visually verify the vertical alignment established by the vertical curve data file.

The existing alignment must be evaluated under existing and design year traffic conditions to generate user cost data for the benefit-cost analysis of a proposed improvement. The traffic information in the global data file can be changed to reflect existing, and then design year, conditions. The user cost data file from the run for the existing alignment in the base year is renamed to identify it for use as input to BOVERC. The user cost data file from the run for the existing alignment in design year is also renamed for BOVERC.

Analysis of a Proposed Alignment

Once existing horizontal and vertical curves have been identified and evaluated, they can be modified by RECAL and the new alignment can then be analyzed in the proposed alignment runs, as shown in Figure 1. The highway alignment improvement data file (curve.dat) is developed by the user and specifies the total number of vertical and horizontal curves to be improved. New data are then provided for each vertical curve identified for improvement. New data can consist of a new K-value or a new design speed. Finally, new data are supplied for those horizontal curves that are identified for improvement. Either the degree of curvature, the radius, or the point of curvature may be changed.

When HPDP models a proposed alignment, the existing horizontal and vertical points of intersection are maintained. Existing horizontal tangent section bearings and vertical tangent section grades must also be maintained. As a result, changes desired by the user can only be implemented by shortening or lengthening existing curves. The proposed curves must still fit into the existing vertical and horizontal points of intersection and tangent section conditions.

The vertical curve parameter file, the horizontal curve data file, the elevation and odometer data file, and the highway alignment improvement data file are read as input by RECAL in the proposed alignment development run. The run produces the alternative vertical curve parameter file, the alternative highway alignment data file, and the highway alignment summary file.

The parameter file and data file from the proposed alignment development run along with the global data file, accident data file, datalog file, and vertical curve data file are then used as input to MAIN in the proposed alignment run. The global data file is used to instruct MAIN to read the proposed alignment data files. MAIN then generates the proposed alignment and evaluates deficiencies on the basis of the proposed alignment just as it does with the existing alignment in the existing alignment runs. Runs using the proposed alignment must be performed for base and design year traffic conditions to accommodate a benefit-cost analysis.

Benefit-Cost Analysis

The final run in the application of HPDP to a highway segment uses BOVERC to conduct a benefit-cost analysis of a proposed improvement. The global data file provides the construction cost, selected discount rate, and number of years between base and design traffic conditions. The four user cost data files generated by the existing and proposed alignment runs in both base and design years are also used as input. The output of BOVERC is the benefit-cost analysis result file that summarizes user costs, construction costs, and the benefit-cost ratio.

BOVERC calculates user benefits by considering travel in only one direction. The benefits realized in one direction as a result of the proposed alignment are calculated and then doubled to estimate the total benefit realized when considering travel in both directions. The final benefit-cost analysis results apply to the complete project even though the input data are the result of alignment analysis in only one direction.

CASE STUDY APPLICATION

The HPDP software was initially applied to a hypothetical case study developed to test minimum performance capabilities. The case study evaluated a 2-mi segment of two-lane highway that contained two widely spaced horizontal curves and two vertical curves. The existing curve lengths were increased to produce a proposed alignment. HPDP successfully evaluated the proposed improvement and provided a complete deficiency summary and benefit-cost results. Results were checked by hand calculation to verify the reliability of HPDP programming.

Although the hypothetical case study evaluated the basic capabilities and logic of the HPDP software, additional testing was required using a longer study segment that better reflected complex, real-world conditions. WisDOT had also identified problems when using the HPDP FORTRAN programs on their computer system, and these problems necessitated additional testing.

WisDOT subsequently provided data on existing and proposed conditions for a 10.7-mi section of U.S. Highway 18 that was to be reconstructed. HPDP was to be applied to the Highway 18 study segment to evaluate the effectiveness of the proposed improvement and to assess the cost-effectiveness of the selected alternative. This would also provide the opportunity to

- Thoroughly test the software,
- Correct deficiencies identified in the software,
- Check the reasonableness of HPDP analysis output,
- Assess the viability of HPDP as a decision making tool, and
- Identify the need for additional work.

Data Availability and Format

WisDOT supplied data in tabular and digital form and also sent plan and profile sheets for the proposed improvements. Tabular data included a listing of vertical points of intersection (PVI) along with PVI elevations, associated vertical curve lengths, and approaching grades. An accompanying sheet established the datalog odometer reading and station of the beginning and end points of the project.

Accident data were also provided in tabular form for 1986 to 1988. Accident locations were identified by a reference point (RP) and a plus distance in hundredths of a mile measured in the easterly direction along Highway 18 between the RP and the accident location. An accompanying sheet provided a similar referencing scheme for intersections and other roadway features. This allowed the accident data to be correlated to stationing and, eventually, to datalog odometer readings.

Traffic counts and forecasts were provided in a sketch that listed latest counts and forecasts for each of four homogenous traffic segments along the project length. Truck classification and annual traffic distribution data were also made available.

WisDOT provided digital data on diskettes. The diskettes contained COGO-type ASCII text files describing the existing horizontal alignment and proposed vertical and horizontal alignment. Horizontal alignment data included horizontal points of curvature (PC), points of tangency (PT), and horizontal points of intersection (PI). These points were given as stations, and data describing identified curves were included. The descriptive data consisted of deflection angle, radius, degree of curvature, and curve length. Vertical alignment data included stations of the PVI, length of the associated vertical curve, and the approaching grade. Station equations were included both with digital and tabular data.

Datalog files for the project length were also sent on diskettes. One file contained the datalog information for the eastbound geometry and one file described the westbound geometry. The same odometer readings were used to describe points in either direction. As a result, an eastbound horizontal curve from odometer reading 11.91 (PC) to 12.13 (PT) would be described in the westbound datalog file as a horizontal curve from 12.13 (PC) to 11.91 (PT).

Existing and Proposed Conditions

The existing alignment for the case study highway follows the terrain closely with few cut sections or embankments exceeding 15 ft. The highway consists of one 12-ft lane in each direction with 4-ft gravel shoulders. The proposed alignment will increase the shoulder width to 6 ft. Grades will be reduced in some areas by filling in low spots in the existing vertical alignment. Several vertical curves will be lengthened and a few will also be moved. The radii of some horizontal curves will be increased and, in some instances, horizontal deflection angles will be reduced.

The WisDOT traffic counts and forecasts were adapted for purposes of the case study. The assumed current year, or 1990, ADT ranged from 1,220 to 3,390 over the four homogeneous subsections. The design year, or 2019, ADT ranged from 1,660 to 4,620. Single-unit trucks constitute 5 percent of the ADT, and multiple-unit trucks constitute 6 percent of the ADT.

Data Processing

Spreadsheet software was used to generate input files and manipulate data into formats readable by the HPDP software. This process included:

- Converting the RP-indexed accident data to an odometer reference point,
- Reformatting the ASCII alignment file and calculating the odometer reading corresponding to each referenced station, and
- Converting the descending westbound odometer data to an ascending basis, and adjusting all alignment parameters (e.g., eastbound PCs became westbound PTs).

Four files had to be prepared: global.dat, vclcrv.dat, accdnt.dat, and curve.dat. The global.dat file requires the most intense user interaction and must be changed for each scenario in which HPDP is applied. For each of the four case study sections, proposed and existing conditions were to be evaluated under base- and design-year traffic conditions. Analyses were to be performed in westbound and eastbound directions for 32 ($4 \times 2 \times 2 \times 2$) separate scenarios for HPDP analysis.

The development of curve.dat files required careful evaluation because HPDP is limited in its ability to simulate proposed alignment changes. In simulating proposed improvements, the user can only effect shorter or longer vertical or horizontal curves. The user's alteration of curve data is implemented by HPDP exclusively as length changes. The proposed curves must still fit into the existing vertical and horizontal points of intersection and tangent section conditions.

Because the WisDOT-proposed alignment violated these constraints, the proposed curve data had to be modified to (a) maintain existing PVIs, PIs, tangent section bearings, and tangent section grades; and (b) avoid the overlap of a PT and the next PC, or of a PVC and the next PVT. When modifying horizontal curve improvements, an attempt was made to approach the proposed radius. Similarly, efforts were made to maintain proposed vertical curve lengths when implementing vertical curve improvements.

Initial trial runs of MAIN revealed several fatal logical bugs in the software. Difficulties were also encountered when attempting to run RECAL. RECAL output was not formatted correctly and RECAL output data were not acceptable as input to MAIN. These problems were solved and additional debugging performed.

Because of resource constraints, the problems experienced while using RECAL, the extensive file preparation efforts, and the unanticipated need for considerable debugging, the case study effort was reduced to the analysis of the longest subsection that had a length of 5.7 mi. In addition, rather than attempt further reprogramming of RECAL, the existing datalog files were used as the basis for manually creating datalog files reflecting the proposed alignment. Appropriate grades, slopes, and bearings had to be assigned to corresponding records in the created datalog files. The new datalog information was then printed to a text file and saved as the proposed alignment datalog files, one for eastbound and one for westbound travel.

Execution of the HPDP software was carried out on a VAX computer accessed using a communications software package running on a personal computer. Input and output files were frequently transferred between the personal computer's resident operating system and the VAX.

HPDP Output

Deficiency analysis summaries for the existing and proposed case study alignments for the eastbound direction are presented in Tables 2 and 3. Each table presents the beginning and ending odometer readings of those road segments that do not meet either a user-specified or a fixed-threshold value for any of the several measures of effectiveness. When a controlling value is listed, that is, the value calculated by HPDP, the percent deficiency is the difference between it and the threshold value.

The operational effectiveness of the proposed improvements can be evaluated by comparing the deficiency summaries for the existing and proposed alignments. The HPDP output for the case study site reveals that deficient passing sight distance segments are not appreciably reduced in the

TABLE 2 DEFICIENCY ANALYSIS SUMMARY: EXISTING EASTBOUND ALIGNMENT

MOE	DEFICIENCY BEGIN(ODMTR)	SEGMENTS END(ODMTR)	THRESHOLD VALUE	CONTROLLING VALUE	% DEFICIENCY
PASSING SIGHT DISTANCE					
	11.77	11.96	1108.0 FT		
	12.19	12.33	1108.0 FT		
	12.50	12.66	1108.0 FT		
	12.78	12.99	1108.0 FT		
	13.23	13.42	1108.0 FT		
	14.04	14.10	1108.0 FT		
	14.28	14.42	1108.0 FT		
	14.53	14.73	1108.0 FT		
	14.96	15.24	1108.0 FT		
	15.32	15.55	1108.0 FT		
	15.62	15.92	1108.0 FT		
	16.06	16.44	1108.0 FT		
	16.48	16.87	1108.0 FT		
STOPPING SIGHT DISTANCE					
	11.81	11.97	450.0 FT		
	12.28	12.36	450.0 FT		
	12.52	12.67	450.0 FT		
	12.86	12.90	450.0 FT		
	14.36	14.45	450.0 FT		
	14.60	14.66	450.0 FT		
	15.03	15.10	450.0 FT		
	15.66	15.82	450.0 FT		
	16.45	16.49	450.0 FT		
SPEED PROFILE					
AUTO SPEED CHANGE					
	11.84	12.08	10.0 MPH	11.7 MPH	21. %
	15.91	16.14	10.0 MPH	14.6 MPH	27. %
	16.16	16.27	10.0 MPH	12.3 MPH	22. %
TRUCK SPEED CHANGE					
	11.96	11.99	10.0 MPH	10.4 MPH	21. %
	15.92	16.14	10.0 MPH	13.1 MPH	27. %
	16.16	16.29	10.0 MPH	11.1 MPH	22. %
AUTO V.TRUCK SPEEDS					
	16.39	16.56	10.0 MPH	14.5 MPH	27. %
LOW DESIGN SPEED CURVES					
	11.85	11.95	55.0 MPH	43.3 MPH	21. %
	12.72	12.79	55.0 MPH	51.5 MPH	6. %
	12.94	13.08	55.0 MPH	48.6 MPH	12. %
	13.36	13.49	55.0 MPH	50.5 MPH	8. %
	15.80	15.88	55.0 MPH	50.8 MPH	8. %
	15.94	16.05	55.0 MPH	40.4 MPH	27. %
	16.15	16.33	55.0 MPH	45.2 MPH	18. %
	16.57	16.69	55.0 MPH	48.8 MPH	11. %
ACCIDENT RATE					
LANE WIDTH			12.0 FT	12.0 FT	
SHOULDER WIDTH			4.0 FT	4.0 FT	
VEH. OPERATING COSTS			0.15 $/MILE	0.31 $/MILE	107. %

TABLE 3 DEFICIENCY ANALYSIS SUMMARY: PROPOSED EASTBOUND ALIGNMENT

MOE	DEFICIENCY BEGIN(ODMTR)	SEGMENTS END(ODMTR)	THRESHOLD VALUE	CONTROLLING VALUE	% DEFICIENCY
PASSING SIGHT DISTANCE					
	11.77	11.95	1108.0 FT		
	12.17	12.41	1108.0 FT		
	12.53	13.01	1108.0 FT		
	13.28	13.31	1108.0 FT		
	13.62	13.82	1108.0 FT		
	14.03	14.06	1108.0 FT		
	14.26	14.39	1108.0 FT		
	14.55	14.61	1108.0 FT		
	14.63	14.74	1108.0 FT		
	14.92	15.22	1108.0 FT		
	15.59	16.28	1108.0 FT		
	16.34	16.44	1108.0 FT		
	16.47	16.86	1108.0 FT		
STOPPING SIGHT DISTANCE					
	11.79	11.98	450.0 FT		
	12.27	12.32	450.0 FT		
	15.62	15.81	450.0 FT		
	16.45	16.49	450.0 FT		
SPEED PROFILE					
AUTO SPEED CHANGE					
	11.84	12.11	10.0 MPH	12.6 MPH	23. %
	15.90	16.08	10.0 MPH	12.2 MPH	22. %
	16.10	16.14	10.0 MPH	10.9 MPH	20. %
TRUCK SPEED CHANGE					
	11.96	12.03	10.0 MPH	10.8 MPH	22. %
	15.98	16.08	10.0 MPH	11.0 MPH	22. %
AUTO V.TRUCK SPEEDS					
	16.30	16.36	10.0 MPH	10.2 MPH	20. %
	16.37	16.53	10.0 MPH	11.6 MPH	23. %
	16.72	16.97	10.0 MPH	11.7 MPH	24. %
LOW DESIGN SPEED CURVES					
	11.84	11.92	55.0 MPH	42.4 MPH	23. %
	15.91	16.03	55.0 MPH	42.8 MPH	22. %
	16.09	16.29	55.0 MPH	52.2 MPH	5. %
	16.56	16.68	55.0 MPH	48.6 MPH	12. %
ACCIDENT RATE					
LANE WIDTH			12.0 FT	12.0 FT	
SHOULDER WIDTH			6.0 FT	6.0 FT	
VEH. OPERATING COSTS			0.15 $/MILE	0.30 $/MILE	103. %

eastbound direction. The percent of the study section length in which passing is not safe is also not reduced by the proposed improvements. Over half of the existing deficient stopping sight distance segments in the eastbound direction on the existing alignment are eliminated by the proposed improvements. However, most of the deficient stopping sight distances that are not eliminated are reduced in length.

The number of curves of low design speed in the eastbound direction is reduced by 50 percent by the proposed improvements. The Leisch speed profile plots for the eastbound case confirmed the design speed gains identified in the low design speed summaries. The total length over which automobile and truck speeds vary from set criteria was also reduced by the proposed improvements.

Westbound passing and stopping sight distance improvements and design speed enhancements were similar to those experienced in the eastbound direction. Speed profile advantages of the proposed alignment were more evident in the westbound direction than in the eastbound direction.

The results of the benefit-cost analysis are presented in the cost-effectiveness data presented in Table 4. The table provides average travel times and operating costs by vehicle type for existing and proposed conditions in the base and design years. The table also notes the benefit-cost ratio for the analysis.

FUTURE DIRECTIONS

On the basis of the case study analysis, a number of software bugs were detected and corrected. However, several known problems remain. In addition, numerous opportunities were

TABLE 4 BENEFIT-COST ANALYSIS SUMMARY

MOE	EXISTING	IMPROVED
CURRENT YEAR		
TRVL TIME (HOUR/VEH)	0.10	0.10
OP COST($/VEH)		
P	1.24	1.22
SU	3.26	3.12
MU	6.33	6.27
DESIGN YEAR		
TRVL TIME (HOUR/VEH)	0.10	0.10
OP COST($/VEH)		
P	1.24	1.22
SU	3.25	3.12
MU	6.37	6.27
CON COST		
($)		1240000.
B/C		1.90

identified for enhancement and expansion of the software to improve its potential usefulness in transportation decision-making.

Problems Remaining

During the case study, the use of RECAL in the application of HPDP was abandoned and datalog files were manually constructed to simulate the proposed alignment. As currently programmed, RECAL should only be used to model simple improvements that lengthen existing curves while maintaining points of intersection. Alternately, for more extensive alignment changes, MAIN should be capable of interpreting manually constructed datalog files for the proposed improvements. At the present time, MAIN also lacks the capability to analyze a study segment that begins or ends in the middle of a vertical curve. However, the accuracy of analysis is not seriously hindered by the absence of this capability.

Some errors were identified in the profile plots developed during the case study. The vertical profile interpreted by HPDP tends to be steeper than the actual profile. In the case of the existing eastbound alignment, HPDP evaluation of the datalog file introduced a significant accumulated error. The beginning point elevation was set by the user, and the ending point elevation derived by HPDP was more than 45 ft higher than the actual ending point elevation. The profiled elevation at the end of the westbound segment was more than 100 ft higher than it should have been. Although these are large values, the discrepancy constitutes only about a 0.33 percent error over the 5.7-mi length of the project. A primary cause of these errors is considered to be the regression analysis methodology currently used by MAIN to adjust the instrumented vehicle data when developing the vertical profile. The regression equations used by HPDP to adjust datalog grades were developed on the basis of a limited amount of data. It is expected that recalibration of the adjustment model using a large sample size will correct the problem.

Additional case studies should be performed to further verify the reliability of HPDP analysis and to identify potential improvements. Two case studies have now been completed. The first case study was done in conjunction with initial software development efforts and was based on highly simplified hypothetical data. Future case studies should be increasingly more challenging to HPDP to allow more thorough evaluation of HPDP strengths.

Software Enhancement

There are additions that can be made to the existing HPDP package that will enhance and ease application. Existing parts of the package could be expanded. New programs could also be written to facilitate the development of input files and to improve HPDP's versatility in accommodating proposed improvements.

The potential for expansion within the existing software is most evident in the sections of MAIN and BOVERC that develop user costs and perform economic analysis. Accident costs are not included in the calculation of user costs. The effect of proposed improvements could be evaluated by applying available relationships between accidents and roadway geometry to each of the accident rate sections for existing and proposed conditions. The effects anticipated from the proposed improvements could then be applied to the base accident rates to estimate the improved accident rate for each of the accident rate sections. Finally, severity and costs of accidents could be estimated and summed to estimate the effect of the proposed improvements on accident costs. These accident costs could then be included by BOVERC in evaluating economic benefits.

The calculation of travel time for user cost evaluation is also in need of enhancement. Travel times are established by available relationships between average vehicle speeds and volume-to-capacity ratios. Highway capacities are determined using standard capacity analysis methodology. The effects of roadway geometry on vehicle speeds, used to establish the Leisch speed profile plots, are not included in the user cost evaluation of travel time. A methodology needs to be developed that would include both volume-to-capacity ratio effects and direct geometric effects on speed and travel time. The relative significance of the effect of each could be governed by the volume-to-capacity ratio experienced in a given case. When volume-to-capacity ratios are high, volume-to-capacity effects should control speeds. When the ratios are low, geometric effects should be more influential.

There are additions that can be made to BOVERC to enhance the economic analysis of alternatives. Evaluations involving multiple study segments could be facilitated if BOVERC could aggregate benefit-cost data for more than one segment at a time. BOVERC could also be modified to include maintenance costs in the calculation of total present value cost in the benefit-cost analysis.

The sight distances along horizontal curves are presently calculated on the basis of an assumed available middle ordinate established for the entire study segment in the global data file. It would be desirable to allow the user to assign different available middle ordinate values to distinct sections within the study segment. MAIN could be modified to accommodate this user input. MAIN should also be capable of using datalog files currently available from WisDOT for either direction on a datalogged roadway. MAIN could be adapted to accommodate all datalog records in these files by switching interpretive modes when descending odometer readings are detected in sequential datalog records. The tedious editing process currently required to develop the various input data files is time consuming and prone to error. Programs could be written that would prompt the user for the necessary data, check the provided data for errors, and assemble the verified data into the required input file.

A program is also needed to create datalog files describing proposed improvements. The program should accept user input specifying the beginning grade and bearing, and the locations and descriptions of proposed vertical and horizontal curves. The program should include a correction of grades so that the grade adjustment performed by MAIN will return the intended proposed grades. The datalog creation software should also accept input in a variety of formats including distances from a reference point, survey stations, and odometer readings. The software could be developed to accommodate English and metric units, and to accept and account for station equations.

The HPDP application procedure could be facilitated by constructing a menu-driven environment in which HPDP could be operated. The menu environment might consist of a shell program that would call appropriate routines at the request of the user. The menu shell could be used to develop input files, execute analysis, manage data, and check the progress of the user involved in an HPDP case analysis. Warnings could also be given if the user overlooked steps in the procedure. Tutorials could be developed to run in the menu shell. The tutorials could explain the procedures to be followed in HPDP application. The tutorial could also lead the user through a sample case study, and could even prompt the user for correct interaction with the software during the sample case study.

HPDP as a Decision-Making Tool

Highway networks are capital investments that depreciate because of use and growth in demand. This depreciation or wear is evidenced by unacceptably high accident rates and travel times, or by elements of the network that are no longer fully functional. Those responsible for managing a transportation network must apply new capital to sections of the network that have depreciated excessively.

HPDP is currently intended for use in the identification and evaluation of specific highway projects. It is not a tool for use in detailed highway design. Highway design typically deals with data that are accurate to the nearest 0.10 or 0.01 ft, as opposed to the 0.01-mi sampling interval used in collecting the datalog information. Appropriate application of the current HPDP software would be in the analysis and evaluation of highway deficiencies, and the preliminary development and screening of alternative geometric design improvements.

The emergence of the geographic information system (GIS) is an area of technological development that is significantly affecting the transportation decision-making environment and that offers new opportunities for the application of tools such as the HPDP software. GIS development efforts at WisDOT have resulted in a commitment to a pilot project designed to demonstrate GIS capabilities through several successively more advanced applications. A significant product of the pilot project was the enhanced management of photolog technology. Photolog data can now be retrieved from an optical video disc used to store the images photographed. An operator can indicate a starting point on a map displayed at a terminal and select a direction along the highway segment that is identified. The appropriate photolog images are retrieved and displayed in the sequence desired at a user-defined rate. Locational accident information recorded for 0.01-mi increments has also been stored and can be manipulated using the WisDOT GIS system. Although the datalog information used as input to the HPDP software is collected in conjunction with photolog images, the GIS system does not currently have the capability to store and retrieve these records.

Several opportunities now exist for integrating the GIS and HPDP methodology. These could be organized into a series of progressively more involved applications.

1. GIS could be used to store and retrieve datalog information. Datalog records could be stored in the same way that photolog images are stored. Datalog records could then be retrieved and combined into eastbound and westbound datalog files. The same map referencing procedures used in photolog retrieval could be applied to datalog selection. The user could either explicitly specify beginning and ending points of the desired datalog information or select the datalog segment by indicating beginning and ending points on a map displayed at the terminal.
2. HPDP could be run for individual projects in the GIS environment. The proposed HPDP menu shell could be activated from within the GIS. The shell could be designed to construct the required existing alignment datalog files from the datalog records stored in the GIS. Beginning and ending points used in the construction could be taken from the user-specified global data file.
3. HPDP could be incorporated by GIS into highway program development. Alternative annual highway improvement programs could be evaluated by simultaneously applying HPDP to all the segments affected by a proposed program. Cost-effectiveness could be determined for each project using current HPDP capabilities.
4. HPDP methodologies could be expanded or incorporated into broader analysis. The GIS environment includes a broad range of data processing capabilities which could significantly enhance highway network management. Accident and traffic data already exist in the GIS environment and could be used directly in HPDP analysis. Pavement management data could be used in conjunction with HPDP results to provide a broader base for decision support when developing and adapting annual and multiple year improvement programs.

In conclusion, the research completed to date provides a basis for further case study testing and enhancement of the HPDP software. The methodology offers promise for facilitating highway deficiency and project development studies, especially within a GIS environment. At the present time, the software should be considered in a development stage, and is not yet ready for widespread application.

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Multimodal Transportation Approaches in Minnesota

MORRIS GILDEMEISTER AND FRED P. TANZER

In the United States, improved multimodal (and intermodal) approaches are required to reduce transportation costs and urban congestion and provide effective rural access. The Minnesota Department of Transportation (Mn/DOT) has been actively involved in multimodal planning for several years and has incorporated it into a variety of planning activities including the Strategic Plan. Mn/DOT's view is that an effective solution to the nation's transportation problems must be based on a multimodal family of vehicles concept. In urban areas, the new concepts must be applied in congested highway corridors. Such approaches also include development of light rail transit and super-speed trains. In rural areas, Minnesota is concentrating on its Rail Service Improvement Program and Freight Access Improvement Program. Aspects of public and legislative support, financial alternatives, and private sector involvement in Minnesota's multimodal planning are also discussed.

A number of factors at both the national and state levels emphasize the need for increased transportation efficiency and for innovative, multimodal approaches to help fill the nation's transportation needs. Foremost among these factors is heightened global economic competition.

The United States needs a top-notch transportation system if it is going to compete in the world market. Recently, in a statement published by the Economic Policy Institute, 327 of the nation's top economists warned that if the country does not increase its infrastructure investment rate it will cripple its ability to compete in the world economy (*1*). For every dollar of export goods, about 25 cents is spent on the transportation of raw materials and intermediate goods in the process of being assembled into final products.

The United States has fallen behind its strongest international competitors in terms of making the infrastructure investments to give it the transportation advantage needed to help offset such advantages as lower wage rates in many foreign countries. According to a recent article, the United States now ranks 55th in the world in the percentage of gross national product (GNP) invested in capital infrastructure (*1*).

David Aschauer, an economist at the Federal Reserve Bank of Chicago, has developed strong evidence that links the lack of investment in infrastructure to the slowdown in economic productivity that the United States has experienced since 1970. His study suggests that investment in highways, mass transit, airports, and sewers is strongly related to a nation's economic productivity and its ability to compete in the world market. Among the seven countries studied by Aschauer, the United States had both the slowest rate of productivity growth and the lowest ratio of infrastructure investment to GNP. Japan leads in both measures (*2*).

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These findings indicate the need for a greater investment in our transportation infrastructure if the United States is going to successfully compete with other nations in the world economy of the 1990s and beyond the year 2000.

Three major areas stand out among overall transportation deficiencies in America. These include the need to

- Reduce transportation costs,
- Manage urban congestion, and
- Provide effective rural access.

Improved multimodal and intermodal approaches will be required to effectively respond to these major issue areas.

TRANSPORTATION COSTS

Reducing transportation costs requires that goods and people be moved by the most efficient means. The availability of effective multimodal transportation alternatives and intermodal connections can help reduce shipping costs to maximize efficiency. Examples of multimodal and intermodal approaches include

- The availability of transit and highway connections for moving people in the nation's congested urban centers,
- The continuation of the operation of profitable rail branch lines,
- The strengthening of roadways to increase their load carrying capacity in areas where rail lines have been abandoned, and
- The provision of improved highway and rail access to water terminals.

These kinds of multimodal approaches will be needed to help ensure U.S. competitive position in the world market. The smooth and reliable functioning of the transportation system is also the key to lowering costs through "just in time" inventory control. Here, costs are kept down by having products available to a manufacturer or retailer just as they are needed, without costly warehousing.

URBAN CONGESTION

Increasing urban area congestion is a second factor that strongly reinforces the need for multimodal approaches and intermodal connections to meet transportation needs.

There is a growing need for increased capacity to move people in the nation's metropolitan areas. In Minneapolis–

St. Paul, congestion is beginning to threaten the levels of mobility needed to preserve the area's attraction for industry and economic development. Forecasts indicate vehicle-miles of travel (VMT) will increase 26 percent by the year 2000, and that 206 mi of the metro area freeway-expressway system will be congested for over 2 hr every weekday.

In the face of this deteriorating traffic situation, it is becoming increasingly clear that new and expanded new road construction alone cannot realistically be expected to solve the urban congestion problem. A major reason is cost, but money is only part of the problem. Besides the dollar costs, there are the social costs of divided neighborhoods, environmental costs, and a public mood opposed to additional freeways. Multimodal and systems management alternatives will be needed to address the congestion problem in an acceptable manner.

RURAL ACCESS

Providing improved access to rural America will also require a multimodal approach and improved intermodal connections. Air, rail, and intercity bus service to rural communities have deteriorated. As a result, rural mobility and access to urban areas have often suffered. In addition, lower-volume rural highways have faced increasing competition for highway improvement dollars from congested urban routes and rapidly developing suburban areas. Resolution of the transportation problems facing rural America will require a recognition that the problems are multimodal in nature and that solutions will demand improved multimodal planning, programming, and funding approaches.

MULTIMODAL PLANNING IN MINNESOTA

The Minnesota Department of Transportation (Mn/DOT) has been actively involved in multimodal planning for several years. The experience in Minnesota suggests that the practice of multimodal planning is most effective when the following five conditions are met:

1. Agency organizational structure and mission encourage multimodal planning and intermodal coordination,
2. Agency philosophy promotes a family of vehicles concept,
3. There is public and legislative support for multimodal transportation solutions,
4. Funding sources are available for multimodal transportation programs, and
5. Private sector initiatives emerge to identify and promote multimodal opportunities.

The presence of such conditions is helping to foster multimodal transportation opportunities in Minnesota.

Mn/DOT's Organizational Structure and Mission

Mn/DOT has established an organizational structure to manage and promote multimodal planning. The Program Management Division, under the direction of an assistant commissioner, is responsible for developing investment and management strategies to enhance the effective movement of people and goods. This structure consists of modal office directors for transit, aeronautics, highway, rail, and waterways. This arrangement promotes ongoing coordination and open discussion of individual modal issues and multimodal relationships and solutions.

The multimodal planning theme is also being incorporated into a variety of Mn/DOT planning activities, including the mission statement of the department's Strategic Plan. The introduction to this plan states the following:

> We are now entering an era where we also need to be good at managing our transportation system. In addition to planning, financing, designing, constructing and maintaining, managing will focus on operating the system. This will require increased coordination and use of all modes of transportation, thus assuring that Mn/DOT will remain a true multi-modal Department of Transportation (*3*).

Mn/DOT's Philosophy Promotes a Family of Vehicles Concept

Mn/DOT's view is that an effective solution to the nation's transportation dilemma must be based on a multimodal family of vehicles concept. The family of vehicles concept includes private automobiles, vans, buses, air, light-rail transit, super-speed train, and bicycles for moving people—and highways, air, rail, and water for moving commodities. In the Twin Cities metropolitan area, an appropriate response to address the area's needs might include highways, improved bus service, light-rail transit, and high-occupancy vehicle lanes. In rural areas, rail rehabilitation, increased highway load-carrying capacity, and transit service may best fill transportation needs.

Multimodal Transportation Activities in Urban Areas

Corridor Design Concepts Minnesota has been a pioneer in the application of multimodal and intermodal transportation system management approaches in congested urban highway corridors. In 1972, the Minnesota Department of Highways (now Mn/DOT) instituted a state-of-the-art freeway management system on I-35W through Minneapolis and its southern suburbs. Since that time, similar traffic management techniques have been applied to other portions of the metropolitan area freeway system.

Minnesota's most comprehensive approach to freeway system management is being implemented on I-394. The I-394 corridor is a radial route extending from the Minneapolis CBD to Wayzata, a distance of about 11 mi.

The I-394 transportation system design concept constitutes an intermodal approach that includes many transportation elements focused on maximizing corridor transportation efficiency and service to users. Some of the elements include the following (*4*):

- Public information programs and community-based rideshare programs and bus services;
- Five new park-and-ride lots and expansions of existing lots throughout the service area;

- Expanded bus service, focusing on a timed-transfer system concept supported by two major transit stations on I-394 and several other stations throughout the service area;
- High-occupancy vehicle (HOV) lanes and bypasses of ramp meters for buses, carpools, and vanpools;
- Adequate law enforcement to support the HOV express lanes;
- Three parking garages offering I-394 users low-cost, transit-accessible, preferential parking for carpools and vanpools;
- Pedestrian skyways connecting the parking garages to downtown Minneapolis employment centers; and
- Work-end public information programs, employer-based rideshare programs, and bus services.

Based on travel forecasts, Mn/DOT expects that the I-394 corridor facility will provide the following benefits when completed:

- Provide a reasonable level of service for the 187,000 person-trips per day estimated for the year 2000,
- Reduce peak-hour congestion by achieving a long-term automobile occupancy goal of 1.6 persons per vehicle,
- Provide improved bus service to effectively serve the projected 14,000 daily riders on I-394,
- Save HOV users traveling the 11-mi trip from Wayzata to downtown Minneapolis an average of 11 min in the peak period,
- Save single-occupant drivers traveling from Wayzata to downtown Minneapolis an average of 5 min in the peak period,
- Save I-394 HOV users \$3 to \$4 per day in parking costs in addition to savings in automobile operating and maintenance costs, and
- Reduce the accident rate by 70 percent.

The I-394 HOV lane and related efforts clearly demonstrate the potential that comprehensive, multimodal, and intermodal approaches hold for relieving congestion and improving transportation efficiency in a major metropolitan area.

Light Rail Transit A variety of approaches will be necessary to solve urban congestion problems. In the Twin Cities, light-rail transit (LRT) can play an important role in providing additional capacity in high-density traffic corridors. LRT is being developed through a partnership among the seven urban counties, the Regional Transit Board, and the state Mn/DOT. Using local taxing authority, the counties have contributed approximately \$20 million to date. The state, since 1988, has contributed over \$10 million for an LRT grant program. The program is being administered by Mn/DOT, and provides funding for LRT planning, preliminary engineering, design, and construction.

The legislation, creating the state grant program, states that (a) regional railroad authorities in the metropolitan area are eligible to receive the funds, (b) the funds must be matched on a dollar-for-dollar basis, and (c) no regional railroad authority can receive more than 60 percent of the funds.

Mn/DOT has established the following categories for allocating LRT funds: (a) design and construction of LRT, (b) preliminary engineering, and (c) comprehensive planning.

More detailed application guidelines spell out the requirements for the three funding categories. Although requirements for a comprehensive plan are extensive, Mn/DOT permits a staged planning effort so counties and corridors not being considered for immediate LRT implementation may still receive funding.

Oversight for Twin Cities area transit is provided by the Regional Transit Board. The Regional Transit Board developed and approved the final metropolitan area light-rail plan February 15, 1990. The \$400 million (1991 estimated cost) first stage includes a line between downtown Minneapolis and downtown St. Paul, yards, shops, and a tunnel up to 2.2 mi in length in downtown Minneapolis.

The Regional Transit Board is considering the feasibility of a 1 percent metropolitan area sales tax to finance the first stage of light-rail transit development. Current proposals suggest that the revenues from the 1 percent regional sales tax could potentially be shared with highway, other transit, and regional trail needs. Metropolitan area counties are to help pay for lines built after the first stage is completed. The 1991 capital cost estimates for a maximum 10-year LRT plan are projected to be approximately \$1.6 billion.

Super-Speed Train Service Super-speed train service offers great promise for relieving airport congestion and increasing intercity transportation efficiency in crowded corridors. Super-speed trains, including both steel wheel and magnetic levitation vehicles, are in the planning stages or operating in at least 17 countries around the world.

There is increasing interest in super-speed trains in the United States. Several states including Florida, Ohio, California, and Nevada have been investigating high-speed rail. Recently, the states of Minnesota, Wisconsin, and Illinois have agreed to conduct a preliminary feasibility study of super-speed train service linking the Twin Cities, Milwaukee, and Chicago. The purpose of the study is to determine whether there is sufficient public interest in using such a super-speed train service.

The \$300,000 feasibility study will explore all super-speed train technologies (including magnetic levitation), their costs, potential route corridors, and ridership. A proposed super-speed train system would likely require private financing.

Multimodal Transportation Activities in Rural Areas

A multimodal approach is needed to properly address rural Minnesota's transportation needs. These needs include the following:

- The capacity to attract economic development and employment;
- Efficient commodity movements;
- Improved transportation, especially for the transit dependent;
- Improved intermodal connections and transfer facilities; and
- Enhanced accessibility to recreational areas.

In order to address these issues, Mn/DOT has extended its multimodal transportation improvement efforts into the small urban and rural areas of the state. Many of these areas suffer from a lack of adequate transportation services. The solutions involve highways, public transportation, rail, and air service.

Rail Service Improvement Program The Minnesota Rail Service Improvement Program began in 1976 with the creation of the Minnesota Department of Transportation. The program is designed to improve rail service by combining state revolving loan funds with rail user and private railroad funds for rail line rehabilitation and other rail service improvement projects (*5*).

Minnesota's Rail Service Improvement Program has been a real success story. The program, which requires local shippers and railroad participation in rail revitalization efforts, is an outstanding example of state-local and public-private cooperation. Without the program, many rail lines that are now viable operations would have been lost. The result would have been higher overall shipping costs, additional damage to the state's highways as a result of increased truck traffic, and a negative impact on the rural economy.

Freight Access Improvement Program In addition to the Minnesota Rail Service Improvement Program, Mn/DOT has developed a public-private approach to roadway improvement financing in rural areas known as the Minnesota Freight Access Improvement Program. This program is especially useful in instances in which it is not financially feasible to preserve rail freight service and yet the need for efficient commodity movement exists. The program involves a three-way match of state funds with local private funds and local road authority funds. The focus of the program is on improvement of local access roads or connectors to enable them to serve as connectors from businesses and communities to the 10-ton road system.

PUBLIC AND LEGISLATIVE SUPPORT FOR MULTIMODAL TRANSPORTATION SOLUTIONS

Public and legislative acceptance and support are critical to the successful implementation of multimodal transportation initiatives. In Minnesota, a number of activities have occurred to promote broader levels of support and heightened awareness of multimodal planning. A good example occurred in 1989, when a long-standing highway interest group, Minnesota Good Roads, Inc., announced that it would change its name to the Minnesota Transportation Alliance. This change served as a visible sign of the group's broadened awareness and interest in dealing with overall surface transportation problems and issues in Minnesota, not just those related to highways.

A second example of the increased emphasis on multimodal planning is evident in the charge and research agenda of the legislatively created Transportation Study Board. This board was given the assignment to conduct a study of Minnesota's total surface transportation needs into the 21st century. The board will recommend a program for making multimodal transportation improvements to meet needs in the years ahead.

MULTIMODAL FINANCING ALTERNATIVES

A variety of transportation financing alternatives must be available to meet the transportation investment needs of the 1990s. A family of financing alternatives concept will be needed similar to the family of vehicles concept. The family of financing alternatives might include private contributions, tax increment financing, impact fees, and toll roads. In addition, the use of traditional transportation revenue sources must be expanded to provide for multimodal programs.

In Minnesota, a new approach in user fee concepts was instituted in 1981 when legislation was passed to permit the phased transfer of motor vehicle excise tax revenues from the state general fund to a state transportation fund (*6*). Under the provisions of this legislation, 75 percent of motor vehicle excise taxes are allocated to highway (shared by state, counties, and cities) and 25 percent of revenues are directed to a state transit assistance fund. Eighty percent of the transit portion of motor vehicle excise tax revenues supports transit systems in the Minneapolis–St. Paul metropolitan area and 20 percent supports transit systems in other areas of the state.

The phased transfer of motor vehicle excise tax revenues for multiple transportation uses represents a significant step in addressing overall mobility needs in Minnesota. The transfer accomplishes the following:

- Supplements existing highway revenues to meet needs of the state, counties, and cities;
- Provides an inflation-sensitive revenue source for highway improvements;
- Reduces dependence on bonding to finance highway projects;
- Provides a stable source of revenue for state assisted transit services, replacing biennial general fund appropriations;
- Permits the expansion of transit program services to meet future needs; and
- Provides a potential source of revenue to support other transportation programs such as rail rehabilitation and light-rail transit development.

The sharing of motor vehicle excise tax revenues between the highway and transit modes represents a breakthrough in terms of intermodal cooperation and revenue sharing. Without consensus building among urban and rural interests and highway and transit proponents, the legislation for transferring motor vehicle excise taxes from the general fund to transportation would not have been passed. It is this consensus building and cooperation among diverse interests that offers the hope and promise of additional multimodal funding approaches as future needs arise.

In addition to motor vehicle excise taxes, Mn/DOT rail service improvement funds also support multimodal planning objectives. For example, when a rail line is abandoned, Mn/DOT, or any established regional rail authority, may use rail service improvement funds to purchase all or part of the right of way through the state's rail banking program. The rail banking program permits these acquisitions conditioned on future use of the right-of-way for transportation purposes. Transportation use may include highways, bikeways, light-rail transit, and pipelines. Rail service improvement funds are also being used to finance the super-speed train feasibility study.

PRIVATE SECTOR INVOLVEMENT IN MULTIMODAL PLANNING

Multimodal planning is most effective when it results in more efficient transportation service. The private sector, rather than government, is most often in a position to recognize how optimal modal choices and intermodal connections can enhance efficiency and reduce transportation costs. For this reason, the continued success of multimodal planning initiatives will be highly dependent on the private sector's ability to serve as a catalyst for identifying and promoting multimodal opportunities. A breakthrough concept in private sector involvement in multimodal planning and intermodal coordination is underway in Europe. Lufthansa provides tickets that combine flying by air and "flying by rail." Passengers purchase one ticket that allows them to move from their origin to their destination by a combination of air and high-speed rail. This is an example of the kind of change that will be needed to make the United States a world class competitor in transportation in the 1990s and beyond.

In Minnesota public and private groups, local businesses, citizen groups, and city, county, and state governments are forming partnerships to make needed transportation improvements (*7*). The business community has been an important factor in transportation decision-making for many years. Industry leaders and business interests have often been the major impetus for transportation improvements. They have also played a leading role in developing strong coalitions supporting legislative programs to provide transportation funding. In the Twin Cities metropolitan area, the Improve 494 Association has been created by private business representatives along the Interstate 494 beltway. The Improve 494 Association has conducted a travel behavior survey and contributed $90,000 to the preparation of an environmental impact statement to review multimodal and intermodal improvement alternatives. The groundwork for a similar association is also being laid in the city of Minneapolis, where business leaders are interested in multimodal and intermodal solutions to downtown congestion problems.

FUTURE DIRECTIONS

Federal and state governments are increasingly recognizing the importance of multimodal transportation policy development, planning, programming, and funding.

Federal transportation policy, *Moving America: New Directions, New Opportunities*, states "program must allow for a broad range of options, permitting investment in cost-effective projects that enhance capacity or make better use of existing resources, such as high occupancy vehicle lanes for carpools and buses. . . . Smooth, efficient travel depends on good connections between different parts of the transportation system." AASHTO recommendations on the new national transportation policy include the following:

- Categorical highway and transit programs, and
- Flexible grant program including both highways and public transit.

In addition, AASHTO supports 20 percent state flexibility for shifting funds between the flexible and categorical programs, further increasing the potential for multimodal program and project funding.

At the state level, last January, the nine-member Advisory Committee For Alternative Transportation Financing recommended the use of new, alternative funding methods in Minnesota to address the serious problem of infrastructure needs. A number of the financing alternatives recommended by the committee offer promise of providing funding for multimodal and intermodal facilities both in the Twin Cities metropolitan area and statewide.

CONCLUSION

Worldwide economic competition, the costs of new improvements and increasing travel emphasize the need for more efficient and cost-effective transportation services to address the nation's needs. Experience in Minnesota suggests that these challenges can best be met when transportation agency funding philosophies, sources, public, legislative, and business interests support multimodal transportation alternatives and intermodal connections. Further development of the mechanisms, associations, and partnerships that foster and encourage multimodal planning can be expected in the years ahead.

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Minnesota Department of Transportation in the Marketplace

Bob Wolfe and Mark Anderson

All of the ingredients of modern commerce are present in the operations of the Minnesota Department of Transportation (Mn/DOT). Some marketing already takes place within Mn/DOT and should be expanded to provide even better products and services. Over the years, the concept of marketing has evolved from one of sales to an entire range of product conception, product development, delivery systems, market analysis, advertising, education, sales, service, etc. Mn/DOT operates in this same competitive environment and competes for the same resources. Indeed, it competes in the marketplace of government services and in the overall marketplace. It has become more customer oriented, beginning with the extensive public involvement in the project development process that started in the 1970s. In addition, interaction with customers in nearly all areas of Mn/DOT is increasing. Mn/DOT is trying to apply modern marketing techniques to all of its operations.

Following the end of World War II, transportation improvements were eagerly sought across the United States. New highway and airport design technologies had been accelerated out of necessity and the public was ready to apply them.

Programs such as the Interstate Defense Highway Network required strong direction and immediate results. Transportation agencies were organized with a top-down management style and adequate resources were made available to do the job. The military management style was commonplace and was, for the most part, acceptable to the citizens who wanted the much-needed improvements.

The post-war country began to change in the 1960s and the change has continued to this day. Words like Viet Nam, Proposition 13, Watergate, global economics, and workforce diversity have come to represent our growing awareness that there are many sides to issues, that there are many different priorities and that what may be good for one group of people may not be so good for others. This diversity has forever changed the traditional bureaucratic management style of government when dealing with clients.

The Northwest District of the Minnesota Department of Transportation recognized the need to change nearly 16 years ago. Initially, a new vision was created that identified the "real bosses" as being transportation clients (timber producers, tourists, sugar beet farmers, etc.) rather than the internal Mn/DOT hierarchy.

The traditional government attitude of take it or leave it and the regulatory approach to clients was replaced with "finding a way to say yes" to clients.

Northwest District, Minnesota Department of Transportation, Transportation Building, John Ireland Boulevard, St. Paul, Minn. 55155.

NORTHWEST DISTRICT PUBLIC CONTACT PROGRAM

The first formal step in the marketing of transportation services was to establish a means of finding out what the clients wanted. A public contact program was developed that included 15 areas of emphasis, ranging from visiting schools and colleges to formal meetings with timber and agriculture association board members.

District staff people were assigned regular public contact responsibilities in all cities, counties, and township associations in the district. These were regular work assignments. Feedback was provided on a simple speed message format that was shared with appropriate staff people for follow-up action.

A couple of interesting things were noticed:

1. Mn/DOT did not fully understand the business and social needs of its northwestern Minnesota clients.
2. Clients generally knew little of the bureaucratic process or the resources available through Mn/DOT.

In other words, Mn/DOT and its clients did not understand each other's business.

It was obvious that this public contact program would have to have two primary objectives:

1. Help Mn/DOT staff to understand the business objectives and needs of external clients.
2. Educate transportation clients about the Mn/DOT programming process and other related services.

Nearly 45 district staff people have been actively working in this process of mutual education. Regular, ongoing contacts with local governments, industries, farm groups, tourism groups, small business owners, schools, and other client groups have established a solid base of information that helps set priorities for investing transportation resources. Consequently, road improvement and highway maintenance activities are geared toward helping clients compete successfully and yet maintain the quality of life so important to rural people.

This contact program was first described as the preconditioning of clients to a process of marketing government services. This would help Mn/DOT meet the priorities and needs of clients.

After several years of mutual preconditioning, it became apparent that the ingredients of success were beginning to follow a pattern similar to time-tested marketing concepts long used by private enterprise. Rather than merely emphasizing the need for government services (convincing people why more public funds are needed), an entire concept of marketing evolved that included product conception, product development, delivery systems, market analysis, advertising, education, sales, service, etc.

All of these elements are important ingredients if a firm (or government agency) is to sell its products (services) in an increasingly competitive and perceptive marketplace. Northwest District staff have become client oriented as a result of these marketing practices. Its clients seem to have embraced the idea and have invited Mn/DOT contractors to be active participants in their business activities. It is now common practice for Mn/DOT staff people to be considered as technical representatives for industry groups and community partners for local governments and special service groups. A visible measure of product success is the tremendous support that Northwest Minnesota gives to new funding of transportation programs.

MARKETING GOVERNMENT SERVICES

In the previous section, the marketing process that intuitively evolved in the Northwest District Public Contact Program was discussed. From some of the current literature on marketing, it was obvious that the client-oriented approach paralleled the customer service–oriented approach to marketing in the private sector.

Successful firms in the private sector learned that pushing goods onto the market was not as effective as learning to satisfy customers. At Mn/DOT, it was learned that it was better to learn about the wants and needs of the clients before going ahead with a transportation project. Successful private companies have also learned to guide their total effort by what their customers want. At Mn/DOT, it was learned that it was best to view the agency as part of the various industries and businesses of the clients and let their needs guide the efforts.

Figure 1 shows a graphic representation of a government service marketing exchange process. It is a modification of a common representation of the exchange process and demonstrates the need for mutual education and the required interdependence of the Marketer (government agency) and the Consumer (road user) if wants or needs are to be satisfied. If each part of the graphic is equally important, the exchange process is likely to be successful.

This process has applications in transportation both at the microscopic level (of specific projects or services) and at the macroscopic level (regional or industry transportation needs.)

Mn/DOT SIX-STEP MARKETING PROCESS

Since the Northwest District began a strong customer-oriented management style in 1974, six key steps seemed to be prevalent in instances where the greatest client satisfaction was achieved. They are as follows:

1. Establish your objective or mission,
2. Identify your customers,
3. Conduct a mutual education or information exchange,
4. Identify wants and needs,
5. Formulate strategy to satisfy wants and needs, and
6. Implement the strategy.

This basic marketing process was taught in a training class at an Mn/DOT Leadership Academy held in St. Cloud on Jan-

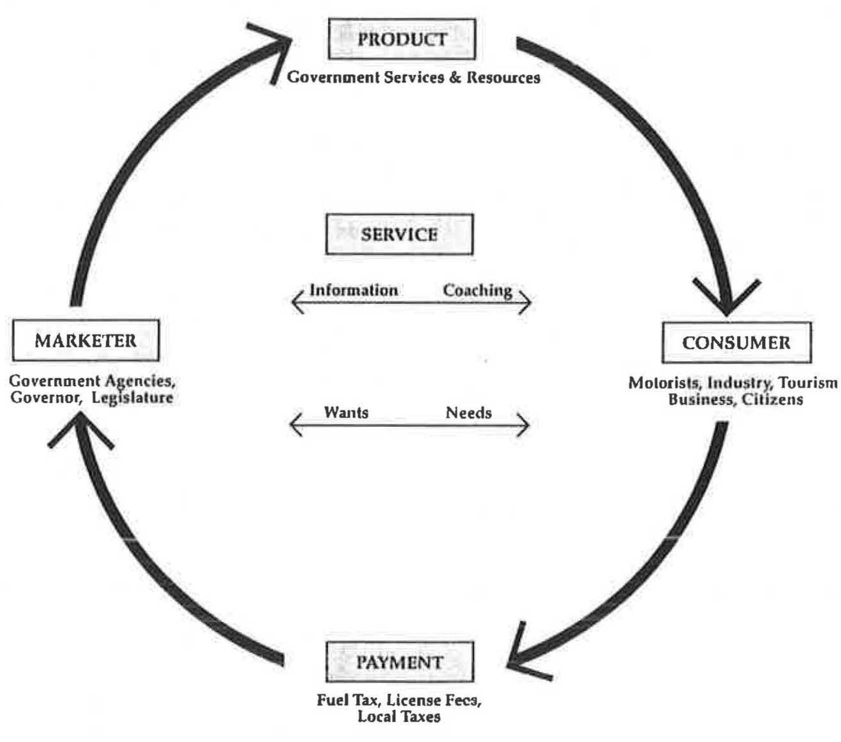

FIGURE 1 The marketing exchange process.

uary 25, 1990. Attendees included supervisors and engineers from the Willmar and Brainerd districts, representing administration, engineering services, and maintenance operations.

One of the up-front costs for the class participants was the requirement to prepare a formal report of the class project. The project involved developing a marketing strategy for the development of a transportation corridor for the Paul Bunyan Expressway (four-lane roadway on TH 371 from Little Falls to Bemidji) and the Western Gateway (four-lane roadway on TH 12 from Wayzata to Willmar).

The class was divided into six teams with three working on each of the two projects. Their products for each of the six marketing steps are summarized to provide some real examples of how the process can work.

1. Establish Your Objective or Mission. This step is critical as it sets the initial direction for the marketing effort. All too often, government agencies come up with the answer before the mutually agreed-on objective is clearly thought out. In reality, there isn't any right or wrong answer but rather an agreed-on objective that may well change after the marketing team gets deeper into the process. This is the time to challenge the traditional approach and let the creative juices flow. The objective above all is satisfying the wants and needs of the real bosses—the customer.

The Leadership Academy class participants generally established objectives or missions that "supported the economy along the two corridors and provided better access to rural Minnesota." Other objectives referred to intermodal coordination, futuristic transportation services (high-speed train), and balance of environmental and economic concerns. The interaction of maintenance, administration, and engineering people was really interesting, demonstrating the potential for broader objective setting.

2. Identify Your Customers. All too often, the government agency response will be focused on single client needs. Today's competition for scarce tax dollars and the necessity to maximize investments as we compete globally, requires contact with a broad range of clients. Partnerships can often be formed that add strength to the marketing effort while dealing with individual customer needs.

The Leadership Academy class identified both broad client groups (truckers, tourists, communities, trunk highway associations) and very specific clients (turkey growers, specific businesses, hospitals, cities, counties).

3. Mutual Education or Information Exchange. Some initial criteria, necessary to achieve the goal of mutual (agency and client) education and information exchange, include the following: (a) be open minded; (b) keep all customer groups informed; (c) identify a central "push group" to overcome barriers, provide energy, and coordinate direction; and (d) look at the history of related projects.

Mechanisms that can be used are public contact programs (with feedback documents); surveys; informal public listening forums; attendance at township, city, and county meetings to inform and learn; and service as technical representatives to industry, business, farm, tourism, and other client groups.

The Leadership Academy class identified the TH 12 Task Force and the Paul Bunyan Expressway Committee as the major contact groups. They also focused on the importance of using the exchange process with legislators, local officials, Central Office support staff, and local citizens (relationship of transportation to overall socioeconomic and environmental concerns).

4. Identify Wants and Needs. For years, the Northwest District has relied on a strong partnership with its clients to identify priority construction projects and appropriate service levels. Timber producers have assembled a composite list of projects that covers the four northern Mn/DOT districts. Farm groups have consolidated their needs and wishes through the Northwest Regional Development Commission. A key to this process is the understanding by all client groups of the formal Mn/DOT programming method that ensures realistic priority setting.

The Leadership Academy class list of needs generally focused on economic development, safety, efficient travel and reduced travel between the metropolitan area and the Willmar and Lakes and Pines areas.

5. Formulate Strategy To Satisfy Wants and Needs. A key step is the development of a blueprint to focus all parties (government and client groups) on the marketing process. Information flow is critical with the key "push group" being responsible to keep effort high, recognizing the ever-present barrier of resistance to change.

A good inventory of related factors such as in-place facilities, funding sources, policy, key players, applicable research data, and existing regional business objectives is a good start. Milestone dates then need to be set up to establish a good foundation of support. Subsequent project-related activities must be targeted at the planned objective.

One of the St. Cloud training groups identified specific activities for its corridor concept such as hiring consultants, public meetings, district coordination, client support, media activities, and proposing special funding packages for decongesting the metropolitan region. Other ideas included risk management practices, priority setting, special statewide conferences on rural and metropolitan economic linkages, and policy changes.

6. Implement the Strategy. There is always the danger of simply "studying an issue to death." This last step, although short and simple, is the area that requires the most energy. It is simply going out and doing it.

EXAMPLES

The Northwest District of Mn/DOT has enjoyed excellent client support, much of which can be attributed to the homespun marketing techniques that have evolved over the past 10 to 15 years. The following specific success stories are given to encourage other government people to try out some marketing.

Timber Producers

Technical classes on highway design, road strength, spring road strength recovery, effect of heavy loads on road fatigue, and highway programming have been taught at annual and special meetings of the Minnesota Timber Producers Association.

Resulting products include a $125 million construction program aimed at high-priority timber routes in three districts, recently passed legislation that increases the gross weight from 80,000 to 82,000 lb for tree-length truck movement (which reduces the number of violations and ensures less road damage), better information flow on spring road restriction postings, and mutual information flow that ties the importance of forest products to all parts of the state (70 percent of the jobs are located in the metropolitan area).

This recognition of the metropolitan rural connection has resulted in a portion of the Mn/DOT program being set aside for low-volume route construction projects. Traditionally, these projects never compete with higher-volume roads. In 1992, the first project will be under contract—TH 6 from Deer River to 11 mi north.

Sugar Beet Growers

This industry moves over 5 million tons of beets to their factories every fall. It is the major cash crop in the Red River Valley. Barriers to success were safety (mud on the road and unskilled truck drivers), lack of 10-ton roads, and poor coordination with Minnesota and North Dakota law enforcement and road officials (both country and state).

Regular annual meetings with all parties are routinely held each September to reestablish lines of communication. Road projects are now scheduled to reduce interference to the massive beet haul, local farmers have installed scrapers on their trucks to remove mud from between dual tires, truck weights have been kept within reasonable limits, road projects have been scheduled to enable 10-ton axle weights and a 10 percent overweight special transportation permit was developed to help move beets faster from the field to the piling sties.

Also turn lanes were installed to permit cleaner, safer access to roads; a truck driver safety practices film was produced, cosponsored by the Red River Valley Growers Association and the two states; and a clear line of communication was organized that puts local plant site managers in touch with key law enforcement people and road personnel during the harvest.

Paul Bunyan Expressway

One of the basic needs of the Lakes and Pines area of northern Minnesota is to have convenient access to the St. Paul—Minneapolis and Winnipeg metropolitan areas. Tourism, timber product movement, and industrial development are the needs and wants. The Northwest District implemented a marketing approach that started locally with Bemidji City business people and local government officials. A four-lane roadway from Bemidji to Little Falls was the goal.

Newspaper articles were generated in local newspapers in the Brainerd area where there were objections to a bypass on the west side of town. Fearing the loss of business, this concept (the centerpiece and highest priority of a Paul Bunyan Expressway) had been aggressively resisted in the past. The marketing strategy was to point out the economic advantages and to assign a local folklore label (Paul Bunyan) that would be catchy. Many meetings, working with client groups, and cooperation from the Commissioner's office, led to the agreement for a bypass. Two other four-lane segments from Bemidji to Cass Lake were programmed for the period 1993 to 1995.

YET TO DO

There is a need for Minnesota to recognize its strengths and weaknesses and to take whatever steps are necessary to compete economically in this fast-changing world. Minnesota must be treated like a large corporation that uses all of the modern business techniques available. It must set basic business objectives both for government and for industry that will best position it to compete globally while maintaining the good quality of life so important to all Minnesotans.

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Defining Telecommuting

Patricia Lyon Mokhtarian

Both as a business response to internal business problems, and as a transportation demand management strategy, telecommuting is gaining acceptance in the United States and elsewhere. Yet there is no consensus on what actually does and does not constitute telecommuting. This paper first indicates why approaching such a consensus is important. It then discusses the definition of telecommuting in two different contexts. In the first context, telecommuting is considered in general, in the context of a variety of other remote work options. Each of the remote work options is classified according to its transportation impacts and its managerial implications. In the second context, the efforts of one group to define non-home-based telecommuting in the specific context of an air quality regulation designed to reduce travel are documented.

Telecommuting is often defined as the use of telecommunications technology to partially or completely replace the commute to and from work (*1*). Both as a business response to internal business problems, and as a transportation demand management (TDM) strategy, telecommuting is gaining acceptance in the United States and abroad. In the United States alone, the federal government (*2*) and the states of California (*3,4*), Hawaii (*5,6*), Washington (*7,8*), Arizona, Virginia (*9,10*), Florida (State Employee Telecommuting Act), Minnesota, and Connecticut (Public Act 90-219) are in various stages of institutionalizing, implementing, or planning telecommuting programs. Numerous other programs are developing that involve local governments or the private sector.

Particularly in California, telecommuting has become an important element of transportation and air quality planning. Telecommuting as a transportation strategy has found its way into several major public policy documents, including the 1989 Air Quality Management Plan for the South Coast (California) Air Basin (*11*), Regulation XV of the South Coast Air Quality Management District (AQMD) (*12*), and the Statement of National Transportation Policy (*13*).

However, despite its increasing popularity, there are about as many definitions of telecommuting as there are settings in which it is being practiced or considered. Not surprisingly, not all definitions are consistent. Consider the following examples:

1. The term "telecommuting" is often used interchangeably with "working from home." Yet there are several varieties of working from home, including home-based businesses and overtime work, that are not commonly considered telecommuting. Telecommuting need not be home based; in fact, some experts feel that the satellite or local work center variations of telecommuting will eventually become the most popular forms (*14*).

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2. Telecommuting is sometimes equated with teleworking—the use of telecommunications-related technology to conduct work (*15*). Not all teleworking is like teleconferencing, which replaces a commute trip. In fact, teleworking may or may not replace travel at all (*16,17*).
3. Initially, telecommuting was thought of as being full time. Many commonly cited drawbacks of telecommuting (e.g., worker isolation) apply most forcefully to the full-time work-at-home version, and little or not at all to other forms of telecommuting. These drawbacks are still being raised as serious obstacles, even though it is widely conceded that full-time work-at-home will ultimately be the least-adopted form of telecommuting.

In some settings, telecommuting is still being defined in terms of how often it takes place. One program specifies telecommuting to be "working a day or two a week from a home or satellite office . . ." (*7*). On the other hand, proposed California legislation (State Assembly Bill 374) would provide tax credit to employers implementing telecommuting programs, provided participants telecommute 3 days or more per week. (The legislation in question has been tabled until the next session, but meanwhile, amendments are being discussed that could provide reduced credit when employees telecommute 2 days a week).

4. Early discussions typically assumed that computers were essential to telecommuting, and that telecommuters were of necessity at least "information workers," if not actually computer programmers and the like. It is now more generally accepted that non-computer-based work (requiring skills of e.g., reading, writing, thinking, talking on the phone) can also qualify as telecommuting. Although the information worker stereotype may persist, in reality many employees who would not be classified as information workers still deal with information (reading, paperwork) to such an extent that they can telecommute at least part time.

In some cases, the variations in definitions are caused by a deliberate choice to emphasize particular aspects of telecommuting or to relate telecommuting to other forms of working. More fundamentally, however, there is not a complete consensus on what does and does not constitute telecommuting. The multiplicity of definitions has several undesirable consequences: (a) The term "telecommuting" means different things to different people, resulting in confusion and misunderstanding. Some people reject telecommuting on the basis of their erroneous or limited view of it (e.g., full-time work at home), without evaluating each different form of telecommuting on its own merits; (b) estimates of the amount of existing and projected telecommuting vary widely, often because they are based on different definitions of the term (*18, 19*), (c) the transportation impacts of other, related, work alternatives may be underestimated at best or ignored at worst, because of the attention focused on telecommuting per se; (d) the transferability to telecommuting of characteristics of other work alternatives may be overlooked; i.e., some knowledge and skills that are already commonplace for related work options may be applicable to telecommuting; (e) finally, those responsible for developing public policy designed to promote telecommuting are struggling to identify practical, monitorable criteria for deciding what constitutes telecommuting.

This paper is divided into two sections dealing with clarifying the definition of telecommuting. In the first section, a classification system for remote work forms is developed. Telecommuting is placed within this classification system and related to other form of remote work. The second section reports an attempt by a Southern California group to define non-home-based telecommuting within the context of air quality regulation. A final section makes some concluding observations.

CLASSIFICATION OF REMOTE WORK TYPES

Telecommuting Criteria

Telecommuting can be considered one type of remote work, but there are a number of others. Before discussing some of those other types, it may be necessary to define the term "remote work" in this context. A definition that is both broad enough and restrictive enough to be useful is difficult to craft. However, one reasonable definition of remote work might be "work done by an individual while at a different location than the persons directly supervising or paying for it."

What are some reasonable criteria for determining whether a particular remote work situation is telecommuting or not? The structure of the word itself suggests two main criteria: tele (a Greek word meaning far or distant)—is the worker physically distant from the primary worksite, i.e., the location of the supervisor? and commuting (traveling back and forth to work)—is commute travel reduced or eliminated? By these criteria, a remote work type would be considered telecommuting if it involved remote management and reduced commute travel.

It is of interest to test a variety of remote work types and related work types against these two criteria: remote management and commute reduction. The position of each type is graphically shown in Figure 1. The following discussion is based on the figure, starting in the top right area and generally moving clockwise. The classification and discussion of each work type vis-à-vis remote management focuses on its relevance to telecommuting. The discussion vis-à-vis commute reduction has points in common with an earlier discussion by Salomon (*18*).

Classification of Remote Work Types by Transportation Impacts and Managerial Proximity

At-home overtime generally does not reduce commute travel. (An exception is a case in which the employee would have to drive back to the office after dinner if it were not possible to

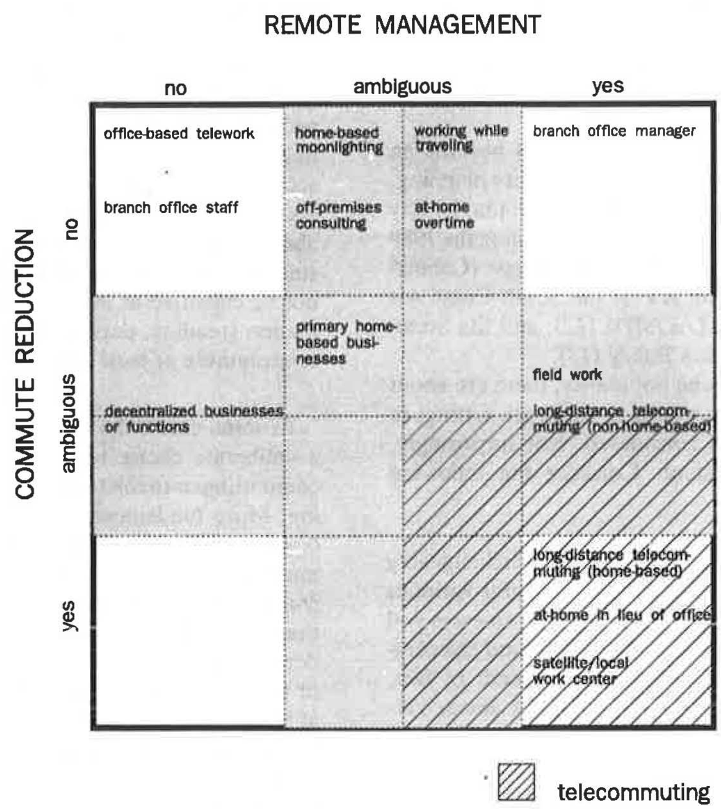

FIGURE 1 Classification of remote (and related) work types.

work from home, but this would not affect peak-period travel.) Technically, the work is being done remote from supervision, but this situation has potentially little relevance to telecommuting. Overtime work is often a short-term "crunch," with a well-defined product and deadline by which performance will be judged. With ample opportunity for on-site observation, managers are usually not reluctant to allow employees (at least, exempt employees) to work at home after they've already put in the normal time at the office.

However, there is at least one way in which at-home overtime might lead into telecommuting. Some employers have established financial incentives for their staff to buy home computers, in the expressed or implied hope that the employees will (a) learn or improve their computer skills on their own rather than the company's time and (b) be likely to put in more overtime when they can do it from home. Regardless of the ethics of that stategy, it does provide a technological base and a foot in the door as far as management policy is concerned, for eventual migration to working from home in lieu of ongoing to the office.

Like at-home overtime, working while traveling does not directly reduce commute travel. Again, it may, strictly speaking, be conducted away from a manager, but experience with it will probably not itself lead an employer to implement a telecommuting program. For one thing, those with the sophisticated tools for working while traveling (carphones, laptop computers, etc.) often are the managers rather than the rank-and-file (field and sales workers are a common exception, however; they are discussed separately later). For another thing, travel time may not be expected to be used productively. Any ability to do so may be viewed as a bonus rather than the norm, and therefore not subject to the usual management scrutiny. Such expectations may grow, however, as the tools for using that time productively become more ubiquitous.

The branch office manager does make a conventional commute trip. It might be argued that the commute is reduced if the branch office is closer to home than the headquarters office, but (a) that is by no means certain to be the case, and (b) it would be valid only if the branch manager actually has the option of working at either place and simply chooses the one with the shorter commute—an unlikely situation.

Supervision of the branch office manager takes place remotely. This type of remote work has some management parallels to telecommuting. Presumably, the office manager and the supervisor set objectives, criteria, deliverables, and deadlines for the work to be accomplished by the branch office, and the office manager's performance is evaluated on how well those objectives are met. Presumably, too, frequent communication takes place between the branch and the headquarters, with performance feedback requested and supplied as needed. These activities are characteristic of well-run telecommuting programs as well.

Field and sales work may or may not involve a reduced commute, depending on whether the trip to and from home is directly from and to a field site or the central office. In many if not most situations, the field worker is still required to report to a central site—to be dispatched, to complete paperwork, to make phone calls, or simply for one's presence to be recorded—before and after the workday. However, some employers are realizing the absurdity of requiring a field worker to drive into the office for a "telephone hour." Los Angeles County's telecommuting program, for example, involves a variety of field workers, including audit staff, welfare fraud investigators, health services inspectors, probation officers, and social service workers (*20*). These types of occupations are not generally classified as information work.

Field work certainly does involve remote management. Performance criteria for many field work jobs are easily quantifiable (number of service calls made, dollar value of sales generated, number of data records gathered), and therefore managing field work is not comparable to managing an information worker whose performance is more subjectively measured. Without disputing that, some parallels to telecommuting can be observed. The element of trust is involved in both cases. The manager often has no guarantee, for example, that the field worker isn't finishing the quota in 6 hr instead of 8 hr, and idling away the other 2 hr, instead of increasing productivity. Trust may be required in other areas, too, such as the legitimacy of all the contacts reported, or of expense account claims. Ultimately, then, the field work manager must make some subjective assessments of merit just as the manager of a telecommuter does.

Long-distance telecommuting, when it is home based, eliminates the commute trip. For long-distance telecommuting based in a local office, it is debatable whether the commute is reduced or not. It could depend on whether the office is a nearby telecommuting center or a highrise in the central business district. It could also depend on the likelihood that a different work arrangement would result in a longer commute. In terms of management, long-distance telecommuting is much like regular local telecommuting. Importantly, though, long-distance telecommuting is likely to be full time, whereas local telecommuting arrangements often involve spending 1 day or more per week in the primary office. In this respect, the long-distance telecommuter more closely resembles the branch office manager than the local telecommuter.

The salaried employee working at home instead of in the office usually meets the telecommuting criteria. However, there are two types of marginal areas: one relating to commute reduction and the other to remote management. The first potential exception occurs when the alternative to working at home is not working at all, rather than working in a conventional office. This exception may be the case for mobility-limited segments of the population such as the disabled, the single parent, and the prison inmate. In these situations, commute travel is not reduced.

Second, some classes of salaried workers do not have supervisors in the usual sense of the word: university professors, top executives of firms or public agencies, the President of the United States, and so on. Whether or not one refers to work at home by these kinds of people as telecommuting, their ability to work at home is unlikely to influence employers to allow it for their less-privileged types of employees. In each of these special cases, however, as with regular telecommuters, the worker is ultimately judged on results, rather than on appearances, time spent in the office, or other superficial measures.

The salaried employee working at a satellite or local center nearer to home than the primary office also fulfills the two telecommuting criteria, assuming the kinds of conditions described in the following section are met. These two categories—salaried employees working at home or at a center near home—are considered as traditional forms of telecommuting.

Because they do not involve management from afar, several work types are not classified as remote but are related to other remote work forms. Branch office staff, as mentioned earlier, are supervised on site. Commute reduction cannot be said to occur, except in the relatively rare cases in which employees are given a choice of working at the branch office closest to their homes.

A related situation is that of decentralization of an entire business or of a functional unit (e.g., personnel or data processing) to an outlying area of a region. The effect on commuting is again ambiguous. If the new sites are chosen specifically to minimize the average commute of existing employees, then it could be viewed as reducing the commute in most cases. On the other hand, if the site is chosen for primary reasons other than minimizing commute travel, then it is likely to increase travel, at least for existing employees who have already centralized their residential locations around the previous site (*21*).

Office-based telework does not reduce commute travel, but may reduce other kinds of travel. For example, an on-site videoconferencing facility may eliminate the need for some business trips. The ability to interact with remote data bases may permit the decentralization of government services, reducing the need for members of the public to travel to a downtown civic center to access those services (*6*).

Where do home-based businesses fit in this classification system? Moonlighting typically does not reduce commute travel, because it is only a secondary job. For a primary home-based business, as for the home-based salaried worker, whether commute travel is reduced depends on whether the alternative is (a) no job, or (b) a conventional job involving a commute. In either type of home-based business, the worker is the owner-manager, so management is, technically, anything but remote. However, the home-based business owner is working remotely from the customer (the person paying for—and therefore, broadly speaking, supervising—the work). In that sense, there are some valuable parallels to telecommuting. The customer and the business owner agree on the amount and type of work to be done for the price, and on a schedule for completing the work. Then, the customer judges the final products against the agreement, rather than by ascertaining that the business owner was in the office every day from 8:00 a.m. to 5:00 p.m. Similarly, telecommuters and their managers agree on performance standards, and the work is judged on those standards rather than on physical presence at a desk.

Finally, a similar argument can be made for virtually any consulting business that is not on the client's premises. Although commute travel is typically not saved, the same aspects of remote management apply as for a home-based business.

Implications of the Classfication System

This classification system has some implications for the managerial acceptance of telecommuting, and for its usefulness as a transportation reduction measure. First, the characteristic of remote supervision is not unique to telecommuting. Similar remote management skills are required in familiar types of jobs: managers of branch office managers, supervisors of field workers, and clients of consulting firms. To the extent that this commonality is recognized, telecommuting should not appear to be a radical departure from ordinary ways of doing business. Exploiting that commonality should lead to improved remote management techniques.

Second, the characteristic of commute reduction is also not necessarily unique to telecommuting. It was suggested that several other forms of remote work could reduce commute travel, depending on the alternative. For example, to the extent that a home-based worker would otherwise be making a conventional commute, the transportation impacts of a primary home business are identical to those of full-time telecommuting. Thus, transportation planners should be interested in tracking remote work types other than telecommuting. It will not usually be practical to ascertain whether, for each individual, the alternative to the current work arrangement would in fact reduce commute travel. However, it is possible to monitor and analyze broad trends in work arrangements—such as home-based businesses, geographical or functional decentralization of businesses, and telework—for their transportation implications.

Finally, even when focusing exclusively on telecommuting, predictions of its transportation impacts will be faulty if too restrictive a definition is used. For example, it has been seen that the universe of potential telecommuters is not limited to information workers, as has been assumed in the past. Also, more commute trips may be eliminated by the large number of people who are willing to work at home 1 day per week than by the small number willing to do it full time. The transportation, energy, and air quality implications are different for non-home-based telecommuting than for the home-based form.

DEFINING NON-HOME-BASED TELECOMMUTING

Background

As mentioned earlier, it is expected that the satellite or local work center will ultimately be the most widely accepted form of telecommuting. Work centers are, initially, more difficult and perhaps more expensive to set up than home-based telecommuting programs, but they have potentially a much broader appeal. For the employer, prospective advantages of a telecommuting center over the home as a workplace include (a) a more professional image, (b) an improved ability to deal with security and confidentiality concerns, (c) an increased confidence in the telecommuter's productivity, and (d) a more conventional worker and property liability context. For the employee, prospective advantages include (a) adequate space to work, which may not be available at home; (b) minimization of family or domestic distractions, which may not be practical at home; (c) the ability to share equipment, facilities, and services too expensive to maintain in an individual home; and (d) professional and social interaction. Many personalities and jobs not well suited to working from home may quite effectively work from a center close to home. Thus, for policies intended to encourage telecommuting, the treatment of non-home-based telecommuting becomes important.

Regulation XV of the South Coast (California) AQMD is one such policy. The Introduction indicated that Regulation XV includes telecommuting among the ways an employer can reduce peak-period vehicle travel to achieve a specified average vehicle ridership (AVR) target. South Coast Air Basin firms with 100 or more employees at a single site are subject to Regulation XV—more than 8,000 employers in all. (The South Coast Air Basin includes Los Angeles, Orange, and the urbanized portions of Riverside and San Bernardino Counties).

Giving an employer AVR credit for home-based telecommuting is straightforward. However, the situation for non-home-based telecommuting is not so simple. In the first place, travel to a telecommuting center would likely involve a vehicle trip, thereby creating significant emissions [a typical 5-mi trip generates 61 percent of the hydrocarbon emissions of a typical 20-mi trip, because a high proportion of the emissions occur during the cold start, the first few minutes that the engine is running (*22*)]. In the second place, no clear guidelines have been set as to what constitutes non-home-based telecommuting. The AQMD does not want a firm to obtain commute-reduction credit by calling a conventional branch office or a decentralized function a telecommuting center, nor does it want conventional field workers classified as telecommuters.

In spring 1990, the AQMD indicated that it was considering granting only partial credit for vehicle trips to a telecommuting center. As part of its request for public comment on this proposal, the AQMD invited the Los Angeles–based Telecommuting Advisory Council (TAC) to develop recommendations on both issues: how to grant credit for non-home-based telecommuting involving a vehicle trip, and guidelines for determining what non-home-based telecommuting is.

The TAC recommendations to the AQMD fell into three main categories: changes to the AQMD definitions of telecommuting; policy statements on granting credit for vehicle trips to a telecommuting center; and guidelines or criteria for determining what a telecommuting center is (S. Yanner and E. Shirazi, letter to S. Siwek). These sets of recommendations are described in the following subsection.

Recommended Definitions

The AQMD had been defining telecommuting as "working at home or at satellite work stations using electronic or other means to communicate with the usual place of work" (*12*). The TAC proposed two changes to that definition. First, it recommended replacing the phrase "satellite work stations" with "an alternate location." Doing so would be more consistent with the nearly standard terminology that reserves the term "satellite" for the special case of a telecommuting facility occupied by a single employer. Second, it added the phrase, "instead of physically traveling to a more distant work site," to emphasize that reducing travel was essential from an air quality standpoint. Thus, the proposed definition reads: "Telecommuting is working at home or at an alternate location and communicating with the usual place of work using electronic or other means, instead of physically traveling to a more distant work site."

The AQMD had no definition specifically for non-home-based telecommuting. The TAC proposed referring to these alternate locations generically as "telecommuting centers," and provided the following definitions: "A telecommuting center is a site, other than the home, from which the employee works instead of traveling to a more distant central work location. There are several kinds of telecommuting centers: satellite work centers are facilities used for telecommuting by the employees of a single organization. The center can be office space obtained expressively for the purpose of telecommuting, or a portion of space devoted to telecommuting within a conventional branch or local office. Local or neighborhood work centers are telecommuting facilities shared by two or more employers. The center may or may not be part of space within an existing office."

Recommended Policy toward Vehicle Trips to a Telecommuting Center

In the AVR calculation for a given primary site, the TAC recommended giving full trip reduction credit for trips to a telecommuting center. The six reasons provided for this recommendation are self-explanatory:

1. When a commuter drives a short distance to rendezvous with a vanpool, carpool, or express bus, the entire trip receives full credit under Regulation XV. The trip to a telecommuting center typically is not longer than the access trip to such a rendezvous point, and the "line-haul" portion of the trip is eliminated entirely. Trips to telecommuting centers result in a greater benefit to air quality than these two-leg transit and rideshare trips.
2. Telecommuting centers substantially shorten the commute trip, resulting in a direct reduction in emissions.
3. Trips to telecommuting centers often avoid the congested urbanized corridors of the region. This procedure improves traffic flows and average travel speed, thereby indirectly reducing emissions.
4. Telecommuting centers improve the jobs and housing balance of the region, a policy that the AQMD supports.
5. The establishment of telecommuting centers is called for in the South Coast Air Quality Management Plan (*11*).
6. The AQMD is searching for every reasonable incentive for employers to reduce the peak-period commute travel of their employees. Failure to allow credit for telecommuting centers is, in fact, a disincentive to the establishment of such centers.

Recommended Guidelines for Acceptance

The TAC proposed seven guidelines for determining whether a specific situation was a telecommuting center. These guidelines were designed to assist a company wanting to claim credit for a telecommuting center, as well as AQMD staff who would evaluate the adequacy of a company's transportation demand management program. The proposed guidelines are as follows:

1. Transportation Demand Management (TDM) Programs. The operation of a firm's telecommuting center should be an integral part of a central office work site TDM program, and monitored accordingly.

2. Distance. An employee's commute to a telecommuting center should result in a reduction of the distance traveled from home to central work site.

3. Linkage to the Office. The telecommuter's job responsibilities should be a direct extension of the work normally performed at the central work site within the AQMD's jurisdiction. Results of the work at the telecommuting center should be transmitted or communicated to the central work site and integrated into the central site's work.

4. Job Mix. A telecommuting center may include selected employees from one or more business units of a company. A telecommuting center may include employees from one or multiple companies, government agencies, or business entities.

5. Employee Characteristics: Employees that work out of a telecommuting center can be full-time telecommuters who, for example, use the facilities more than half of the work week or timeframe, or part-time telecommuters who use the facilities 1 to 2 days per week, on an occasional or drop-in basis.

6. Supervisors. The full- or part-time presence of a supervisor at a telecommuting center is not a required criterion for defining a telecommuting center. A supervisor may or may not visit the employees at the telecommuting center, or may work from a telecommuting center provided that results in a reduction of the supervisor's commute.

7. Telecommuting Employee Population. As long as all other telecommuting criteria are met by a group of employees of a firm at any telecommuting center, such employees should be considered telecommuters reporting to a central worksite. A telecommuting center, regardless of the number of telecommuters, will not have a separate employee count or AVR requirement. Nontelecommuting employees that work at the same site will be subject to Regulation XV.

Discussion of the Recommended Guidelines

Telecommuting Employee Population Guideline

The seventh guideline is a policy statement reinforcing the principle that a telecommuting center should be treated differently than a conventional company facility, even if it happens to be colocated with that conventional facility. For a conventional facility, the employees are viewed as reporting to that site, and any site with more than 100 employees reporting to it is subject to Regulation XV. The AQMD had suggested that if a telecommuting center had more than 100 employees, it too should be subject to Regulation XV as a separate worksite, and should meet the AVR target at that site.

TAC members argued that, by definition, telecommuters report to a different location, and are contributing to improving the AVR at that primary site. Requiring them to do even more would be a double standard that other strategies for trip reduction do not have to meet. The issue becomes especially important when the AQMD lowers the applicability threshold to 50 or even 25 employees at a single site (as is called for by the AQMP within the next few years).

Supervisors Guideline

The sixth guideline, supervisors, requires an explanation, in view of the previous emphasis on remote management. It is intended primarily to deal with the exceptional case in which an employee and supervisor are both telecommuters, and happen to live close enough to each other to be using the same telecommuting center. Assuming the supervisor had other staff at the primary office and at other telecommuting centers, the principle of remote management would still hold.

However, some TAC subcommittee members wished to explicitly include another type of special case. They considered a situation in which a company establishes a small telemarketing unit in an outlying part of the region. They supposed that the unit is an expansion of a larger, existing telemarketing section at the primary office. Existing employees are assigned to the new unit only if they live nearby, and any new employees are drawn from the local (not regional) labor market. The company wants to have a supervisor manage the new unit, and transfers or hires someone who also lives nearby. Under the guidelines given, this unit could qualify as a telecommuting center.

However, such a situation should be classified as a form of functional decentralization rather than telecommuting. It may still be beneficial from an air quality standpoint and desirable to encourage this kind of location activity (as current air quality regulations do not)—but without the element of remote supervision, it is not telecommuting.

TDM Programs Guideline

The first criterion, TDM Programs, deliberately excludes informal or ad hoc non-home-based telecommuting from qualifying for Regulation XV credit. Consistent with AQMD's intent for other TDM stategies (including home-based telecommuting), the intent is to force an employer to (a) proactively plan to achieve transportation improvements, and (b) be public and accountable about transportation-related company policies. Thus, a side benefit of Regulation XV for telecommuting advocates is that firms are beginning to document and formalize the ad hoc telecommuting that has been there all along. However, the TDM criterion is a somewhat artificial constraint on telecommuting. Ad hoc arrangements have been, and will probably continue to be, a nonnegligible proportion of total telecommuting.

Employee Characteristics Guideline

The fifth guideline, Employee Characteristics, states that employees can telecommute from a center full or part time. There was some deliberation among the TAC subcommittee members as to whether a telecommuter should be expected to physically report to the primary office with some regularity (e.g., at least once every 2 weeks). Such a requirement would help distinguish telecommuters from branch office workers. On the other hand, mandating a physical trip to the primary office every 2 weeks would mean that at most 90 percent of the work trips could be reduced, rather than 100 percent. It seemed inappropriate for an air quality agency to impose a restriction that decreased the trip reduction that could be achieved. Thus, it was ultimately decided to leave such policies up to the individual firms involved.

Other Guidelines

The weakest of the guidelines are the third, Linkage to the Office, and fourth, Job Mix. They fail adequately to distinguish a telecommuting center from a branch office, field site, or decentralized function. In all four cases, a job could be construed to be a "direct extension of the work normally performed at the central work site," with results "transmitted or communicated to the central work site . . ." If the supervisor is off-site, it may be assumed that the facility is not a branch office or decentralized function, but it could certainly be a field location, for which the supervisor would almost always be off-site. Having an on-site supervisor may mean the location is probably not a field location, but the facility is not automatically excluded from being a telecommuting center. How, then, can telecommuting centers, branch offices, field locations, and decentralized functions be distinguished? Two additional guidelines are proposed. The first guideline helps to distinguish between telecommuting and field work and the second to differentiate a telecommuting center from a branch office or decentralized function.

1. Location Independence. Work done at a telecommuting center should be capable of being performed anywhere there are, at most, the same facilities available as in the primary office. It should not have to be performed at a specific location because of properties intrinsic to that location.

That is, telecommuting is location independent, whereas field work is by definition location dependent, that is, it must be performed at a specific location because of properties intrinsic to that location (e.g., because that's where the customer, equipment to be serviced, unit to be audited, or activity on which data are being collected is).

2. Organizational Structure. A telecommuting center is characterized by the absence of a self-contained pyramidal organizational structure. Telecommuting staff should report to off-site managers (except for the case in which both manager and staff reduce their commutes by working at the same telecommuting center), and telecommuting managers should have at least one off-site staff person reporting to them.

Thus, both branch offices and decentralized functions generally have a pyramidal structure, with a well-defined hierarchy of reporting. The structure is normally self-contained, meaning that everyone under the top person in the pyramid is on site. Employees work at that site because of their place in the organization, regardless of residential location. A telecommuting center, on the other hand, has no intrinsic organizational structure. Functional units are fragmented, and telecommuting center employees are often working for a variety of company departments (or a variety of companies), unrelated to each other. Employees work at a particular site because of residential location, regardless of their place in the organization. Figure 2 shows the distinction between conventional and telecommuting organizational structures; below, the site refers to the telecommuting center, not the primary work site.

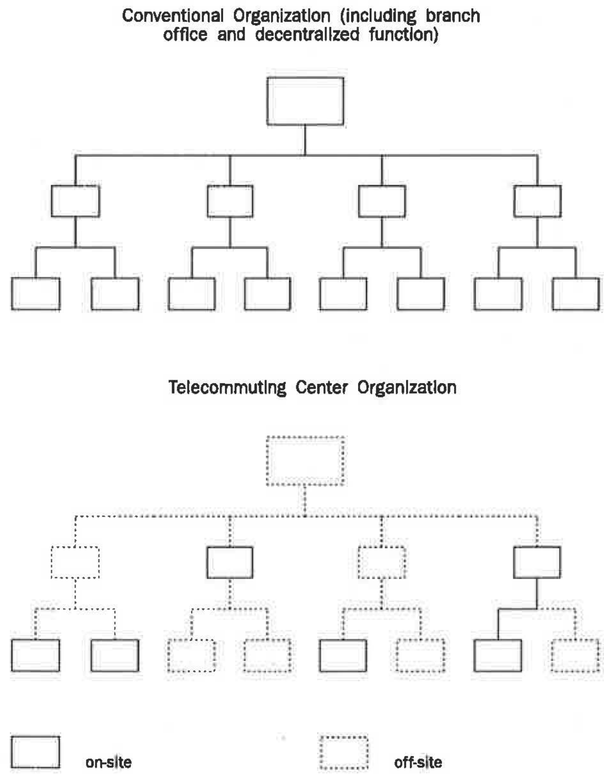

FIGURE 2 Comparison of conventional and telecommuting center organizations.

The Job Mix guideline was intended to acknowledge that difference in organizational structure as typical, but it falls short of identifying it as a distinguishing feature between telecommuting centers and other types of facilities. The specific wording was adopted as a compromise between those who wanted the case in which an on-site manager supervises a locally hired unit to qualify as telecommuting and those who did not.

Finally, it is useful to document the debate that took place surrounding the second of the seven guidelines, Distance. Early discussions centered on requiring a certain proportion of the commute trip distance to be eliminated to receive full credit for a trip to a telecommuting center. As a precedent, there has been an unwritten rule of thumb that at least 70 percent of the commute trip length must be in a bus, vanpool, or carpool to receive full credit as a ridesharing or transit trip under Regulation XV.

However, some members of the group felt that it should not be an all or nothing proposition. For long commutes, the absolute number of miles saved should be considered, even if the 70 percent (or some other arbitrary) threshold were not met. For example, suppose a worker lived at Lake Arrowhead in the San Bernardino Mountains and commuted to Fullerton in Orange County, about 80 mi away (by no means unheard of for Southern California). If a telecommuting center were established in Riverside, about halfway between Lake Arrowhead and Fullerton, the employee should get credit for eliminating the 40 mi of the commute that were most congested, even though it was only 50 percent of the total distance.

This position turned out to be controversial. Some members of the group felt that such long-distance commutes should not be encouraged at all, because they contribute to urban sprawl and to degradation of the quality of life in small resort communities. Eventually, it was decided to opt for simplicity, which led to the unelaborated concept of distance reduction quoted earlier. As a fallback option (that is, if the AQMD were unwilling to grant full credit for proportionately small distance reductions), an alternate guideline was prepared (but not presented to AQMD), that would grant partial credit for commute reductions of less than 70 percent.

Outcome of the Telecommuting Advisory Council Proposal

The AQMD has not yet issued a formal response to the TAC's proposed definitions, policy, and guidelines. There was no need for urgency, as few or no companies had claimed credit for telecommuting centers in their TDM plans. However, that is perhaps a self-perpetuating phenomenon. Companies will be reluctant to establish telecommuting centers when it is not clear how they will be treated under Regulation XV. Thus, the AQMD could have an important catalytic effect by adopting some set of guidelines and publicly supporting telecommuting centers as an appropriate element of a TDM plan.

In the meantime, the definitions and policy proposed by TAC have been formally endorsed by the Southern California Association of Governments (Executive Committee Meeting, May 3, 1990) and the Riverside County Transportation Commission (meeting, June 13, 1990).

SUMMARY

The definitions of telecommuting and its various subforms have been clarified. Telecommuting is only part of the universe of remote work types, and is often confused with other members of that universe. On the basis of the etymology of the word "telecommuting," two simple criteria were proposed for determining whether or not a form of remote work is telecommuting: (a) Is there remote supervision? and (b) Is the length of the commute trip reduced? The case is made for learning from related forms of remote work. Work forms that involve remote supervision can provide insight into the management of telecommuters (and vice versa), and work forms that involve commute reduction should not be overlooked by transportation planners.

Further, progress has been made toward a definition of non-home-based telecommuting, or telecommuting centers. The TAC proposal to the South Coast Air Quality Management District is presented as an important first step toward the acceptance of telecommuting centers as a useful strategy for reducing peak-period travel and improving air quality. Perhaps the most valuable contribution of the TAC proposal is its set of guidelines for determining what constitutes non-home-based telecommuting. The seven original guidelines (numbered 1 through 7) proposed by TAC are augmented by two other guidelines designed to help distinguish telecommunicating centers from field work sites, branch offices, and decentralized functions.

Although the process of defining telecommuting centers has started, it may not yet be complete. Definitions, policies, and guidelines may continue to be refined as additional empirical experience with telecommuting centers is gained. It is hoped that documenting the process undergone in one part of the United States will benefit other areas seeking to encourage the adoption of telecommuting as a transportation and air quality strategy.

ACKNOWLEDGMENTS

TAC was founded by the author while employed by the Southern California Association of Governments, and is currently cochaired by Elham Shirazi of Commuter Transportation Services (Los Angeles) and Margery Gould of the County of Los Angles. The Telecommuting Center Subcommittee was chaired by Sue Yanover of Pacific Bell. The roles of Sarah Siwek, Fred Ruby, and Ramam Peddada of the South Coast Air Quality Management District in encouraging the development of guidelines for the treatment of telecommuting centers is acknowledged. Finally, earlier drafts of this paper have profited from the comments of various colleagues.

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The analysis, inferences, and conclusions expressed here are those of the author, and not necessarily those of TAC or its members.

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Travel Behavior Impact of Telecommuting Following the San Francisco Earthquake: A Case Study

JOANNE H. PRATT

A severe earthquake in the San Francisco Bay area offered an unexpected opportunity to study the relation between telecommuting and travel behavior under emergency conditions. Coincidentally, the state agency with the highest participation in a state telecommuting pilot project was located in San Francisco. Interviews with pilot telecommuters, postearthquake telecommuters and managers in the Public Utilities Commission (PUC) revealed telecommuting as a flexible response to a transportation emergency that could be expanded without delay because it was a known and accepted work mode of that institution. The experience of the PUC suggests that increased telecommuting can help minimize work disruption within an organization that has previously implemented telecommuting. The number of days telecommuted was limited both by job-related factors and management policy. Although those persons already telecommuting before the emergency increased their number of telecommuting days only temporarily, if at all, new telecommuters were added, nearly half of whom were continuing to telecommute months after the emergency was over. Thus a short-term modification of behavior stimulated by emergency conditions led to long-term changes in travel behavior.

The Loma Prieta earthquake on Tuesday, October 17, 1989, provided a unique opportunity to study the travel behavior impact of telecommuting under emergency conditions. In San Francisco, Oakland, and other Bay area communities, buildings were severely damaged or destroyed, highways were structurally impaired, a freeway in Oakland collapsed, and one section of the Bay bridge collapsed. Closing of the San Fransicso Bay bridge for 1 month disrupted commuting, particularly for people living in the East Bay area and beyond. Commuting from the north and south also was slowed as many motorists from the east drove either north around the Bay, crossing into San Francisco by the Golden Gate bridge, or south, crossing the San Mateo bridge to reach peninsula highways (Figure 1).

In such a transportation crisis, a work breakdown or slowdown caused both by internal delays and interruption of delivery of goods and services from suppliers, consultants, and others on whom the primary institution depends might be expected. With a breakdown in transportation affecting commuters, increased absenteeism and tardiness would be expected. Even expanded ride sharing and mass transit use would not fully mitigate delays caused by the streets and transit system's being used to overcapacity.

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Such a transportation emergency would seem an ideal situation for an organization to implement widespread telecommuting, that is, to take commuters off the streets by allowing staff to conduct their work from offices in their homes. At the time of the earthquake, one large public institution, the California State Public Utilities Commission (PUC) had had trained telecommuters in place for about 1½ years as part of a 3-year pilot telecommuting project for state employees (*1*). The focus of this study was to probe the changes in telecommuting that took place, and why the amount of telecommuting increased, decreased, or remained the same.

Did the telecommuting patterns of the pilot telecommuters change in response to the emergency? If they were already successfully telecommuting 1 or 2 days a week, they might increase their work at home to 4 or 5 days. Did additional staff begin to telecommute and, if so, did they stop telecommuting when the Bay bridge reopened? If management favored telecommuting, the number of telecommuters would increase in response to the emergency. But would the new telecommuters be permitted to continue telecommuting once the emergency was past?

Finally, were the factors that either favored or limited telecommuting objective, that is, task-related, equipment-related, or a function of ride sharing arrangements, or were subjective factors overriding, such as employer and employee attitudes regarding the benefits or disadvantages of telecommuting?

BACKGROUND

The California Telecommuting Pilot Project, planned in 1985, was implemented beginning in mid-1987 (*2*). The author participated as a consultant. Most of the pilot telecommuters were not affected by the earthquake because they lived and worked in the Sacramento area. Of 14 participating agencies, only the PUC is located in San Francisco. Although the majority of PUC telecommuters live in the Bay area, some commute from homes located over 50 mi from their jobs (*3*). Evaluation of pilot telecommuters compared with a matched group of controls has been documented (*4*). Results of a separate, largely anecdotal, study of a sample of both PUC pilot telecommuters and PUC staff who began telecommuting in response to the emergency are described in the following sections.

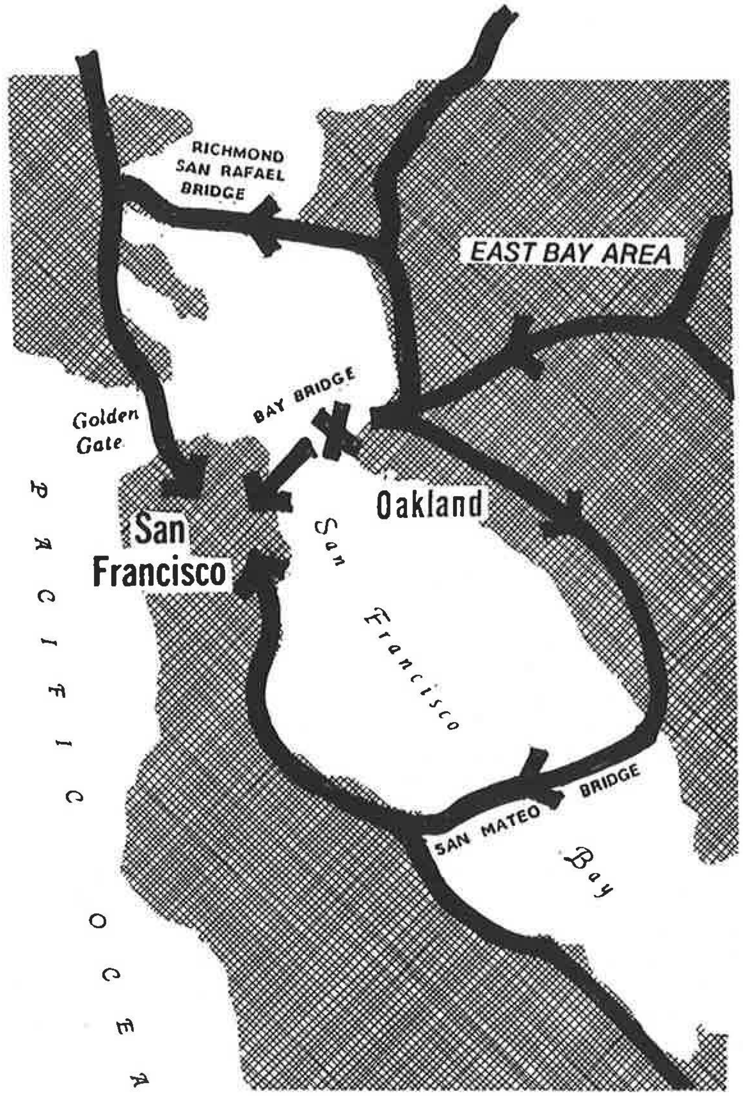

FIGURE 1 San Francisco Bay Area commuting routes.

SURVEY METHODOLOGY

Sample

A telephone survey was conducted within the PUC, which "has the largest number of participants in the State's Telecommuting Pilot of all the state agencies" (*4*). As of June 1989, the reported number of total state telecommuters was 230, with 71 working in PUC (*5*). Assuming similar participation 4 months later, at the time of the emergency, about 8 percent of the PUC Bay area staff of 880 had been telecommuting for nearly 1½ years.

Forty-five professional staff from 5 of the largest of the 10 divisions within the PUC were surveyed (Table 1) (*3*). None of those interviewed held clerical positions. The sample included 20 pilot telecommuters out of a total of 30 who began telecommuting about May 1988, one of four midpilot telecommuters who began 4 to 6 months later, and three managers who themselves telecommuted. All were scheduled for training May 19 and 20, 1988. Additionally, five chiefs or managers who did not telecommute were interviewed.

The remaining third of the sample consisted of postearthquake telecommuters who began telecommuting after the earthquake occurred. Sixteen of 33 people mentioned by coworkers or managers as having begun to telecommute after the earthquake were interviewed. One of those was a manager. Another prepared to telecommute but never actually started.

A supplementary sample of 8 pilot, 1 midpilot, and 17 postearthquake telecommuters was composed of persons on the training lists and new telecommuters who could not be reached for interviews. Information about their telecommuting was obtained from managers and coworkers who were in the survey sample.

TABLE 1 SAMPLE OF TELECOMMUTERS AND MANAGERS INTERVIEWED

Group	Pilot Telecommuters Total	Pilot Telecommuters Interview Sample	Post-Earthquake Telecommuters Total	Post-Earthquake Telecommuters Interview Sample	Non-Telecommuting Managers Interview Sample
Initial Telecommuters	30	20	32	15	
Mid-pilot Telecommuters	4	1			
Telecommuting Managers	6	3	1	1	
Non-telecommuting Managers					5
TOTALS	40	24	33	16	5

Interviews

Semistructured telephone interviews were used to elicit the rich detail of personal attitudes and perceptions about telecommuting that might not be revealed in responses to written questionnaires. In order to obtain as full a view as possible of the telecommuting experience from the interviewee's perception, questions were not held strictly to a specific wording or sequence. The interviews were begun December 18, 1989, 2 months after the earthquake (1 month after the Bay bridge reopened) and completed April 20, 1990, 6 months following the emergency. Some persons on the training lists did not actually attend the training; others could not be reached after several telephone calls. Information about some telecommuters who had been transferred or who could not be reached by phone was obtained from their managers and coworkers.

Telecommuters were questioned about their telecommuting pattern before, immediately after, and 2 to 6 months following the earthquake, their job title and branch, and where they lived. They were asked to describe their home office work place, how it was equipped and whether they had adapted it for telecommuting. Finally, they were asked whether they felt they were more productive when they worked at home and, if so, in what way.

Managers of telecommuters were asked the size of their groups, the names of their telecommuters, and if they telecommuted themselves. They were then asked to recall the memoranda or briefings they received on handling the emergency, the means they used to offer these options to their groups, and the names of those who chose telecommuting. They were questioned about their selection critieria for post-earthquake telecommuters, and any observed differences between them and pilot telecommuters. They were asked if they planned to continue telecommuting within their group indefinitely.

Managers and coworkers also were asked about other people in their groups who were telecommuting before, immediately after, and months following the earthquake. The persons named are referred to as the "supplementary sample" of 26 telecommuters.

FINDINGS

Travel Behavior before the Earthquake

Before the earthquake, the California Telecommute Pilot Project conducted an impact assessment of telecommuting on trip rates. On the basis of a sample of 66 telecommuters (representative of all pilot telecommuters including the PUC subgroup), the study found that "telecommuting indeed reduces peak-period trips while adverse impact (e.g., increase in nonwork trips) is not apparent." The decrease in daily average trip rates "shown by the telecommuter employees is almost twice that of the control group employees . . ." which confirms that "telecommuting leads to an overall reduction in trip generation" (*6*).

Although up to 3 days per week telecommuting was said to be permitted as PUC policy, there was no evidence that before the quake anyone was telecommuting more than 1 or 2 days per week. Of the interviewed sample, four never started and four stopped for equipment, job-related, or personal reasons (see Table 2). According to their coworkers, some of the pilot group who were not interviewed telecommuted only a few days, or never started, for reasons such as retirement, transfer to another branch, owning an incompatible computer, and limitation of telecommuting to the period of a maternity leave. Telecommuting days that were missed for any reason could not be rescheduled. These anecdotal findings are consistent with midterm and final reports that state participants telecommute, on the average, 1.5 to 1.6 full days at home (*4,5*).

Management Response to the Earthquake Emergency

In the chaos resulting from the quake, the San Francisco PUC headquarters building was closed and the computers were down. Wednesday through Friday, employees were put on administrative leave, although reportedly several telecommuters continued to work (*4*). By the following Monday, October 23, when employees were expected back to work, one division manager already had telephoned managers and decided to increase the numbers of telecommuters. At a meeting held that afternoon, the top managers in the division discussed the emergency and, as one option, they formalized the rules to expand telecommuting. Managers in other branches recalled a similar story. That first day they were back, the executive director authorized adding telecommuters with complete branch discretion in helping staff get to work in that difficult period. Other options included a compressed work week, decreasing the required core hours, allowing staff to start earlier to shift travel to off-peak hours, added parking incentives for carpools, and larger discounts on transit passes (*3*). (A 9/80 compressed work week schedule, for example,

TABLE 2 POSTEMERGENCY TELECOMMUTING BEHAVIOR OF PILOT GROUP

Reason	No. of times mentioned
8 Pilot Telecommuters Not Telecommuting at Time of Emergency	
4 *Never started, and did not start telecommuting after emergency*	
No computer or incompatible computer at home	2
Changed to compressed work week	1
Personal preference	1
	4
4 *Stopped before earthquake and did not restart telecommuting after emergency*	
No computer or incompatible computer at home	1
Face-to-face meetings required	2
Field trips	1
Traffic returned to normal	1
Transferred to another group	1
Personal preference	1
	7
16 Pilot Telecommuters Telecommuting at Time of Emergency	
1 *Increased telecommuting*	
Completed seasonal task	1
3 *Decreased telecommuting after temporary increase*	
Travel	1
Personal preference	1
Field work	1
	3
8 *Did not change telecommuting during emergency*	
Commuted on BART	4
Moved to San Francisco	1
Supervisor restriction	1
Traffic returned to normal	1
No reasons given	1
	8
4 *Decreased or stopped telecommuting*	
Business travel	1
Field work	1
Supervisor attitude	2
Worked in district office	1
	5

means working 9-hr days for 8 week days, 8 hr for a 9th day, and not working on the 10th weekday.) Later that same day or the next morning, managers called together their entire staffs and discussed options and passed the word along in memoranda. One postearthquake telecommuter recalled a note from the Information Resources Department explaining that telecommuting was an option and asking "if you have a computer and can you call in or log in." Telecommuting was completely voluntary for the employee but required the supervisor's approval.

Travel Behavior Immediately after the Earthquake Emergency

Change in telecommuting patterns related to the emergency were primarily a function of the telecommuter's job requirements at the time. Reasons for decreasing the number of telecommuting days or stopping altogether were similar for both pilot and new telecommuters.

Pilot Telecommuters

Of the 21 pilot telecommuters and 3 telecommuting managers, only 1 permanently increased his amount of telecommuting (from none before the earthquake to a sustained 1 day per week) immediately after the earthquake (Table 2). Coincidentally to the earthquake, he was able to work Wednesdays at home beginning in October because he finished a seasonal period that had required his supervising in the main office. Three people temporarily increased their telecommuting. One of those people who was doing earthquake-related field work telecommuted part time 5 days a week, reporting from home by the office automation system. Eight telecommuters did not change their schedules. One of the eight, for example, who lived in San Francisco, became a priority person to staff the office. Four people decreased or stopped working at home on their scheduled days. Finally, none of the four who had never started telecommuting nor the four who had stopped before the earthquake started to telecommute because of the emergency.

Those who did telecommute benefited from not having to drive or take mass transit when the Bay bridge was down. Bay Area Rapid Transit (BART) parking lots were full and parking was difficult to find nearby; trains were crowded and late. On days when they worked at PUC, employees coped by commuting outside peak periods, parking at friends' houses when they rode BART, and commuting by the ferry that was put into emergency operation.

Postearthquake Telecommuters

The postearthquake telecommuters added as a result of the policy change circulated from the executive director of the PUC were concentrated in C division, which had taken immediate aggressive action to expand telecommuting. That division added 32 new people (Table 3). Within the division, managers who already had telecommuters tended to let additional staff telecommute. One manager of 18 people, for example, had three pilot telecommuters, and added eight. Another manager's group of 21 had two pilot telecommuters and added four. That group had 3 or 4 people on compressed work week and another 14 whose commuting did not change after the earthquake.

The four other sampled divisions were less active in expanding telecommuting. Only one new telecommuter was added—in Division B—although all four had pilot telecommuters. Many of one manager's group lived in San Francisco or on the Peninsula, so nothing changed, no additional telecommuters were added. In other groups, the reason was upper management's not permitting both compressed work week and telecommuting. In some groups, a lot of employees preferred a compressed work week. Some worked flextime, i.e., they worked 8-hr days but not from 8:00 a.m. to 5:00 p.m. One employee, for example, worked from 6 a.m. to 2:30 p.m. to cut commuting time from 1½ hr to 25 min.

But there may have been employees who did not think of themselves as telecommuters. For example, the counts may underreport telecommuting in Divisions D and E whose employees were out in the field full time doing safety inspections of structures following the earthquake. As a pilot telecommuter in one of the divisions remarked: "I guess you could say they were telecommuting since they were doing field work reports at home and sending them in via their computers just like I was, but they weren't officially on the program."

Long-Range Changes in Telecommuting

Pilot Telecommuters

In an effort to estimate the pattern of telecommuting following the emergency, that is, to understand whether telecommuting was continued under normal conditions, individuals, managers, and peers were asked for names of people who were and were not telecommuting at that time. The numbers convey a sense of the telecommuting pattern, but should not be taken as an absolute count. Sixteen of 34 persons (47 percent) listed on the May 19–20, 1988, training schedules as pilot telecommuters (but not managers) were telecommuting at least 2 months after the earthquake. They continued their preearthquake telecommuting pattern, typically using BART to get to work the other 3 to 4 days. Eight of the group (26 percent) never started. The one person mentioned earlier who started telecommuting after the earthquake coincidentally, because his work finally permitted him to begin, continued to telecommute. Three people had stopped telecommuting before the earthquake. Incomplete information was obtained for the remaining six. Two or more months after the emergency, one of four midpilot telecommuters was still telecommuting; another had stopped. Whether or not the others were still telecommuting could not be determined.

Of the interviewed pilot group who continued to telecommute, eight had computers, three did not. Three pilot telecommuters who owned computers stopped for reasons such as travel or field work, rotation to another groups, and for personal reasons. Other reasons for not continuing to telecommute included lacking a computer at home, change in task demands, supervisor attitude, and a personal situation or preference such as changing to a compressed work week, wanting to ride in a carpool with a spouse, or wanting to take advantage of the PUC child care facility.

Postearthquake Telecommuters

Thirty-two employees were named by managers or coworkers as having begun telecommuting in response to the emergency. Sixteen (50 percent) started and were continuing to telecommute at the same rate for at least 2 months after the earthquake with the exception of two persons who telecommuted fewer days because of the holidays, business travel, and easier

TABLE 3 DISTRIBUTION OF TELECOMMUTERS WITHIN PUC DIVISIONS

Division	Pilot Telecommuters	Post-Earthquake Telecommuters
A	2	0
B	12	1
C	18	32
D	5	0
E	3	0
	40	33

commuting. Twelve (38 percent) telecommuted for 1 month, then stopped. Another four individuals were identified as telecommuting after the earthquake but coworkers were not sure whether they had continued after the Bay bridge reopened.

As discussed later, having a computer in the home office influenced whether or not the postearthquake telecommuters continued to telecommute after the emergency was over (Table 4). Because they used a computer in the main office, they were limited in the tasks they could carry out at home. Other factors affecting telecommuting behavior included not liking to carry bulky work materials back and forth, particularly if they commuted via mass transit, transfer to another group, because they had completed the report or task, and interruption of telecommuting by the holidays.

Those who reported business travel and face-to-face meetings required were staff who needed to be at PUC the days they were in the city to interact with other members of their groups.

This study did not uncover any telecommuters who had stopped because a manager was dissatisfied with their performances. With regard to postearthquake telecommuters, it may have been too soon to identify problems at the time managers were interviewed. (If there were any pilot telecommuters in that category, they likely were no longer in the program.) However, telecommuters were alert to their supervisors' general attitudes toward telecommuting and adjusted their requests to telecommute accordingly.

The new telecommuters felt positive about their experience. Most people worked alone in their homes in either a separate room or place such as an alcove of the living room or hall desk. Despite the fact that many postearthquake telecommuters lived in the east Bay region with available mass transit, they began and continued to telecommute.

Managers' Attitudes and Perceptions

Managers generally were satisfied with telecommuting, and planned to continue it within their groups indefinitely. As one supervisor commented, "it wasn't division policy to cut back. We play it by ear. We're more relaxed—so long as there is no problem." Another understood that "after a while in some groups they had telecommuters who couldn't concentrate at home. Telecommuters had small kids or other distractions." The supervisor makes it clear to his group that telecommuters can stop and restart again when the home situation permits.

After the earthquake, managers did not use the selection process required for the pilot group. "Since it was an emergency, anyone who wanted to telecommute, we tended to say 'yes.' " One manager felt that the pilot only was needed "so if the state decides to form a policy we'll get our say as to our needs. They didn't have to have the pilot in order to telecommute. A manager could say OK, work at home. We have lots of authority delegated to us. A lot of staff wanted to telecommute once in awhile. Upper management told supervisors that they had flexibility and should be lenient. After the earthquake they allowed some people to telecommute who wouldn't have [been allowed to] otherwise."

Managers noticed little difference between the pre- and postearthquake telecommuters. "We kind of monitor them.

TABLE 4 EMERGENCY-RELATED TELECOMMUTING BEHAVIOR OF POSTEARTHQUAKE GROUP

Reason	No. of times mentioned
32 Post Earthquake Telecommuters	
14 *Continued telecommuting*	
2 *Decreased telecommuting*	
Business travel	1
Holidays	1
Commuting easier	1
	3
12 *Telecommuted one month, then stopped*	
No computer, no office automation access from home	4
Task-related, e.g. project finished	2
Bulky reference materials inconvenient to carry back and forth	1
Business travel	1
Face-to-face meetings required	1
Holidays	1
Reason not reported	5
	15
4 *Long range telecommuting unknown*	4

Some people gave more than 1 reason.

The new telecommuters are the type we would have chosen anyway. The earthquake took waverers and added them to the program." Typically, like the pilot telecommuters, postearthquake telecommuters submitted a work plan to their supervisors for approval. It was then passed to the manager. Supervisors had a positive perception of work effectiveness: "Seeing the work done it was obvious that telecommuters were doing at least 8 hours work at home." "If anything the productivity has increased" and telecommuting was "good for morale."

Managers who were less enthusiastic about telecommuting remarked that "too many changes are being made." One manager would accept one more telecommuter, but feels he doesn't have highly motivated, responsible people, and moreover, has not had strong requests by staff to telecommute. Another manager is afraid that "if telecommuting becomes a right, employees I don't trust would get to work at home. Telecommuting depends on the individual." He wants telecommuting to be a managerial option. He knows the capabilities of his staff—"we have people we'd rather not have."

Most of the managers interviewed feel that so long as there is reasonable structure they will support telecommuting. The questions are "Will the telecommuter be available?" "Is the telecommuter there when you call at home?" "Does he have a PC, modem, and office automation connection?"

DISCUSSION OF RESULTS

Factors Promoting Telecommuting

The PUC initiated a 5-year Transportation Management Program in 1989. That transportation and energy conservation policy was reaffirmed after the quake: "Our current objective is to continue the post-quake reliance on public transit, ridesharing, flextime and telecommuting in the Bay Area" and maintain the 50 percent reduction in single-occupancy vehicle travel by its employees that was achieved from 1989 to 1990 (*3*). That commitment appears paramount in analyzing why people who began telecommuting to mitigate the impact of an emergency continued to telecommute when normal conditions were restored.

What part did the State Pilot Telecommuting Program play in opening opportunities for more employees to telecommute? Having a trained body of telecommuters in place with managers enthusiastic about or, at worst, tolerant of telecommuting for their own people, was critical. Also influential was verbal endorsement by the governor of California on Tuesday, October 24, 1989, a week after the earthquake. On October 31, the governor issued Executive Order D-82-89 requesting all state agencies, among other measures, to "implement telecommuting procedures and programs to increase work at home or at satellite facilities." In late November, the Department of General Services held management briefings on "Telecommuting During the Earthquake Recovery: Mitigating Traffic Congestion and Office Space Options" to PUC and other state agencies. However, evidence gathered from employee and manager interviews suggests that new PUC telecommuters were added prior to the briefings.

Discrepancies in the reported numbers of telecommuters blur the extent of telecommuting. Even in a formal telecommuting program, work assignments interrupt telecommuting schedules, sometimes for indefinite periods of time, so that accurate counting of telecommuters is difficult. This study found that neither managers nor coworkers were always up-to-date on who was telecommuting.

Most employees enthusiastically endorse telecommuting and feel they are more productive working at home. Under emergency conditions, telecommuters saved time and stress by not having to leave their homes early in the morning and commute on overcrowded streets and mass transit. One employee could sleep an extra 2 hrs, so felt the quality of her work was better. But also under normal conditions telecommuters report working "harder at home than at PUC because there are no interruptions." "At PUC they work in cubicles and you can hear everything . . . so I get most of my work done at home." Telecommuting saves transportation time and "you don't have to stop for lunch so you have long stretches of time to work in." Moreover, telecommuters were pleased about their productivity: "I don't even think about the time I'm not being paid. I just get the job done. It's more relaxing at home, more productive. When I come in to work I have to get up, get ready, get to the bridge, get here, get set up, while at home all I have to do is start."

Factors Limiting Telecommuting

Policy

In spite of PUC's stated goals to encourage telecommuting, several guidelines acted to limit the number of telecommuters and telecommuting days. First, there was a perceived policy that forced the worker to choose between telecommuting and a compressed work week. Some managers thought the policy was in effect; another thought it had been changed in response to the emergency and might or might not have been reinstated.

Limiting telecommuting to 2 or 3 days did not appear to affect the actual time telecommuted because of workers' task-related needs to be at the main work site, to travel, or perform work in the field. The more serious barrier to increased telecommuting is the limitation of each telecommuter to an approved schedule of, for example, Tuesday and Thursday or Monday and Wednesday home-based work. A telecommuting day cannot be rescheduled if telecommuters are called for a meeting or needed elsewhere on their home office days. Some postearthquake people who stopped telecommuting might have established a routine if the end of the year holidays had not disrupted their schedules so soon after they had started to telecommute. Because they could not make up days that fell on a holiday, many found their actual number of days at home to be very few.

PUC's policy of training some of the staff by rotating them among branches for periods of 6 months deters telecommuting in two ways: first, telecommuters are uprooted from established telecommuting patterns by placement in new groups in which they are neither well enough known by their supervisor nor familiar enough with their new tasks to work at home immediately. Some transferred individuals hoped to be permitted to start telecommuting again when they had worked a little longer with their new branch. Second, having flexible work options as well as staff rotation gave some managers the perception that everything was changing at once, leading to chaos.

Their supervisor's attitude was mentioned by several people as the reason they stopped telecommuting. Although managers who were less than enthusiastic about PUC's policy apparently did not deny their staff the opportunity to telecommute, they did nothing to encourage it. From the perspective of a telecommuter, "the general lack of organization in the office forces the organization to rely heavily on the presence of people. Management reacts to crisis management." Telecommuting gives him "three hours of life," and he "wouldn't mind working in those three hours rather than fight traffic." Another telecommuter felt his supervisor's attitude is changing because telecommuters "are showing they do good work."

Equipment

Although lack of a computer did not deter most people from starting to telecommute after the earthquake, it did affect whether or not they continued after the first few weeks. Lack of a computer at home was the most common reason given by the postearthquake group for stopping telecommuting. Four of the 12 who stopped said they needed a computer at home (8 are known to have had them). Several mentioned the importance of sending files back and forth on the office automation system. Other factors also affected telecommuting behavior.

Three pilot telecommuters also stopped telecommuting for lack of a computer and one never started because his computer was incompatible with the office automation system. Of the interviewed pilot group who had not stopped telecommuting, 13 had computers, 3 did not.

Many telecommuters from both groups added equipment at their own expense. They had purchased a phone outlet, business line, a 386SX computer (because a borrowed portable "fails so much it's frustrating to use"), modem, software, and office furniture. One completely equipped a home office feeling that "it was an obligation to set up a home office with communication with everyone before starting to telecommute." Several people mentioned that the state pays for a call-back system on the office automation system so the employee does not have on-line telephone charges.

Being on the office automation system was crucial to getting the job done from a home office. Of 19 computers owned by telecommuters (both groups combined), only 2 were not equipped with modems. According to the Information Resources Department, before the earthquake, 180 telecommuters in state agencies had been given a security password to reach a port selector on the office automation system. Following the earthquake, 30 more telecommuters were added. Because of incompatible equipment, several telecommuters had only partial use of the office automation system; they could send notes but not edit files.

CONCLUSION

The Loma Prieta earthquake created an emergency travel problem that could be mitigated by telecommuting. The existing pilot set a precedent such that adding telecommuters did not require an organizational change. Because the PUC organization was prepared with a tested plan in operation, managers were able quickly and smoothly to add telecommuting volunteers. The disaster created a sudden increase in incentive for management to expand the concept. Managers and staff knew what telecommuting is and how it worked at PUC. New telecommuters could and did ask their pilot telecommuting coworkers about the experience before deciding to volunteer. Telecommuting reduced stress because employees did not have to change their travel times or be subjected to long commutes on overcrowded freeways and public transit. Work disruption within the organization was minimized. Particularly important was the ability of workers in the field conducting critical safety checks to send back reports by computer from their homes. The division that had the most telecommuters before the earthquake added the most in response to the emergency. Managers seemed comfortable with telecommuting in their departments and expected it to continue. Those not enthusiastic about telecommuting admitted it had benefits but, in actuality, their own groups had people on a compressed work week with few or no telecommuters.

Evaluated in terms of the pilot project guidelines, pilot telecommuters increased their telecommuting time only temporarily, if at all, then returned to preearthquake schedules when the Bay bridge reopened. But looking at telecommuting in a broader sense, the pilot group who were on business travel, out doing field work, or working in a district office also were telecommuting. New telecommuters were added who continued to telecommute. Nearly half were still telecommuting when interviewed 2 to 6 months after the earthquake. Most of those who had stopped telecommuting did so, not because of dissatisfaction with telecommuting, but for equipment, job-related, or personal circumstances. Travel behavior changed because telecommuting as a work option was given permission under emergency conditions that was not rescinded when traffic returned to normal.

In contrast to the California PUC, a Texas newspaper publisher had no preexisting telecommuting program when disaster struck. Under more transitory emergency conditions—a fire that shut down the press room—the Dallas Times Herald improvised work from homes and satellite locations in hotel rooms. Management did not think of the experience as telecommuting. Unlike the PUC experience, the incident did not result in permanent change in travel behavior. No policy changes resulted, only the lesson learned that every paper "has to have a doomsday defense set up . . . a fall back" (*7*). This one comparison suggests that long-term travel reduction will not be achieved unless management is educated about the concept and benefits of telecommuting under normal business conditions.

The telecommuting behavior of pilot and postearthquake telecommuters revealed in this study suggest the following employer actions that would promote long-term telecommuting:

- Provide computers for use in home offices or laptop computers equivalent in performance to telecommuters' on-site equipment,
- Supplement employee-owned equipment as needed with a modem and updated hardware and software,
- Pay telephone costs or costs for a call-back system on the office automation system,
- Make available duplicate copies of bulky reference materials or provide scanning assistance from the central office,
- Publicize top management support of telecommuting to encourage reluctant middle managers to participate,

- Publicize policy that staff may both telecommute and work compressed work weeks, if that policy is in effect,
- Permit shifting and make-up of telecommuting days where feasible, and
- Explore ways to accommodate telecommuting within the staff rotation program.

As for future plans at the PUC, the internal Employee Transportation Plan proposes continuing telecommuting as one option to promote alternatives to single-occupant vehicles. Specifically to expand telecommuting participation, the plan recommends (a) purchasing 10 to 15 laptop computers, (b) doubling the telephone lines to 18 (to accommodate 10 to 15 more telecommuters), and (c) over the next 5 years installing an additional 18-port dial-in unit to the office automation system (*3*).

The present findings suggest that several times more than 15 additional telecommuters could be anticipated so far as task-related factors are concerned. The study identified 33 new telecommuters by name, examining only half of the divisions, albeit the largest, in PUC. Added because of an emergency, most new telecommuters, if their tasks permitted, would continue to telecommute. Providing laptop computers would help those who travel or work in the field or do not own a computer although employees express their willingness to equip their offices at their own expense. Of even greater priority is access to the office automation system that many telecommuters increasingly need to perform effectively from home. Finally, it is apparent that more research is needed on the factors determining choice of telecommuting versus a compressed work week to anticipate travel behavior when planning transportation management programs.

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Future of Intelligent Vehicle-Highway Systems: A Delphi Forecast of Markets and Sociotechnological Determinants

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The development of intelligent vehicle-highway systems (IVHS) in the United States is characterized by a high level of uncertainty regarding system development and social response. Although there appears to be much interest and support for pursuing this new approach for increasing the capacity, efficiency, and safety of road transportation, it is difficult to say at this point what set of functions, technologies, standards, and institutional arrangements will eventually evolve into an accepted architecture for IVHS in the United States. There is uncertainty about the financing of system development, the outcome of competing systems and desired functions, consumer acceptance of the concepts and products, and about almost every aspect of the development of IVHS. This paper presents the results from a recent survey that summarizes the opinions of experts in a range of fields related to IVHS. The Delphi forecasting methodology was used to generate a consensus on predicted market penetration for various IVHS including motorist information, vehicle navigation, vehicle location and identification, route guidance, automatic tolls and road pricing, collision avoidance and warning, speed and headway keeping, automated highways, and automated guideway systems. In this paper the system is explained, the market forecasts are presented, related institutional and technical barriers are identified, and the results of the survey are compared with similar surveys conducted in Europe and the United States.

The development of technology is always uncertain. The course of technology development is determined in part by undefined societal needs, uncertain institutional support, and unexpected technical breakthroughs. However, technology development is also determined in part by processes that are known or can be influenced. For example, the future of a particular technology can be estimated by current market trends, recent developments in related technologies, current levels of institutional support, and an assessment of the nation's level of commitment to research and development in the area. Given that some things are known, and that others are uncertain, effective planning for technology development requires an assessment of current knowledge and intentions as they impinge on the future of the technology in question. It requires reducing the uncertainty wherever possible, understanding the sources of uncertainty where it cannot be influenced, and formulating a common vision for those who are required to act. This is the task of assessing the future of "intelligent" transportation systems.

Considering the recent and expected technical advances in electronic communication and processing, it is easy to imagine a future transportation system where "smart" vehicles will communicate with "smart" roadways to increase traffic throughput and safety while providing a more hospitable environment for the motorist. Advanced information systems may someday provide the driver with real-time information on traffic incidents, road and weather conditions, traffic congestion, and preferred routes from origin to destination. Advanced traffic control systems may use real-time information on traffic conditions, models of optimal traffic flow, and centrally coordinated signals to direct traffic through the network in a more efficient manner. Advanced vehicle control systems may help the driver avoid collisions, and regulate vehicle speeds in response to traffic. The most futuristic systems may even take complete control of the vehicle, providing fully automated steering, acceleration, and braking for the driver.

In fact, some early incarnations of intelligent vehicle-highway systems (IVHS) are already being tested in Europe, Japan, and here in the United States. Ongoing advances in a range of technologies are likely to spur further research, development, and demonstration activities in IVHS over the next 10 years. In order to set research and development priorities and to coordinate related activities in this area, it is necessary to think carefully about likely implementation scenarios and their possible impacts on society.

Results of an opinion survey conducted at the University of Michigan (UM) to assess the future of IVHS are described. These advanced road transportation systems integrate the intelligence of microprocessors, sensors, scanners, transmitters, displays, and other related electronic systems with the infrastructure of the highway and automobiles, to improve the communication and control functions of road transportation. The Delphi method was used to assess the opinions of a panel of experts in areas of research related to IVHS. Their opinions were elicited and refined through an iterative interrogation process, where a "spiraling dialogue" among the experts converged on a set of forecasts for a range of system categories. These forecasts were used as an input to a research planning process for UM's program in IVHS. In the sections that follow, the issues that the panel addressed, the method that it used to address these issues, and the forecasts and lists of determining factors that emerged from its controlled discussions are described. The opinions indicate that a new era of smarter road transportation in the United States is about to begin.

It is helpful to place the current flurry of activities in historical perspective. The marriage of vehicle and highway

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through advanced technologies is not a new idea. Researchers, inventors, entrepreneurs, and other visionaries have long recognized the benefits and opportunities provided by this marriage, including increased mobility, safer streets, a cleaner environment, more effective use of resources, and improved comfort and convenience, to name a few. Not the least of these opportunities has been the possibility of tapping a large and receptive market for these benefits. In an attempt to investigate or capitalize on these opportunities, the most enterprising of individuals have delivered a host of mechanical and electronic devices designed to inform the driver, control the vehicle, and manage traffic, some of which are commonplace today, others that are left in relative obscurity. In order to provide a commonplace example, the standard AM–FM radio has been the traditional electronic supplement to static road signs for informing the driver of traffic and road conditions. Traffic advisories are not only provided periodically by standard FM carriers, but schemes have been used to override the carriers to provide important traffic bulletins in limited local areas. The citizen band radio provides another ordinary example of a driver information system. During the late 1960s and early 1970s, the two-way citizen band radio experienced a short-lived surge of popularity bringing all sorts of useful and less-than-useful information to the driver. Cellular mobile telephone is the most recent entry in the vehicle-highway communications arena. New and adaptive uses of these commonplace technologies promise to increase the driver's knowledge of traffic conditions and thereby increase the driver's responsiveness to these conditions.

Other more intriguing developments in intelligent vehicle-highway systems have emerged in the areas of navigation, route guidance, vehicle control, and traffic control. French (*1*) provides a colorful historical overview of early developments in vehicle navigation and route guidance, including the description of a device designed in 1910 that had routes encoded on punched disks which activated real-time guidance instructions at points measured by the rotation of the vehicle's wheels. The Chadwick Road Guide sold for about U.S.$1,000 in current dollars and never became a "hot-selling" item. French details a number of similar mechanical and electronic guidance systems that have come and gone over the years, none of which really captured the motorists interest or dollars. It seems that maps have ruled the day.

In a more ambitious attempt to merge driver information with navigation and traffic management systems, the FHWA supported early research on cooperative route guidance, which was intended to tie in vehicle navigation and location technologies with centralized traffic control (*2*). The Electronic Route Guidance Systems (ERGS), which emerged from this effort in the late 1960s, used short-range transmitters mounted on proximity beacons to collect information from induction loops buried beneath the roadways. As cars passed by, they transmitted vehicle location and trip destination information to the roadside beacons. This information was relayed to a traffic management center for processing. Travel times and routes were computed at the center transmitted to the network of beacons. Vehicles near the beacons would receive local route instructions that were displayed on the vehicle's dashboard. The traffic management center would use various types of static traffic information along with the real-time vehicle location and destination data to determine the appropriate timing of signals and routing instructions. This project was terminated by Congress in 1970 following limited testing, but the basic concept is currently being tested in demonstrations of cooperative route guidance systems in Europe and Japan.

Going as far back as 1939, the New York Exhibition presented a scale model demonstration of automatic vehicles traveling smoothly in platoons. Bender, et al. (*3*) reviewed the history of this exotic line of vehicle research. In the early 1960s, General Motors Corporation conducted extensive research on the subsystem aspects of automated vehicle control and electronic highways. During the 1960s and 1970s, operational tests of these systems were conducted at General Motors Corporation, Ford Motor Company, Ohio State University, among other research organizations around the world. During the 1970s, there was also a surge of interest in multimodal transportation systems. For example, the TRW systems group proposed an elevated guideway that would carry automobiles on pallets between cities. Many other similar systems have been proposed, none of which have advanced beyond a limited demonstration stage. For these and other early incarnations of advanced transportation, the effectiveness and cost of the technology were the primary barriers.

Although the concept of IVHS is not new, recent technological advances promise to make these systems more effective and affordable, meriting a second look at the concept. Breakthroughs in integrated circuits, microprocessors, sensors, scanners, displays, and systems engineering promise to make the old concepts new again, and incite new innovations in advanced transportation systems. This is hardly a technology push, because the ideas of vehicle-roadside communication and advanced traffic control have been around for some time. Rather, it is a technology release, in which recent technological advances are providing new opportunity to accomplish an existing vision.

UNIVERSITY OF MICHIGAN PROGRAM IN IVHS

In response to the opportunities looming on the horizon, a number of organizations have recently initiated or renewed the investigation of IVHS. Research arms of the federal government, state and local governments, universities, motor vehicle manufacturers, and electronics companies have recently launched projects or programs in IVHS. A shared goal of the recent activities in the United States is to become competitive with the better organized and funded IVHS programs in Europe and Japan. This goal has led to a cooperative spirit among the leading participants in the United States. It is a commonly held belief that the programs in Europe and Japan have at least a 5-year lead in their administration of IVHS research and implementation of IVHS demonstrations. Levels of funding for these programs are not entirely certain, but estimated in the billions. In the United States, informal cooperation among principal actors in the form of ad hoc workgroups and committees has yielded results in conceptualizing a national agenda for research and development in IVHS. A few cooperative research efforts are already underway, and others are being planned for the near future.

UM is one of the handful of research universities addressing the topic of IVHS. In the spring of 1988, UM initiated a research program to address both technical and institutional issues related to the development of advanced transportation systems in the United States. A program was envisioned that would build on (a) the distinctive research strengths of UM, (b) the interests and support of the Michigan Department of Transportation, (c) the interests and related technical capabilities of the nearby automotive industry, and (d) linkages and complementarities with other research universities. In order to bring these ingredients together, a pragmatic outlook toward the incremental development of IVHS was adopted. The concept merged basic and applied research with an emphasis on the vehicle and driver components of IVHS.

Planning of the research program required insight into the expected development of IVHS so that those areas of research that would have the greatest impact could be targeted. This is where the Delphi forecast came in. The future of a range of intelligent systems and the issues regarding the development and implementation of those systems needed to be assessed to identify propitious topics for research. The Delphi method would enable interrogating the minds of the experts in a wide range of topics affiliated with IVHS toward this end. It would also provide an opportunity to collect market projections that would be of interest to the industrial sponsors.

OBJECTIVE OF THE STUDY

UM's program in IVHS is supported by the voluntary contributions of the nearly 20 participating sponsors of the program. Most of these sponsors are involved because of some recent or long-standing involvement with research and development in IVHS. As such, they represent an invaluable resource with access to experts in IVHS and other related fields of endeavor. The Delphi study provided an opportunity to exploit that expertise in a task of fundamental interest to the university, government, and industry supporters, namely, to obtain technology and market forecasts for a range of system categories.

The principal purpose of this study was to explore the future development and market penetration of selected IVHS categories in light of an optimistic scenario for government support. The research would address the timing of research, systems introduction, and levels of market penetration for 10 systems categories:

- Automatic tolls and road pricing,
- Automatic vehicle location,
- Automatic vehicle navigation,
- Motorist information,
- Cooperative route guidance,
- Collision warning,
- Collision avoidance,
- Speed and headway keeping,
- Automated highway, and
- Automated guideway.

It was important to address each of these categories separately, as each system category is directed at a unique information or control function and typically involves distinctive system components and technologies. For each of these categories, the factors contributing to the emergence and development of these systems, including both social and technical considerations, were to be addressed. These factors would provide leads to topics for potential research and development. Finally, the social and technological impacts of the systems were to be assessed; the benefits associated with each system category were especially to be delineated. This process would provide a basis for estimating the value of each system category. Again, these factors were likely to depend on the type of system being addressed. There is little value in grouping these categories together and addressing them as a single IVHS.

PREVIOUS IVHS DELPHI FORECASTS

The survey was designed and conducted with the advantage of having previous results from earlier Delphi studies on selected aspects of IVHS. The earliest of these surveys was a Delphi study sponsored by the California Department of Transportation (CALTRANS) and undertaken in 1974 by the Center for Futures Research at the University of Southern California (*4*). The study was part of an effort for developing a statewide multimodal transportation plan for California. They polled 46 experts in a wide range of technical and nontechnical fields to reach consensus on forecasts for 146 developments and trends in a broad range of transportation and social areas. One of the forecasts concerned "the introduction of automated highways on a more than experimental scale" in California. The consensus of opinion in 1974 was that the earliest that the introduction of automated highways would occur was in the year 2000, the latest that it would occur was in the year 2020, with a consensus that the most likely year of introduction was, surprisingly, the year 2000.

A more recent Delphi study conducted in Europe addressed the emergence and market penetration of IVHS under the designation of "road transport informatics" (RTI). The research was part of the Automobile Road Information System Evolution (ARISE) Project that was undertaken by the Swedish National Road Administration (SNRA) and later moved to the International Institute for Applied Systems Analysis (IIASA) in the beginning of 1986 (*5,6*). The objective of this study is to create new and better scenarios as a means of investigating how RTI will evolve. In order to accomplish this, Sviden combined the Delphi methodology with the construction of detailed written scenarios. The main results of the research were summarized as descriptive scenario scenes for the years 1990, 1995, 2000, 2010, 2020, and 2040. The scenario has interactive route guidance systems (IRG) being introduced in 1995, speed and distance keeping (SDK) and collision avoidance (CA) systems being introduced in 2000, and an automated highway chauffeuring (AHC) system being introduced in 2010. Also by the year 2010, all of the information and traffic management systems are in use by a majority of all automobiles. By the year 2040, all of the systems, including the vehicle control systems, are being used by a majority of all automobiles. Major improvements are made all along the way in quantified measures of satisfaction, cost, speed and throughput, and safety.

Sviden's Delphi on RTI influenced the design of the UM Delphi on IVHS. It provided the initial idea for system classifications, although the classifications that were eventually settled on did not completely match, and it provided the framework for measuring market penetration. A major advantage of keeping with a similar format is that it allows comparisons of the results across the Delphi studies.

Apparently the FHWA also saw the advantage of keeping with the RTI study format in its 1988 Delphi on advanced vehicle and traffic control technology in the United States (*6*); it followed the system classification-market penetration format for forecasting the emergence of selected IVHS technologies. In this case, the Delphi was one element of an overall evaluation of current and anticipated technological developments that would be expected to improve vehicle and traffic control. The purpose of the Delphi was threefold: (a) to evaluate specific vehicle and traffic control systems for their applicability to U.S. highways, (b) to determine the appropriate role of FHWA, and (c) to estimate when particular milestones might be achieved for the 10 systems. The Delphi administrators surveyed 11 managers and technical specialists from the FHWA on the expected development and impacts of the 10 system categories. They were asked to make their predictions with regard to both optimistic and pessimistic social and economic scenarios. The work forms used by the FHWA panelists include for each system category (a) a questionnaire to assess the anticipated support by various interest groups, (b) a questionnaire to evaluate costs, reliability, and benefits to selected interest groups, and (c) a system description form. The panelists' forecasts of market penetration indicated that the expected system introduction of all systems, with the exception of automated highways, would be achieved by the year 2007. Automated highways were expected to be introduced by 2026. Because of the major public outlays required for an automated highway system, the report concluded that the benefits do not appear to justify the costs, although selective implementation may pay off. Most other systems received more favorable cost-benefit evaluations, noting that most production decisions will be determined by the consumers and the vendors of the products. The panelists did agree that on-board motorist information systems and cooperative adaptive traffic control systems would become widely implemented in the near future and that the FHWA should play a major role in their development.

There is general agreement between the ARISE and FHWA research that most of the advanced systems under consideration will be introduced within the next 10 years. Further discussion of the ARISE and FHWA studies will continue in a later section in which the forecasts are compared with the results of the UM survey.

DELPHI METHOD

In the mid-1950s, the name "Delphi" was adopted by Norman Dalkey and Olaf Helmer at the Rand Corporation for a forecasting method that used the consensus opinion of an expert panel to predict trends and events. The Delphi technique used an iterative procedure for eliciting and refining the opinions of a panel of anonymous experts by means of a series of individual interrogations.

The essential features of the Delphi are (a) remote and explicit communication, (b) statistical summary of group responses, (c) iteration and controlled feedback, and (d) anonymity among the participants. Participants are generally surveyed by means of a mailed questionnaire; the panel may be described in a general sense, but the participants never meet face-to-face, nor are they informed of the others' precise identity. Anonymity eliminates interpersonal static and influence processes, confining the interaction to exchanges of ideas and formal means of persuasion. After the participants complete their questionnaires, an exercise manager summarizes their responses and returns the summary to the participants so they may use it to revise their earlier answers. In contrast with direct discussion in a typical committee, the Delphi manager controls the communication process in an effort to eliminate redundant or irrelevant material and to focus the effort on the crucial issues. Finally, in the traditional Delphi, the manager uses simpler descriptive statistics, usually the median and interquartile ranges, to summarize the panel response. By using a statistical index, the Delphi process reduces the pressure to conform and ensures that the opinion of every member plays an important role in determining the final response. There is normally some convergence toward the median after several iterations, but the normal outcome usually reflects some range of divergence. Rather than forcing unanimity, the Delphi process allows, and in some cases promotes, divergent responses.

Rationale for IVHS Delphi

Delphi is the method of choice when a consensus of expert opinions is desired and the feasibility of extracting reliable opinions from a standard committee is in question. That was precisely the situation when it was decided to forecast IVHS technologies to assist in project planning effort at UM. IVHS is a complex array of technologies and interdependent systems, some of which have been tested, others of which have not even been thought of. The prospects for trend extrapolation were limited. It would be meaningless at this time to attempt to isolate measurable functional capabilities of IVHS to chart their progression from the past into the future. Rather, talking to knowledgeable people was needed to obtain a quick sense of the prospects for research, development, and implementation of IVHS in both the short and long runs. Because this expertise was distributed among a number of individuals with narrow perspectives on this wide subject, a means of encouraging productive interaction among a set of 20 to 30 individuals, many of whom did not know each other, and who might have difficulty communicating with each other because of their vastly different backgrounds, was needed. The Delphi technique appeared to be the appropriate choice.

The Delphi technique does not require data for trend extrapolation. It merely requires that a representative sample of experts that are seen as credible to both the study sponsors and the study users is identified. Recent efforts to establish a new program in IVHS at UM provided an opportune resource for identifying the needed expertise. The sponsors and newly appointed advisors represented a unique set of organizations with some background and expertise in IVHS-related activities. It was put to them to identify the most appropriate personnel from their sphere of acquaintance. It turned out that the individuals that the advisors nominated for participation had the desired range of expertise to address the wide range of sociotechnical questions posed by the prospects of developments in IVHS. The Delphi technique afforded the panelists the opportunity to interact with one another in a controlled setting in which they could jointly address the opportunities and barriers confronting the development of an IVHS capability in the United States.

Delphi Panel

Sponsors of the UM IVHS project included the big-three U.S. automotive companies, their electronic component suppliers, telecommunications companies, state and federal transportation agencies, and representatives of transportation user groups. All sponsors have representatives that serve as members on the project advisory committee. In June of 1988, members of the committee were asked to identify individuals from their organization that were knowledgeable in IVHS technology or related policy issues and to request that they participate in the Delphi exercise. Most organizations found one person in their organization who could serve as the designated expert in IVHS, others identified up to three individuals, a few could not find an appropriate participant. By the time that the survey was initiated, there were 32 panelists participating in the survey representing 13 sponsor organizations. There was some attrition in each of the three rounds with 22 of the participants responding in the last round.

In keeping with the provisions of the Delphi process, the identities of these panelists remain confidential. The anonymity of the participants ensures that during the process the panelists' ideas are judged on merit and not on the reputation or personality of the panelist. It also enables the panelists to make uncertain forecasts concerning complex social and technical matters without fear of embarrassment or ridicule. The participants can forsake conventional wisdom or their conservative line in favor of an honest assessment of the future.

PROJECTIONS OF IVHS CATEGORIES

Discussion of the IVHS categories is organized by their targeted source of control, with either the roadside, the driver, or the vehicle being the targeted control constituent. Three broad categories of IVHS will be used:

- Advanced traffic management systems (ATMS) for roadside control,
- Advanced driver information systems (ADIS) for driver control, and
- Automated vehicle control systems (AVCS) for vehicle control.

Mobility 2000 addressed heavy vehicle and commercial operations as a fourth and separate category; however, commercial issues have been folded into the first three categories.

These categories were first delineated at the Mobility 2000 workshop that addressed scenarios for a national agenda in IVHS (*8*). For the purposes of this paper, each broad category encompasses a number of specific system categories. An ATMS controls traffic through roadside displays or signals, which may be coordinated, or even optimized, at a central control facility. Although ATMS is a well-developed field of application and research, few of these systems involve significant vehicle-highway interaction; automatic tolls and road pricing (ATRP), as a subcategory under ATMS, was included in this study because of the clear linkage between vehicle and highway components. The ADIS assists strategic and operational driver control functions through effective information distribution, processing, and display. Included in this category are automatic vehicle location, automatic vehicle navigation, motorist service information, cooperative route guidance, and collision warning systems. All of these systems assume driver control of vehicle operations and routing and advise the driver accordingly. Vehicle-highway interaction is mediated by the driver. Finally, automated vehicle control systems transfer control from the driver to the vehicle to simplify the driving task and improve traffic flow. Vehicle electronics that were strictly autonomous were excluded from consideration. Four types of control systems that involved vehicle-highway interaction were addressed: collision avoidance, speed and headway keeping, automated highway, and automated guideway systems. The distinction between automated highways and automated guideways is that automated guideways use modified vehicles and some form of physical guideway, whereas automated highways have intelligent vehicles guided by signals or electronic detectors. Descriptions of the individual system categories follow.

- Automatic Tolls and Road Pricing (ATRP). These are systems that can identify individual vehicles in traffic and assess tolls on the basis of usage and other factors. These capabilities are accomplished without the effort on the part of the driver or a toll collector. The typical system requires several functional elements including: a vehicle-mounted transponder or tag; a roadside sensor; a computer system for processing and storage of data; and a billing system for assessing and collecting user fees. ATRP may be considered a combination of two systems. First, there is an automatic vehicle identification (AVI) system that identifies the individual passing vehicles. Four types of detection are used for vehicle identification: (a) optical and infrared, (b) induction loops, (c) radio and microwave, and (d) surface acoustic waves. Then, there is a computerized charging and billing system that determines the fees on the basis of the time of day, location, and congestion levels.
- Automatic Vehicle Location (AVL). Advanced communication systems would allow fleet managers to monitor vehicles in the field and deploy them more efficiently. This is the primary function of AVL systems that provide vehicle location information to a central authority. The methods for locating the vehicles are, in most cases, identical to those used in automatic vehicle navigation (AVN) systems. Locations are determined through dead reckoning, proximity beacon, GPS satellite, or Loran-C radio frequency navigation. This information is transmitted to a control center where locations are presented as coordinates or on a video mapping system. Location information can be used with fleet management software to dispatch vehicles most efficiently. One example of this type of system is II-Morrow's vehicle tracking system (VTS) that is being used to dispatch emergency vehicles in Detroit. This implementation of AVL has six dispatch stations that monitor some 760 police, fire, and emergency vehicles. The vehicle tracking system, operating on the Loran C navigational network, allows dispatchers at computerized graphic

workstations to route the nearest vehicles to the scene of an emergency.

• Automatic Vehicle Navigation (AVN). Automatic vehicle navigation uses a variety of methods to determine the present position, heading, direction, and distance of the vehicle in relation to a selected destination. The driver is informed of his position relative to a selected address or the existing street geometry, which helps the driver to navigate the vehicle to the desired destination. These systems would generally include devices for positioning, stored digital road maps, a computer, and some form of visual display or voice synthesis.

Navigation techniques currently under development include dead reckoning, proximity beacons, ground-based radio (e.g., Loran-C and cellular), satellite, and map matching. Dead reckoning calculates the vehicle's position by keeping track of the vehicle's travel distances and directions from a known starting point. Proximity beacons communicate location information to the vehicles using short-range radio, microwaves, or infrared signals. Loran-C is an example of a radio navigation system in which the vehicle's position is determined from differences in the arrival time of signals from three or more land-based transmitters. The Navstar Global Positioning System (GPS) will have 24 satellites spaced in orbits to enable vehicles to determine their positions by analyzing the travel times of signals from at least four satellite transmitters. Finally map matching methods, like that used in the Etak Navigator, use artificial intelligence to locate the vehicle by comparing the vehicle's path with the road patterns of a digitized map and using a deductive algorithm. Each approach has a particular set of devices and configuration. All five existing methods may be used separately or in combination, and other methods under development may supersede these in the future.

• Motorist Information (MI). This is one of the more eclectic system categories representing all systems that communicate travel, traffic, road, and vehicle information to the motorist. Applications might include digitized road maps, local traffic regulations, emergency broadcasts, public service messages (e.g., weather, traffic, incidents, construction, parking availability, etc.), roadside service information (e.g., service stations, food and lodging, rest areas, shopping, etc.), and other forms of information either useful or entertaining to the motorist. Although automatic vehicle location (AVL) and automatic vehicle navigation (AVN) systems are closely related to MI, these two system types are sufficiently distinct to have their own category and therefore are not included here. Limiting MI to at most one-way communication links, from an information transmission center and to the vehicle, distinguishes this category from the two-way cooperative route guidance (CRG) systems.

• Cooperative Route Guidance (CRG). A logical extension of the motorist information and automatic vehicle navigation systems is to establish two-way communication between the vehicle equipment and a traffic control center. The advantage of these closed-loop systems over one-way motorist information systems described above is that (a) the traffic control center can monitor specific vehicles to improve their assessments of areawide traffic conditions, and (b) they can potentially provide better navigation information to the driver by taking account of real-time traffic conditions. CRG systems are of two types: those using long-range radio broadcasts to link the vehicle with a traffic control center, and those also using short-range communications to link the vehicle to roadside infrastructure.

An example of the first type is the Pathfinder experimental demonstration project that is designed to test the feasibility of using a CRG to assist motorists in avoiding adverse traffic conditions. The experiment, which is a collaborative effort between the FHWA, the California Department of Transportation, and General Motors Corporation, is being conducted along the Santa Monica Freeway in California. In this case, the CRG configuration includes an Etak Navigator linked by radio to a packet radio system, which in is in turn linked by radio to a central workstation, providing two-way communication between the workstation and the vehicle. The motorist sends information on the vehicle's location, heading, and speed by radio link to the central workstation, where it is processed along with freeway and arterial data to determine real-time congestion levels, and later relayed back to the equipped vehicles. The motorist receives information on the levels and location of congestion in the form of symbols on the Etak Navigator, text, and voice synthesis. The Advanced Mobile Traffic Information and Communication System (AMTICS) being tested by the Japan's National Police Agency is a similar but more comprehensive system, relying on a teleterminal system for small-zone radio communication, combined with static service information supplied through recording medium.

Examples of systems using short-range communication and beacons are ALI–SCOUT in West Germany, AUTOGUIDE in the United Kingdom, and the Road-Automobile Communication System (RACS) in Japan. The ALI–SCOUT system is a cooperative effort by Bosch-Blaupunkt and Siemens using post-mounted infrared transceivers along the roadside and dead-reckoning navigation in the vehicles providing some computational capability in the vehicle as well as two-way communication between the vehicle and a central computer. Equipped vehicles transmit their travel times to the beacons; they are then relayed to a central computer where they are used to calculate route recommendations. These recommendations are then relayed to the beacons and transmitted back to the vehicle along with part of a city map. The AUTOGUIDE system being tested by the Transport and Road Research Laboratory in London is similar to ALI–SCOUT in that it uses infrared transceivers mounted on beacons to establish two-way communication between the equipped vehicles and a central computer. The Japanese Ministry of Constructions' RACS demonstration also uses a similar approach, but relies on microwave communication between the vehicle and the beacons. In addition, the two-way communications include voice messages and facsimile services between the motorist and a wide range of locations (home, office, etc.) beyond the central computer similar to, but much simpler than, cellular telephones.

• Collision Warning (CW). In-vehicle warning systems caution the driver when on a collision course with another vehicle or object. Not only is the area in front of the car scanned to detect a rapidly closing potential collision, but the driver's blind spots in the rear outermost corners of the vehicle are monitored to facilitate lane changes in traffic. Once an obstacle is detected, a signal or message is delivered to a display on the instrument panel, the windshield (as in a head-up display), or on the rear-view mirror (e.g., for lane changes). The detection component of the system can be based on radar, sonar, infrared, or laser technology. Laser, radar, and infrared are generally preferred for front and rear interval control in existing applications. Ultrasonic waves are likely to be used for monitoring blind spots on the side of the vehicle. CW systems are to be distinguished from incident detection systems that provide motorists with information concerning collisions and other incidents far enough in advance so the motorist can modify his or her route. General Motors has equipped a number of its vehicles with near-obstacle detection systems (NODS) that warn the driver of objects that are in the near-field vehicle's path, but are not necessarily in the driver's view. One vehicle has a detector mounted near the back bumper to warn the driver about objects while backing up. Another GM vehicle warns the driver of objects in the blind spots.

- Collision Avoidance (CA). Automatic braking is the principal component of a collision avoidance system. CA is a logical extension of CW, which detects rapidly approaching objects but does not provide automatic braking for the driver. Like collision warning systems, CA systems use radar, sonar, infrared, or laser detection to sense approaching targets. However, once an approaching object is detected, the signal is sent to a signal processor that calculates and analyzes the distance and relative velocity of the object, as well as the ground speed of the vehicle, to determine the probability of collision. For example, if a collision is deemed probable, electromagnetic actuators may deploy the brakes to an appropriate degree. Radar technology is currently the preferred approach because it is the most resilient in inclement weather. Throttle and steering control are other possible elements of an advanced CA system but they are not considered in this discussion or projection.
- Speed and Headway Keeping (SHK). These systems combine throttle control with possibly some limited radar braking capabilities to ensure safe and efficient distances between vehicles on the roadway. Current implementations of throttle control customarily use pneumatic servos that operate the throttle in response to a vacuum obtained from the engine's intake manifold. Cruise control is one form of throttle control that responds to feedback on vehicle speed. As in the CA system, radar braking would involve target sensing, signal processing, vehicle ground speed measurement, command logic and controls, and electromechanical actuators. However, in the most basic system "intelligent cruise control" would only use throttle control, and perhaps some light braking, adjusting the vehicle's speed in light of information on road and traffic conditions, speed of other vehicles, obstacles, and electronic speed limits. SHK systems promise to allow for shorter headways between vehicles thereby increasing the capacity of the roadway. For example, a number of similarly equipped vehicles would be able to form a platoon, with compressed headways, and travel at relatively stable speeds. Like cruise control, SHK also promises to reduce the overall driving effort. One panelist reported that Volkswagen, Mercedes-Benz, and the German Army Research and Development Center have demonstrated driverless control at 100 km/hr with clear lateral definition. The Martin-Marietta Autonomous Land Vehicle is a similar concept.
- Automated Highway (AH). This form of vehicle control is the most advanced, combining elements of SHK and CA, and adding further control features, to enable vehicles to travel on their own, without any form of continuous control by the motorist. Vehicles would be totally automated in all aspects of control. In an automated highway environment, the vehicle would, in effect, operate itself, taking itself from origin to destination according to programmed instructions. Elements of the total control function have been discussed under SHK and CA. However, AH requires more than automated steering, braking, and throttle control. The AH concept calls for full longitudinal and lateral control of the individual vehicle combined with automated approaches for navigation, entering, egressing, and merging. All issues of control at both the microscopic (individual vehicle) and macroscopic (traffic) levels would have to be resolved. Furthermore, the control systems would have to be fail-safe. Many of these issues have been addressed in the development of automatic guided vehicles systems (AGVS), which have been implemented for materials transport in factories and for traversing hazardous areas. However, the routing and control problem is much more complex in a dynamic highway environment.
- Automated Guideway (AG). This category aims to combine the advantages of automated guideway transit (AGT) and normal street vehicles. AGT is a class of transportation systems in which unmanned vehicles travel along guideways with exclusive right of way. A common form of AGT is the urban shuttle that moves back and forth in a single elevated guideway or around a closed loop; the Detroit People Mover would be an example, but this is not the type of system that the panelists addressed. The dual-mode form of automated guideway in which private vehicles are used in a conventional way in local traffic but are switched to a guideway in dense corridors was addressed by the panel. A system was imagined in which everyday vehicles would travel on the conventional street system in most areas and then switch to a specially equipped guideway at certain access points where pallet cars would carry the vehicles along a guided network. The pallets would conceivably move the vehicles with short headways at a uniform and fast speed. Dual-mode maglev systems also fall into this category. The key distinction between AG and AH is that AG uses standard vehicles and some form of physical guideways whereas AH has intelligent vehicles guided by signals or electronic detectors.

In the sections that follow, each of the 10 system categories are described in terms of their function and components, and illustrate by real-life examples when they exist. The market projections will address five steps of development. In order of likely occurrence, these are defined as

1. Successful Laboratory Tests. Satisfactory completion of the research, development, and demonstration phase, with agreement on standardized interface specifications.
2. System Introduction. Vehicles and corresponding roadside components are marketed and sold for either public or private use, however limited the initial deployment may be.
3. Majority Use by Commercial Vehicles. The majority of commercial trucks and cars in commercial use is outfitted with the required components. Majority means greater than 50

percent of the vehicles in those areas where the system is deployed. Some of the systems, for example the automated toll systems, are of a nature that restricts their use to specific regions or areas, and this limitation was considered by the panelists in providing their estimates.

4. Majority Use by All Automobiles. The majority of all automobiles including passenger cars. Again, this is greater than 50 percent within the area of implementation.

5. Mandatory Use by All Road Vehicles. All new vehicles are required by statute to be equipped with the IVHS feature in question.

COMPARISON OF PROJECTIONS

In this section, the trends among the specific system groupings are compared. This process will involve three levels of analysis. First, the extents of market penetration of the advanced traffic management systems (ATMS), advanced driver information systems (ADIS), and the advanced vehicle control systems (AVCS) are described and compared. Again the distinction between these categories is the source of control, with ATMS emphasizing the roadside, ADIS the driver, and AVCS the vehicle. Second, the developments of the 10 individual system categories (ATRP, AVL, MI, etc.) are compared to illuminate significant similarities, differences, and groupings that might affect research and policy agendas. Finally, several significant groupings of IVHS that are distinguished on the basis of some unique technical feature are compared. The most interesting subgroupings are ADIS1, which combines automatic vehicle location and automatic vehicle navigation, AVCS1, which combines the two early forms of control systems—collision avoidance and speed and headway keeping—and AVCS2, which combines the fully automated highway and guideway systems. In presentations of the preliminary results of the IVHS Delphi, the term "backup system" was used for the AVCS1 category because collision avoidance and speed and headway keeping assist or "back up" the driver; they do not take complete control of the vehicle (*9–11*).

Figures 1–3 show both aggregate and disaggregate projections of the assorted IVHS categories. For each of these figures, the vertical axis presents the succession of levels of product development and market penetration, starting with "successful laboratory tests" on the bottom and moving all the way up to "mandatory use by all road vehicles" on the top. The horizontal axis presents a timeline of the future in 5-year increments up to the year 2080. Following the year 2080 are the "later" and "never" responses.

The forecasts for the aggregate groupings (e.g., ADIS, ATMS, AVCS) were determined by taking the median panel projections for the IVHS categories in that group.

Perhaps the most informative comparison is among the projections of the broadest IVHS categories, ATMS, ADIS, and AVCS, shown in Figure 1. A quick glance at the graph should reveal a distinct sequence in the development of the three technology categories. The ATMS category, which consists of only automatic tolls and road pricing in this case, is the first to attain majority use; the ADIS category is the second, and AVCS category is the third.

In terms of majority use by all automobiles ATMS precedes ADIS by 10 years, which in turn precedes AVCS by 20 years. The panelists predicted that it will be 2035 before the control systems are used by a majority of automobiles. This precedent relationship is nearly uniform, from successful laboratory tests through mandatory use, with the exception that the panelists did not expect ADIS to be mandatory.

The second striking characteristic is that according to the panel both ATMS and ADIS systems have been successfully tested in the laboratory. Again, the panelists ignored the requirement of standardized interfaces in making the determination of success in the laboratory. Although evaluation, human factors, institutional, and other applied social and be-

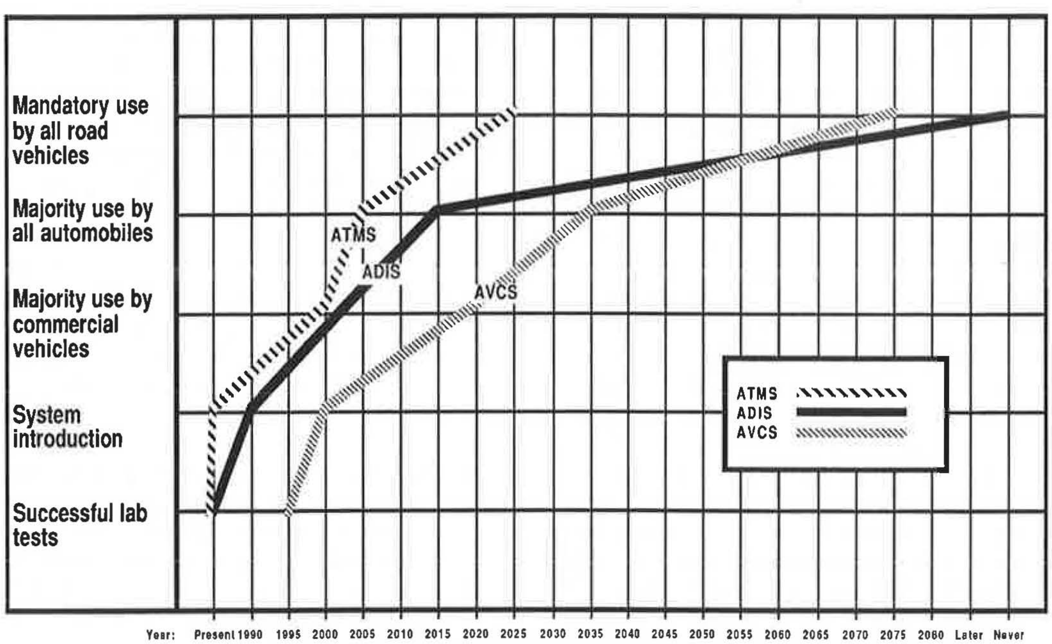

FIGURE 1 Median projections of IVHS market penetration by primary group.

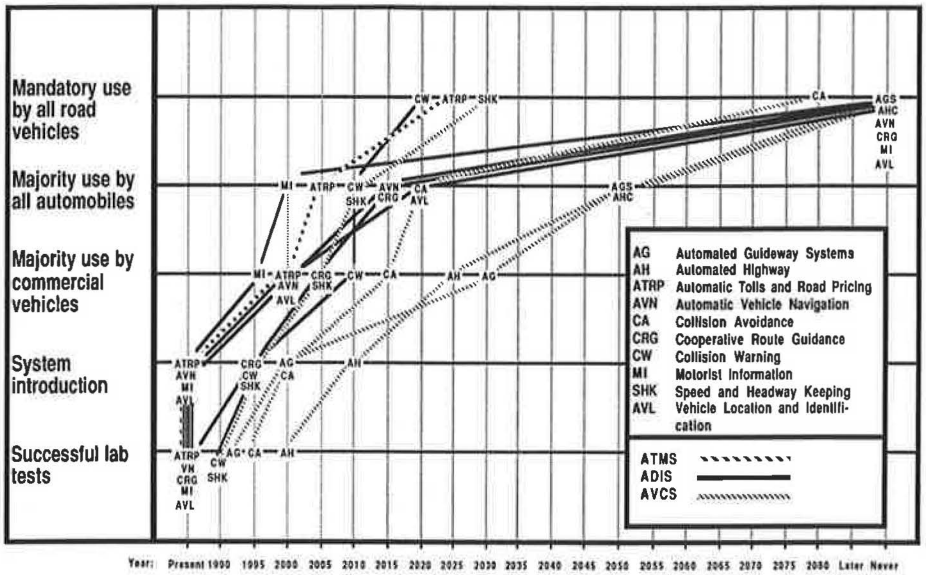

FIGURE 2 Median projections of IVHS market penetration by functional categories.

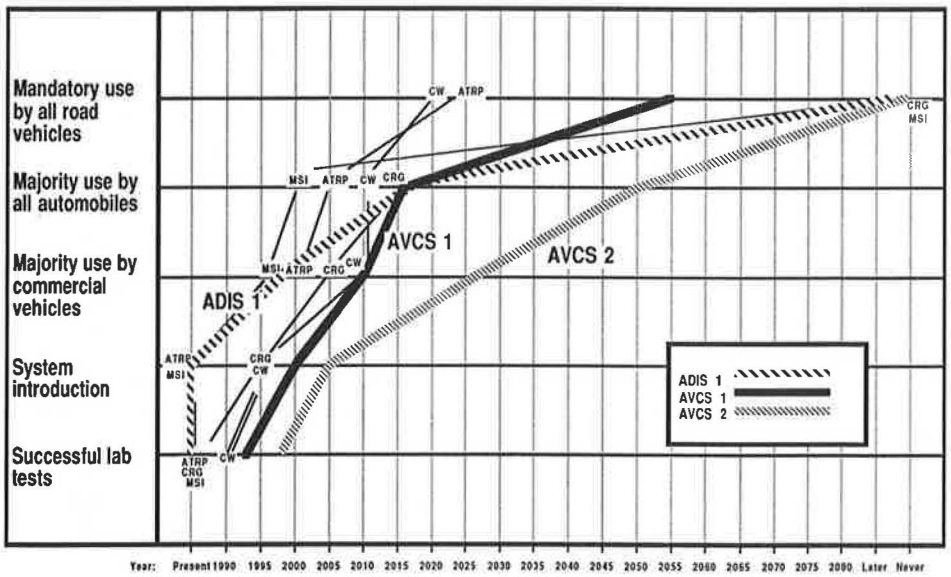

FIGURE 3 Median projections of IVHS market penetration by subgroup.

havioral research questions remain, most of the basic technical research has been successfully completed in these categories. Exceptions are technical research in the areas of traffic science and system integration. However, there are few unique technical research issues at the device or component level. In fact, automatic tolls and road pricing have already been introduced in a few applications, as is the case with most ATMS. Many of the ADIS categories have also been introduced with complete introduction of this grouping being just a few years away. Projected testing and introduction of AVCS lags about 10 years behind ADIS, with all three system categories being successfully introduced by the year 2000. These system technologies are not futuristic imaginings, but real-life, mostly proven approaches that will be implemented by the year 2000. According to the panel, only the more complex ADIS and AVCS categories require any form of basic technical research in the years to come.

The third characteristic worth noting is that in all three cases majority use by commercial interests will precede majority use by the general public. Apparently, trucking and emergency fleets will recognize and benefit from the economies of these systems before the private automobile consumer.

The last pattern of interest in this broadest level of analysis is that most of these systems, most notably the ADIS and AVCS systems, with a couple of exceptions that will be discussed later, are not likely to be required for all road vehicles. The vast majority of these systems will be optional and will depend on the motorists' purchase of the required in-vehicle components.

Figure 2 allows a more detailed comparison of both the broadest and finest system categories. The key in Figure 2 shows the line patterns for each of the broadest system categories as discussed in the preceding paragraphs (i.e., ATMS, ADIS, and AVCS). With this finest level of detail, the patterns discussed earlier reflect the most general tendencies for market penetration, and in reality some overlap occurs in the market penetration of the broad system types. For example, Figure 2 shows that motorist information systems, under the ADIS category, is on the leading edge of market acceptance. The panelists predict that MI systems will be accepted and deployed before the lone ATMS (i.e., automatic tolls and road pricing) is deployed. Similarly, the commercial use of collision warning, under the ADIS category, will follow the commercial use of speed and headway keeping, under the ATMS category. In fact, according to the panel, speed and headway keeping will attain widespread use before most of the ADIS technologies. The point is that there is indeed some overlap in the market penetration of the broad categories when viewed from the most detailed perspective. Nevertheless, as can be easily seen from the shading of the trend lines the general sequence of development is ATMS, ADIS, and then AVCS.

Figure 2 shows that the panelists predicted that MI systems will be used by a majority of automobiles by the year 2000. This system is the first of all the systems to reach this stage. It implies a rapid deployment of autonomous in-vehicle and roadside-to-vehicle information systems over the next decade. The most likely first step into widespread use of MI is continuous or periodic FM traffic and weather broadcasts from a traffic monitoring center. With this modest system, the government authority would be expected to provide the monitoring and information broadcasting services while automotive and radio manufacturers would be expected to provide modified radio units, if required. In any case, if a majority of vehicles will be using this type of system by the year 2000, and if it is assumed that the system requires a modified radio that would come with a new car purchase, then it can be concluded that discussions of system and technology standards will be initiated and concluded in short order. Both government and industry will have to move rapidly if this level of market penetration is to be achieved for even the simplest of systems by the year 2000.

The two-way communication capabilities of cooperative route guidance (CRG) will lag behind the developments of MI systems by 5 to 15 years. Figure 1 shows that while both MI and CRG systems have been successfully tested in the laboratory, only the one-way MI systems have reached the introduction stage; the two-way CRG systems are not expected to be introduced until 1995. Again, system introduction denotes the stage in which manufacturers market components for public or private use. With a later start, CRG will also take longer to penetrate the market. Although MI will take 5 years to reach majority commercial use after introduction, and 10 years to reach majority general use, CRG will take 10 and 20 years after introduction to reach these respective stages. In other words, the expected market penetration for MI will proceed at approximately twice the rate of the expected CRG market penetration. Although MI will reach majority use of all automobiles by the year 2000, CRG will not reach majority use until the year 2015.

Motorist information and cooperative route guidance systems are not entirely independent concepts and MI may well be a building block for CRG if the MI systems are designed for upward compatibility. Alternatively, CRG is a target system that may be composed of the other ADIS elements including motorist information, navigation, and location components, along with the new element of two-way information flow and the use of vehicle location and destination information to monitor, predict, and route traffic. CRG also incorporates elements of advanced traffic management. As a result, CRG is likely to become the focus of an effort to develop an integrated approach to vehicle-highway information and control.

CRG and CW are the slow runners in the ADIS field. Figure 2 shows that system introduction for both these systems is expected by 1995. This date diverges slightly from the aggregate ADIS projection in Figure 1, in which the systems are introduced by 1990. This divergence is important because it indicates that some fundamental research will be required for selected ADIS topics. The panel expects that it will take some time to develop and implement the vehicle-to-center information retrieval and analysis component of CRG and reliable detection in CW. Fundamental technical research is needed in both of these areas.

According to the panel, nearly all of the systems, with the exception of AH, are expected to be introduced by the year 2000. The concentration of systems at "system introduction" in Figure 2 implies intensive research and development within the next 10 years. Most of the systems, with the notable exceptions of the two most advanced control systems, AH and AG, will have reached majority use by the year 2020. This includes CA and SHK, the two early forms of vehicle control. The clustering of systems reaching "majority use" before 2020 in Figure 2 implies a major effort in system implementation and vehicle component sales over the next 30 years.

Figure 2 also shows the sequence and timing of mandatory system use. According to the panel, most of the systems will never become mandatory. Several exceptions, however, are worth noting. These are CW, ATRP, SHK, and CA. Three of these systems could have a significant impact on traffic safety: CW, CA, and SHK. If they prove reliable and affordable, it seems reasonable that they would be required on certain vehicles. ATRP is the other mandatory system; it would be required on those roads for which the system is implemented to eliminate congestion at toll booths and possibly to implement variable user fees.

The third set of projections, shown in Figure 3, accentuates three system subgroups that present combinations of similar IVHS categories. The first subcategory worthy of attention is labeled ADIS1 and could be called automated navigation and location systems. It combines AVN and AVL systems because they share a similar technological foundation and follow a similar course of development and implementation. These systems have already reached the "system introduction" level of development and should be employed in the majority of commercial vehicles by the year 2000. Transfer to majority private use is expected to take much longer, between 15 and 20 additional years, primarily because of the relatively high cost for the private consumer. It is expected to be 2015 before AVN is adopted by a majority of all automobiles and 2020 before AVL is adopted at that level. Private use coincides with a similar penetration of CRG and there may actually be a linkage between integrative system configuration and consumer demand. In other words, if CRG configurations adopt an in-vehicle map display and user interface, then it is quite likely that the demand for vehicle navigation and location systems will be determined by the deployment and demand of CRG systems, and vice versa. In any case, these systems are never expected to become mandatory.

The second subgroup shown in Figure 3 is the combination of CA and SHK, which has been labeled AVCS1. These systems have also been called "backup" systems because they supplement the driver control task without relieving the driver of all control functions. In actuality, CA is an authentic backup system that takes over the braking function when the driver fails to respond promptly. SHK is intended more to assist the driver by providing full and continuous relief from selected control functions, namely, regulation of vehicle speed through throttle and braking control. The similarity between these IVHS categories is that they represent partial vehicle control and they are both in the fundamental technical research stage. Braking is a common element of these systems, although with unequal emphasis. SHK is expected to advance faster than CA because SHK targets the throttle control function in continuously moving traffic, similar to cruise control, except it involves sensing of distances between vehicles. Braking may also be involved in SHK, but is not the pivotal element. In contrast, braking is the central element, and often the only element, of most CA systems. CA is not just relied on to regulate speed in a fairly clear and continuous path. Rather, CA is intended to detect and avoid obstacles that are either unnoticed by the driver or are moving too quickly for the driver to respond to them. This technical problem appears to be much more difficult. Nevertheless, the pattern of market penetration of these systems is similar and distinct from the more advanced control systems represented by AVCS2. A major feature of this subgroup is that the systems are expected to become mandatory sometime in the future.

The final subgroup is the complete control classification AVCS2. The systems included are the AH and AG systems. In these systems, the driver is relieved of all vehicle control functions for long stretches along the highway or guideway. As described in the individual system description, AH is more than a simple combination or extrapolation of the autonomous CA and SHK technologies. It requires full longitudinal and lateral control of the vehicle in dynamic traffic, including the ability to enter, exit, and merge with traffic. Vehicle guidance may be another element. As shown in Figure 3, these advanced control function are not expected until far into the future. The panel does not expect AVCS2 to be mandatory.

CROSS-CATEGORY ANALYSIS

The panel forecasts are presumably the product of the accumulated knowledge and assumptions of the panelists. In order to fully interpret the projections presented earlier, it is useful to know what factors the panelists considered in making their estimates. The panelists were instructed that they were to be optimistic about the allocation of government funds for IVHS research, development, demonstration, and implementation activities. However, beyond this general guideline the panelists were free to envision whatever sociotechnological dynamics they regarded as likely and important. As part of the Delphi exercise, the panelists were asked to identify and explain those factors that they considered in estimating the market penetration of the 10 categories of IVHS. Specifically, the panelists were asked to delineate what they viewed as (a) the driving forces for implementation, (b) the barriers to market penetration, (c) constructive government policy initiatives, and (d) the expected sociotechnical impacts from adoption of the systems. They listed factors for each of the 10 IVHS categories.

• Barriers to Implementation. The principal barriers to implementation of IVHS were social, economic, and institutional. Only system reliability and human factors could be considered technical. The cross-cutting barriers to implementation are listed in order of importance as ranked by the panelists:

1. Cost to the consumer;
2. Reliability;
3. Lack of demand;
4. Government and manufacturer liability;
5. System effectiveness;
6. Setting appropriate standards;
7. Planning for transition to new, more advanced, technologies;
8. Cost to government;
9. Human factors in system design;
10. Slower traffic, and
11. Limited applicability.

• Driving Forces. What will lead society to adopt these new systems? The panelists addressed this question by identifying and ranking a number of driving forces for adoption of IVHS. In this section only those forces are addressed that cut across a number of system categories. The driving forces for implementation of IVHS listed in order of the ranking by the panelists are

1. Increasing traffic congestion,
2. Desire for improved safety,
3. Motorists' desire for comfort and convenience,
4. Public's demand for travel information,
5. Declining technology and operating costs,
6. Incremental process toward advanced systems,
7. Commuter's preference for highway over rail,
8. Novelty of the technology, and
9. Promise of travel on designed lanes.

• Government Policy. How will the federal, state, and local governments be able to assist in the development and implementation of IVHS? The following lists presents the cross-cutting items ranked highest by the panel:

1. Limit the liability borne by manufacturers and government,
2. Establish effective standards,
3. Federal funding or incentives for research and development,
4. Department of Transportation leadership and commitment,

5. Provide the necessary public infrastructure,
6. Federal funding for construction and operation,
7. State and local enabling legislation, and
8. Dedicate lands and roadways.

• Social Impacts.

• The list of social impacts is similar to the list of driving forces, except that it also includes several negative outcomes. The cross-cutting items in order of rank are

1. Reduced congestion,
2. Improved safety,
3. Increased comfort and convenience for motorist,
4. Driver acceptance of automated control,
5. Increased automobile commuting, and
6. Smoother flow of traffic.

• Consistency Among the Delphi Studies. The forecasts by UM, ARISE, and FHWA were relatively consistent in terms of the pattern and sequence of system development. There was some discrepancy about the timing in system introduction in the United States, with the FHWA placing introduction of most systems about 10 years behind the other surveys. This could be explained by the FHWA's exclusive focus on public highways. However, this explanation is not certain.

Perhaps the most significant finding from the survey is that, given the right conditions, there is likely to be a great deal of progress made in the development of an intelligent vehicle-highway system in North America over the next 10 years. As an indication of things to come, the survey indicates that all of the systems, with the exception of AH, will be introduced by the year 2000. This implies significant technical and institutional advances between now and the turn of the century. It also assumes significant levels of government support and cooperation between the public and private sectors.

COMPARISON WITH OTHER DELPHI RESULTS

In an earlier section, the results of several previous Delphi surveys on IVHS were reviewed. At this point, it seems appropriate to compare the results of the UM survey with those of the ARISE and FHWA projects. For this purpose, two simple, but useful, comparisons of the trends that emerged from the three studies will be made, not for the purpose of selecting the "correct" forecast, but to get a sense of the robustness of the results when all three surveys are combined. The comparisons will examine the forecasted dates for system introduction and for majority use. This type of comparison was made possible by the close similarity in the formats of the questionnaires.

Before a discussion of the results is presented, the differences between the three surveys need to be clarified. These differences may explain some variation in the results. First, there is a difference in the geographic regions that the panelists were to consider in making their forecasts. The panelists in the ARISE survey were mostly from Western Europe and North America; however, there were a few members from Japan and several other countries. Although the panelists were not instructed to consider any specific geographic region, it can be assumed that the diversity in their origins would result in a global perspective on "road transport informatics." There might be some emphasis on Europe because that was the source of the project and the home of nearly half of the panelists. By way of contrast, the UM and the FHWA panelists were all from North America and they were instructed to only forecast technology applications within North America. The FHWA panel was the most restrained by instructions to address only those applications on public highways in the United States.

Second, there were distinct differences in the composition of the panels with regard to professions and sector of employment. The FHWA panel only included experts that were employed by the FHWA. The largest group of ARISE panelists were also employed by government agencies. However, approximately 20 percent of the panelists were employed by industry. A substantial number were also employed by research and academic institutions. The reverse was true of the UM Delphi panel. Nearly 70 percent of the panelists were employed by industry, the remainder were employed by government. None of the UM panelists were employed by research at academic institutions.

A third difference, that one will see immediately when looking at the tabulations of forecasts, is that the panelists in the three surveys did not address identical sets of systems categories. The FHWA survey addressed more traffic control systems, the UM survey addressed more vehicle control systems, and the ARISE survey fell somewhere in between. Furthermore, the system descriptions were not identical, but they were similar enough for useful comparisons.

A fourth difference is that the panelists were asked to make different assumptions regarding social and economic trends. The ARISE questionnaire listed a series of social and economic trends that appeared relatively conventional and were void of surprises. The FHWA questionnaire provided the panelists with both optimistic and pessimistic background scenarios. Only the results from the optimistic scenario are reported here. The UM questionnaire instructed the panelists to assume a healthy economy and that the federal government would be strongly committed to research in this area.

Given that these differences are known, it is worthwhile to review the differences and similarities in the outcomes of the forecasts. Table 1 presents the comparison of expected dates for system introduction from each of the three surveys. Note the overall similarity in the UM and ARISE forecasts. The FHWA forecasts system introduction to be approximately 10 years further into the future for each and every system category, despite taking estimates on the basis of their optimistic scenario. Although no explanation is offered, this expectation may be related to the restriction of addressing implementation only on public highways. Despite the higher values for the FHWA, the pattern of projections is fairly uniform among all three surveys.

CONCLUSIONS

This Delphi study combined both exploratory and normative approaches to forecasting in order to assist the UM IVHS research planning project in anticipating near-term events and in developing a research and administrative strategy designed

TABLE 1 COMPARISON OF EXPECTED DATES FOR SYSTEM INTRODUCTIONS

System category	UM	ARISE	FHWA [1]
Automatic tolls and road pricing	Achieved	1993	2007[2]
Coordinated adaptive traffic control (FHWA)	--	--	1997
Interactive, adaptive traffic control (FHWA)	--	--	2007
Automatic vehicle location	Achieved	Achieved	1996
Automatic vehicle navigation	Achieved	Achieved	1996
Motorist information	Achieved	Achieved	1999
Motorist information 1 (FHWA)	--	--	1991
Cooperative route guidance	1994	1995	2001
Collision warning	1995	--	--
Collision avoidance	2000	2000	--
Speed and headway keeping	1995	2000	2014
Automated highway	2010	2010	2026
Automated guideway	2000	--	--

[1] This is the FHWA prediction for introduction of new vehicle and traffic control systems onto U.S. public highways. These forecasts were based on an optimistic economic scenario.

[2] This projection is specifically for congestion pricing on U.S. highways.

to meet realistic goals. The individual system forecasts were exploratory in the sense that they predicted market penetration on the basis of selected assumptions. The forecasts describe the near-term limits to IVHS developments given sufficient institutional support for these efforts. The listing of factors that may influence the development of these systems is more normative in nature; these lists may serve to illuminate potential opportunities and roadblocks along the path to developing an IVHS capability in North America. Knowledge of these factors also helps to circumscribe reasonable goals and strategies for research and development in the area. This section describes the limitations of the exploratory forecast and how the normative assessment, along with the plan for periodic updates of the Delphi study, provides a sound basis for formulating a research strategy in IVHS.

The survey indicates that progress in the development and the implementation of IVHS will depend on significant technical and institutional advances over the next ten years. The technical problems appear to be fairly well-defined; the design of driver information systems being the most immediate technical concern and the reliability of the advanced vehicle control systems being the crucial long-run issue. The institutional considerations are much less certain. The survey indicates that the turbulent institutional environment has the potential to slow, or even halt, the progress toward a comprehensive IVHS capability in the United States. In fact, the most likely and consequential near-term barriers to development and implementation of IVHS are the possible lack of consumer demand for and acceptance of these new transportation alternatives and the failure of our institutions to support the cooperative development of IVHS. Thus, the successful implementation of IVHS in North America will require a concerted effort on the part of the participating manufacturers, government agencies, and other interest groups to cooperate in resolving the issues of liability, standards, and support for research, development, and demonstrations. Cooperation among the key participants will need to continue through implementation and operation of many of the systems presented because both the vehicle and the highway elements will be fused into a unified whole. Existing institutional arrangements are unlikely to provide adequate support for these efforts and institutional innovation must be sought. The unconventional nature of the institutional problems posed by IVHS limits the ability to predict relevant social, political, and economic events with any degree of certainty.

In his respected critique of forecasting methods in public policy making, William Ascher (*12*) contends that the predictive value of a forecast is determined primarily by the core assumptions on which it was based. If the core assumptions are uncertain or wrong, then the conclusions of the forecast are likely to correspond. If the assumptions are accurate, then the forecast is likely to have greater predictive value. Ascher's insights have significant bearing on the strategy for and use of forecasting in deliberations on the future of IVHS. Because the institutional arrangements are so critical to the progress in IVHS, any forecast of technical advances in this area will be extremely sensitive to anomalies in the institutional arena.

The primary difficulty in providing accurate predictions of developments in IVHS is precisely that the environment for social decision making in North America is complex and rapidly changing, limiting the ability to anticipate events in a turbulent institutional environment. The core institutional assumptions for the survey were highly optimistic and uncertain; should the assumed institutional mechanisms fail to produce the anticipated levels of support, then the predictive value of the forecasts will diminish. For example, should the federal government fail to support the development of IVHS, or should the central institutional actors fail in their efforts to collaborate in this area, then little progress should be expected in the area of cooperative route guidance, which requires substantial levels of government support and institutional cooperation. Therefore, the expert forecasts that resulted from this survey should be viewed with an understanding of the optimistic assumptions on which it was based, and used more as a tool for setting goals and making near-term decisions rather than for predicting the long-run future. The optimistic explanatory forecasts are most useful in assessing the technological feasibility of meeting societal goals regarding the development of particular systems. They should be interpreted as the lower threshold for advancements in these technologies.

With the limitations of the forecasting methodology in mind, a strategy was developed for anticipating institutional events and technological breakthroughs for the purpose of developing and revising the research strategy. First, great emphasis was placed in the Delphi study on identifying and ordering a number of impinging factors, including possible barriers to implementation, driving forces for implementation, government policy initiatives, and the social impacts of IVHS. Knowledge of and sensitivity to these factors will assist in anticipating possible difficulties that lay ahead and in channeling research and administrative efforts more effectively. A relatively open-ended approach was taken in this portion of the survey to encourage originality on the part of the participants and to avoid the possibility of overlooking important factors. Second, the plan is to repeat the Delphi on a periodic basis to update the assessments as events unfold. This will help avoid what Ascher (*12*) terms "assumption drag," where the forecast relies on outdated core assumptions, which accounts for the gross inaccuracies of many policy-related forecasts. This initial Delphi study was designed with the intention to provide a foundation for a series of similar studies in the years to come. For example, the structure of the next Delphi should emerge from the results of the initial study.

Institutional issues notwithstanding, the prospects for rapid development of intelligent vehicle-highway systems in North America suggest that organizations with stakes in the future of road transportation get organized to guide progress in this area and respond swiftly to opportunities as they arise. Motorists demand the freedom of mobility delivered by the automobile. To the extent that IVHS can increase the throughput of existing roadways, reduce vehicle travel times, increase the motorists' comfort, convenience, and safety, and generally provide the motorist with information that either makes the driving time less aversive, more productive, and possibly more entertaining, the motorist freedoms will be extended and a market for these products will be assured. If IVHS can deliver these advantages as expected, the primary question becomes one of cost—to vehicle manufacturer, automobile insurance companies, and ultimately the vehicle owner; to the government operating organization and the local taxpayer; to the U.S. Department of Transportation and the taxpayers. As the cost of these systems tumble, the markets for the products and services will surface.

Elements of IVHS have already been introduced, but the full market potential of IVHS will not be realized until the key actors in the public and private sectors commit to a common vision of "smart" road transportation. The results of the Delphi survey indicate that, under the right institutional conditions, the commercial and noncommercial market will arise in relatively short order. Majority commercial use of most advanced driver information systems is expected by the year 2000. Adoption by the general public is not far behind. This result implies a lot of work between now and the imminent turn of the century. Research on system integration and the human consequences of IVHS must be supported and conducted at an internationally competitive level, systems must be designed and demonstrated to be effective and reliable, new technical standards need to be set, potential shifts in liability risks must be reconciled, operating organizations must be established, and a host of other milestones must be accomplished before a fully integrated and supported IVHS capability is established in North America. The survey of experts was directed at determining feasible progress in IVHS in the years to come and at issues that will require action if this is to be achieved. Perhaps the results can serve to inform the individual stakeholders about what is possible and to help shape a shared vision of IVHS in North America.

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Is Jobs-Housing Balance a Transportation Issue?

GENEVIEVE GIULIANO

Jobs-housing balance has become a major planning and public policy issue. Despite its popularity and apparent acceptance among public policy makers as a solution for traffic congestion and air pollution problems, there is little consensus on what jobs-housing balance means and little evidence that a jobs-housing balance policy would have any significant effect on these problems. The jobs-housing balance policy is premised on the idea that job and housing location choices are closely linked, and that policy intervention is required to achieve a balance of housing and jobs. Existing evidence suggests that the relationship between where people choose to live and work is complex, and may have little to do with job access considerations. Further, patterns of urban growth and travel indicate that balancing occurs as part of the urban development process. It is concluded that jobs-housing balance is not an effective solution for traffic congestion and air pollution concerns. Rather, these problems are better addressed in a more direct way.

Jobs-housing balance has become a major planning and public policy issue. The concept has attracted particular attention in Southern California, where clean air goals have become the central focus of both long and short range planning efforts. Despite its popularity and apparent acceptance among public policy makers, however, there is little consensus on what jobs-housing balance means and little evidence that a jobs-housing balance policy would have any significant impact on traffic congestion or air pollution.

This paper presents an assessment of jobs-housing balance. The concept, its historical roots, and its expected contribution to traffic congestion and air pollution problems are discussed. Then, the reasons why jobs-housing balance policy has attracted much attention among planners and policy makers are explained. Conceptual issues related to jobs-housing balance policy are addressed and existing evidence on patterns of urban growth and travel are evaluated. This evidence suggests that balancing occurs as part of the urban development process, and that commuting patterns are not closely related to jobs-housing balance. Finally, the overall viability of jobs-housing policy is assessed, and recommendations for addressing traffic congestion and air pollution concerns in a more direct way are provided.

WHAT IS JOBS-HOUSING BALANCE?

Jobs-housing balance is a new label for a planning concept that has a long history: the balanced or self-contained community (*1–3*). A balanced community is one in which residents can both live and work. Implicit in the concept is a broad mix of housing types to accommodate households (workers) of a range of income categories. Jobs-housing balance applies this concept to contemporary metropolitan areas. Jobs-housing balance refers to the distribution of employment relative to the distribution of workers within a given geographic area. A community is considered balanced when these distributions are approximately equal, and when available housing choices complement the earning potential of available jobs.

The central concern of jobs-housing balance as it relates to transportation policy is the journey to work. The concept implicitly assumes that workers choose to work as close to home as possible (or that workers choose homes as close to their jobs as possible). If a given area has a much greater concentration of employment than resident workers, workers must be drawn from other areas, leading to longer commutes. Similarly, if resident workers greatly outnumber job opportunities, they must seek jobs in other more distant areas. Even when the number of jobs and workers is approximately equal, long commutes may result if the mix of jobs and housing are not compatible. Thus, all other things equal, the more balanced the community, the shorter the commute.

There are many problems involved in establishing a workable definition of jobs-housing balance. Because of differences in household size, workforce participation rate, etc., it cannot be defined simply as a ratio of jobs to dwelling units. Dwelling units are also not identical, so the mix of housing available within a given area must somehow be compared to the mix of jobs. True balance would involve perfectly complementary housing and job characteristics. In addition, some acceptable range of balance must be identified. For example, is ± 10 percent of the regional average appropriate or achievable? How is such choice to be made?

An equally difficult problem is that of geographic scale. What is the appropriate spatial unit for measuring jobs-housing balance? Regions are balanced by definition, as they are identified as economically self-contained units, but regions are large spatial entities. The concept implies a commuting range: the mix of housing within a reasonable commute distance from a given employment site. However, defining a reasonable commute range is clearly arbitrarily (e.g., is 20 min more reasonable than 30 min?). Furthermore, the dispersed distribution of employment characteristic of U.S. metropolitan areas implies overlapping commute sheds, and jobs-housing balance assessment must somehow incorporate these multiple-employment locations.

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WHY JOBS-HOUSING BALANCE HAS BECOME A MAJOR POLICY ISSUE

Jobs-housing balance policy is proposed as a solution for traffic congestion problems. Congestion is increasing rapidly in high-growth areas as a result of a stable supply of transportation facilities and constantly increasing travel demand. Suburban areas that have become the focus of rapid employment growth such as the I-680 corridor in Contra Costa County, California, or Tyson's Corner, Virginia, have experienced severe increases in traffic congestion (*4*). Central city areas undergoing extensive redevelopment, such as the Wilshire corridor in Los Angeles, are also becoming heavily congested. Jobs-housing balance provides an obvious and apparently simple solution for traffic congestion: move workers and houses closer together, thereby reducing the amount of commuting and its consequent peak-period congestion.

Jobs-housing balance is not complementary to the traditional transportation policy goal of improving mobility. It could be argued in fact that transportation improvements promote jobs-housing imbalances by reducing the cost of travel and thus creating incentives for more travel. Improving mobility is based on accessibility considerations, that is, on the perceived value of providing access to spatially dispersed activity opportunities. Jobs-housing balance, on the other hand, seeks to promote less travel (shorter trips) by developing appropriate mixes of land use.

The link between jobs-housing balance problems and traffic congestion is made in various ways. Rapid employment growth in suburban areas has led to concerns that the future job base would outstrip the local workforce, leading to additional congestion problems. For example, plans for the Hacienda Business Park area in Pleasanton, California, called for about 60,000 jobs at build-out. If all jobs were held by local residents, the workforce would require about 44,000 dwelling units, compared to the existing general plan build-out of 21,400 units (*5*). Consequently, substantial in-commuting of workers from other communities is anticipated. This in-commuting overlaid on a complex pattern of cross-commuting is expected to generate additional congestion.

Jobs-housing balance policy also reflects more general concerns about developing and maintaining communities with an adequate variety of employment and a housing mix affordable to a wide range of income levels. Exclusionary zoning practices, growth limitations, rising development costs, and rapid economic growth have resulted in a shrinking supply of affordable housing in many metropolitan areas (*6–8*). The lack of affordable housing is perceived to be related to traffic problems: in a search for lower-cost housing, workers move to outlying areas far from their jobs, thus incurring long commutes and contributing to traffic congestion (*9*). If affordable housing were available near their jobs, it is reasoned, lower-income workers would not have to commute so far, and traffic congestion would correspondingly decrease.

In addition, jobs-housing balance policy complements growing public pressure to manage or limit growth. Over the past decade, rapid population growth in many areas has created demand for all manner of public facilities, yet has not generated the additional tax revenue to fulfill these demands. Among the most visible of these facility problems is traffic congestion, and it is often the focus of growth management plans or growth limits. Jobs-housing balance provides public agencies with a politically acceptable means of responding to these concerns by placing controls on new development.

Finally, the potential promise of jobs-housing balance may be almost irresistible. In Southern California, for example, the adopted long-range regional plan includes a growth management plan that incorporates a jobs-housing balance element (*10*). The growth management plan promotes jobs-housing balance by redirecting just 9 percent of new jobs and 5 percent of new housing expected between 1984 and 2010 to job-poor and housing-poor areas, respectively. The Southern California Association of Governments (SCAG) land use and travel forecast models estimate that these shifts will result in a 35 percent reduction in vehicle-miles of travel, and commensurate reductions in vehicle emissions. (These estimates have been subject to much criticism and debate among local policy makers and interest groups.) Given such optimistic projections, it is certainly not surprising that jobs-housing balance policy has been met with great enthusiasm by many Southern California planners.

IS JOBS-HOUSING BALANCE A VIABLE POLICY?

Viability of jobs-housing balance policy rests on two critical assumptions: first, that policy intervention is required to achieve jobs-housing balance, and second, that there is a significant causal relationship between jobs-housing balance and travel behavior. This section discusses related conceptual issues and existing empirical evidence.

Policy Intervention to Achieve Jobs-Housing Balance

The history of urban and regional development suggests that jobs-housing balance is part of the development process. As cities grow and decentralize, typically a first wave of residential development is followed by a second wave of commercial and industrial development. This process has been extensively documented both by geographers and by urban historians (*11–13*). This process also makes economic sense. Absent significant institutional or political barriers, jobs and workers would be expected to be located in close proximity to one another. Because travel constitutes part of the costs of providing goods and services, efficient producers would seek to minimize this cost. Excessive travel costs would generate higher production costs that would in turn reduce a region's competitive advantage.

Barriers to Jobs-Housing Balance

The argument for policy intervention therefore hinges on whether institutional or political barriers to jobs-housing balance exist. There is certainly reason to suspect such barriers do exist. First, current fiscal problems of local governments could result in policies that would inhibit jobs-housing balance. Local governments have responded to the loss of traditional revenue sources in part by favoring revenue-enhancing development (retail and commercial, as well as other nonresidential uses) and by avoiding development that could add to municipal costs (for example, lower-cost housing) (*14*). Moreover, new development is expected to pay its own way (*15*). Thus, incentives facing both public and private sectors promote the most profitable types of development. Consequently, redevelopment projects typically replace deteriorated housing with offices and luxury apartments in central cities, whereas shopping centers and research parks have become favored accompaniments to large single-family housing tracts in the suburbs. Such policies may inhibit provision of housing in jobs-rich areas or job formation in housing-rich areas.

Another potential barrier to jobs-housing is the exclusionary zoning practices characteristic of many suburban municipalities (*9*). Local jurisdictions have used zoning powers not only to protect fiscal resources but also to protect existing residents from undesired land uses (*16*). Low-income housing is a frequent target of such policies, as are uses perceived to have any negative environmental impact. Such practices, particularly if used extensively, can restrict the supply and location of low-cost housing opportunities.

Evidence of Jobs-Housing Balance

Given that it is certainly possible for mismatches between jobs and housing to exist, it is appropriate to determine whether such mismatches have in fact been observed, and whether the balancing process described earlier can be documented. Unfortunately, data limitations restrict the extent to which these issues can be explored. Some partial evidence is described here.

The sequential process of population and employment growth is presented in Table 1. It gives population and employment data from 1940 to 1985 for Orange County, California, one of the five counties that make up the Los Angeles metropolitan area. Orange County grew rapidly as a residential suburb of Los Angeles workers, beginning in the 1950s. Jobs began to follow the population in the 1960s and 1970s, and by 1980 the county was achieving balance. This process is indicated by the change in the employment-population ratio from a low of 0.19 in 1955 to 0.46 in 1985.

Another way of illustrating this process is by comparing the number of resident workers with the number of jobs within a given area. Table 2 presents this comparison for two different years, 1974 and 1988, for the five counties within the Los Angeles metropolitan area. These comparisons are only approximate, as the job data are generated from wage data (and thus exclude self-employed workers), whereas the worker data is based on updates of U.S. census data. Los Angeles, the most heavily urbanized county, was balanced in both years, with an approximately equal number of resident workers and jobs. Orange County is moving toward balance; the increase in the number of jobs was greater than that of resident workers over the time period. Riverside-San Bernardino and Ventura counties, on the other hand, became less balanced over the same period. These are the region's outlying counties that are the new residential suburbs. As the development process proceeds, these counties should shift toward balance in the 1990s.

A third piece of evidence regarding the distribution of jobs and housing in the Los Angeles region is shown in Figure 1, in which the ratio of jobs to occupied housing units is graphed as a function of distance (in miles) from the Los Angeles

TABLE 1 POPULATION AND EMPLOYMENT FOR ORANGE COUNTY, CALIFORNIA

Year	Population	Employment	E/P Ratio
1940	135,900	41,800	.31
1950	219,400	46,600	.21
1955	434,800	81,500	.19
1960	748,900	165,800	.22
1965	1,175,800	293,100	.25
1970	1,456,700	418,900	.29
1975	1,729,300	568,800	.33
1980	1,932,700	843,800	.44
1985	2,088,300	961,600	.46

Source: Compiled from U.S. Census data, County of Orange Census updates, and State of California Economic Development Department data.

TABLE 2 LABOR SUPPLY AND DEMAND BALANCE TRENDS IN THE LOS ANGELES REGION

	1974			1988			
County	Resident Workers	Jobs	Ratio Wrks/Jobs	Resident Workers	Jobs	Ratio Wkrs/Jobs	Change in Ratio (%)
Los Angeles	3,263,000	3,082,500	1.059	4,173,100	4,121,900	1.012	-4.4
Orange	775,300	565,400	1.371	1,345,600	1,140,100	1.180	-13.9
Riverside/ San Bernardino	465,400	351,900	1.323	939,700	648,700	1.449	9.5
Ventura	171,700	124,000	1.385	351,700	230,600	1.525	10.1

Source: State of California Employment Development Department.

central business district (CBD). The data are 1987 estimates generated by the regional planning agency. Given a regional average of 1.35 workers per occupied housing unit, Figure 1 shows that most of the urbanized region is approximately balanced. The downtown core area is job rich, but not to the extent that might be imagined. Further, the area 5 to 10 mi from the CBD is job poor, suggesting a surprising amount of balance overall within the total 10-mi range. Finally, the area from 10 to 50 mi from the CBD is quite balanced, and it contains two-thirds of all the region's housing units and jobs.

These data support the idea that jobs-housing balance occurs as part of the urban development process, at least at the gross spatial level for which data are available. Admittedly, these data cannot capture any mismatches that might exist between the types of jobs and housing. However, such mismatches seem unlikely. When job growth is disaggregated by sectoral composition (e.g., manufacturing, services, wholesale, and retail trade), employment increases are found in all major sectors throughout the region. Moreover, because jobs within each sector cover a range of skill and wage levels, it appears that a large mix of jobs is available throughout the region.

Additional evidence that jobs-housing balance exists is provided by an earlier study that examined the degree of homogeneity of local municipalities (*17*). The purpose of the study was to determine whether the Tiebout hypothesis (which states that individual households choose residences located where public facilities, amenities, and the associated tax burden match their preferences, a process resulting in homogenous communities) was supported by the actual make-up of different communities. If in fact households "vote with their feet," population characteristics such as income, ethnicity, or education level should be relatively homogeneous within municipalities and heterogeneous between them. Using 1970 census data from all municipalities with a population of at least 1,000 in the 12 SMSA's of Pennsylvania, it was found that population characteristics within municipalities were similar to that of the region as a whole. That is, there was as much heterogeneity within municipalities as between them, prompting the conclusion that the stereotypical homogeneous suburban community had little basis in fact. Although exclusionary practices may be widely used, the results of this study suggest that they may not be effective in achieving homogeneity within communities.

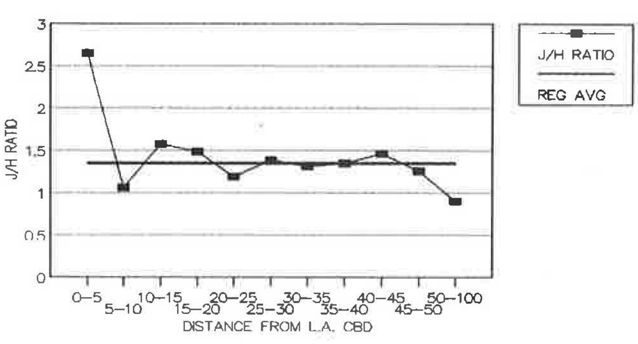

FIGURE 1 Jobs-housing ratio by distance from Los Angeles CBD, 1987.

Jobs-Housing Balance and Commuting

The second premise of the jobs-housing balance argument is a causal link between balance and commuting. Conceptual issues related to jobs-housing balance and commuting are discussed first.

Factors Affecting Where People Live and Work

There are several reasons why this causal link between commuting patterns and jobs-housing balance may not exist. First, it is not clear that living close to work is a high priority for most people. Studies of residential location choice indicate that many factors beyond housing price and characteristics are involved in where people choose to live. These include neighborhood quality, availability of parks and other amenities, quality of schools, racial and ethnic mix, microclimate characteristics, etc. (*18–20*). Thus, even if balance between worker and housing attributes could be demonstrated, it does not follow that workers would in fact choose to live in the local area.

Second, compared to housing costs, commuting costs are small (*21*). Because housing costs generally decline with distance from major employment centers, additional commuting costs can be traded off for cheaper housing. Thus, many households choose to live in outlying areas, consume more housing, and commute further to work. Notable here is the strong preference among U.S. households for single-family housing. These two points suggest that it is difficult to predict where workers might live, because their willingness to incur longer commutes vastly increases the number and variety of housing choices available to them.

Third, there are a growing number of multiple-worker households. Locational decisions for these households are even more complex, and living near one household member's job may mean living far from another's.

Finally, jobs-housing policy must rely on the regulation of structures, such as provision of housing units at specific affordability levels, or provision of commercial or industrial square footage, yet there are no assurances regarding the use of these structures over time. Household mobility is high in the United States, and most people hold several different jobs over their working careers. Employer mobility is increasing as well, as a greater proportion of U.S. industry is made up of "footloose" activities. In some areas, institutional barriers like rent control or property tax policy may inhibit residential relocation even when jobs change. For example, California's Proposition 13 reassesses property value only at the time of sale or major structural change. Thus, even if the mix of residential units and commercial and industrial sites were somehow perfectly matched, and even if the resulting jobs base were perfectly matched with the resident workforce at some point in time, balance would likely be short-lived.

Given all of these considerations, then, it would appear that the only way to guarantee that workers live near their jobs would be to mandate the housing choices of workers. Although this idea brings all the ills of the 19-century factory town in mind, there are several examples of related efforts in more recent years, such as affordable housing programs that give priority to local workers, employer-based housing programs (for example, on-campus university housing offered often at below-market rates to faculty and staff), or priority hiring programs for local workers.

The relationship between jobs-housing balance and traffic congestion is also subject to question. The journey to and from work is not the only source of peak-period travel. In fact, recent research indicates that work trips account for only about one-fourth of all weekday person-trips, and that work trips do not constitute a majority of trips even during peak periods. Nonwork travel is the single largest category of travel and is increasing at the most rapid rate (*22*). The effect that jobs-housing balance might have on nonwork trips is uncertain. For all these reasons, then, jobs-housing balance is probably not significantly related to commute patterns, and jobs-housing policy is unlikely to have much effect on traffic congestion.

Evidence of Jobs-Housing Balance and Commuting

The demonstration of a significant relationship between jobs-housing balance and commuting patterns is critical to the policy intervention argument. Interestingly, an extensive literature review revealed that this issue has been given little attention, and that little empirical evidence exists to support or refute the idea. The concept of jobs-housing balance influencing commuting patterns is reasonable. Large concentrations of jobs (downtowns, major suburban centers) have to draw workers from a large commute shed. Conversely, when jobs are dispersed (e.g., have a similar distribution to that of population), commutes should be shorter.

Some related evidence is provided by 1980 U.S. census data. Table 3 presents mean commute times for two residence location categories (inside the central city, outside the central city) and three workplace categories (CBD, inside central city; and outside the CBD, outside central city). Percent shares of total commuting are also listed. Table 3 indicates that CBD workers have the longest commute, whereas commuters who both live and work outside the central city have the shortest commute. These suburban areas presumably have more dispersed employment. Commuters who both live and work in the central city have the next shortest average commute, but it is notably longer than that of the suburb-to-suburb commuters.

The national data do not permit controlling for possible concentrations of employment outside the CBD. For example, it is possible that the inside central city jobs are more clustered than the outside central city jobs, thus explaining the longer commutes. The 1980 Los Angeles region commute flow data can be used to further explore this idea. Table 4 presents mean commute distances for workers by place of work. Work locations are classified as centers if they have at least 10,000 jobs and a density of at least 10 jobs per gross acre. Core centers refer to the centers clustered around downtown Los Angeles; other categories are self-explanatory. The employment-population ratio for each location category is also presented.

The table indicates that, as expected, workers with jobs in centers have longer commutes than workers with jobs outside centers, except in the case of the outer counties. However, within each category (center, not within center), there is no apparent relationship between balance and average commute distance. Indeed, as a group the suburban county centers are

TABLE 3 JOURNEY TO WORK TRAVEL TIMES BY ORIGIN-DESTINATION CATEGORIES IN THE LARGEST URBANIZED AREAS, 1980 (*23*)

	Place of Residence			
	Inside Central City		Outside Central City	
Place of Work	Travel Time (min)	% Share of Trips	Travel Time (min)	% Share of Trips
CBD	33.4	4.5	42.1	3.7
Inside CC, Outside CBD	25.5	24.7	33.0	14.3
Outside CC	29.9	6.8	19.5	45.7

TABLE 4 MEAN COMMUTING DISTANCE AND EMPLOYMENT-POPULATION (E/P) RATIOS BY JOB LOCATION

	Within Centers		Not Within Centers	
	Distance (Miles)	E/P	Distance (Miles)	E/P
LA Downtown	13.9	1.47		
Other Core Centers	11.2	1.14		
Other LA County Centers	13.2	1.80		
LA County Total	13.0	1.48	10.8	.32
Orange County	11.3	2.80	9.9	.39
Outer Counties*	8.3	2.27	8.8	.25
TOTAL	12.7	1.55	10.3	.32

*Riverside, San Bernardino, Ventura.

far more unbalanced than even downtown Los Angeles (assuming that the employment participation rate is relatively constant throughout the region), yet average commute distances are shorter. Commutes for workers with jobs not within centers exhibit the same patterns; outer county workers have the shortest commutes.

These results suggest that there are other factors involved that contribute to generally shorter commutes in suburban areas independent of structural or jobs-housing balance considerations. These may include the presence of negative externalities in central city areas; the relative homogeneity of suburban areas (making it easy to locate near one's job, or conversely negating any advantage to living far from one's job); the concentration of highly specialized jobs in central core areas, or the preferences of workers for low-density environments.

Cervero (*24*) focuses on the jobs-housing mismatch issue in his recent study of suburban employment centers (SECs). Defining a 3-mi radius as the appropriate commute shed for each SEC, he notes that the observed high average rents and selling prices of the available housing implies that it would be unaffordable to many SEC workers. However, such a comparison does not consider multiple-worker households, and affordability is determined by household income. Moreover, the availability of secondary wage earners has been identified as primary motivation for the suburbanization of back-office activities, e.g., shifting lower-wage jobs to suburban locations in response to labor force ability (*25*). Also, a 3 mi radius implies a much shorter commute range than typically exists within U.S. metropolitan areas (*26*).

Cervero (*24*) also reports average work trip distance and time for 12 of the SECs in his sample as 11.1 mi and 24 min, respectively. He contrasts these with Pisarsky's (*26*) national estimate for the average suburb-to-suburb commute of 9 mi and 18 min, on the basis of 1980 census data, and attributes the difference to rising congestion and widening jobs-housing imbalance. Although the difference fits with the jobs-housing mismatch explanation, it is also possible that the difference is caused simply by sampling differences, because the SEC data come from a variety of sources, and may nor may not be representative of suburban employment centers in general.

Only one recent study has dealt directly with the relationship between jobs-housing balance and commuting. Using 1985 cross-sectional data from the suburbs of San Francisco, Cervero (*9*) found that longer commutes are associated with jobs-housing mismatches, particularly for low-wage workers in affluent suburban employment centers. Housing cost and availability were found to be significant explanatory factors in residential location choice, and in areas where the housing stock within the employment zone did not match the characteristics of workers in the zone, more interzonal commuting was found to occur. The Cervero study also documents jobs-housing imbalances within local communities both in the San Francisco and Chicago regions. This study provides some limited evidence that jobs-housing mismatches can lead to longer commutes.

Commuting Patterns in Planned Communities

Another approach to examining the relationship between jobs-housing balance and commuting is to look at commute patterns of workers living in planned communities. Planned communities are by definition balanced; they are conceived of as self-contained units with a mix of housing and jobs. Planned communities provide balance opportunities: job and housing mixes are matched so that people have the opportunity to work close to home. The two most famous post-World War II planned communities in the United States, Reston, Virginia and Columbia, Maryland, are both considered successful in terms of developing a balanced community. If jobs-housing balance promotes shorter commutes, such patterns should be evident in planned communities. An extensive study of planned communities in the United States was undertaken during the 1970s. Part of the study involved a comparative analysis of travel patterns between 15 matched pairs of planned and unplanned communities (*27*).

Table 5 presents some findings regarding the commute characteristics of heads of households in the two groups of communities. The data are based on surveys conducted in 1972–1973. The degree of similarity between the two groups is remarkable. Workers in planned communities are not more likely to live and work in the same communities than their counterparts in unplanned communities. It is important to note that the average share of workers working in their home communities reported by Zehner (*27*) favorably corresponds with Cervero's reported findings based on 1985 data—about 20 percent for suburban communities with large employment centers (*4*). The propensity to live and work in the same community does not appear to be related to jobs-housing balance. Even in communities with large job concentrations (e.g., more jobs than workers), the majority of workers in

TABLE 5 COMPARISON OF JOURNEY TO WORK CHARACTERISTICS IN PLANNED AND UNPLANNED COMMUNITIES (*27*)

	PLANNED COMMUNITIES	UNPLANNED COMMUNITIES
Share of Workers Employed in Community of Residence	14.0%	16.0%
Median Worktrip Time	25.0 min	25.0 min
Median Worktrip Distance	9.9 mi	10.8 mi
Percent of Trips 0 ≤ 5 mi	27.0 %	30.0 %
Percent of Trips > 5 mi ≤ 15 mi	37.0 %	34.0 %
Percent of Trips > 15 mi	36.0 %	36.0 %
Auto Mode Share (Drive Alone + Carpool)	94.0%	94.0%

the Zehner study were found to work outside their home community.

Table 5 also indicates that work trip characteristics, including distance, travel time, and mode, are almost identical for workers in the two groups. Moreover, median distance to work for planned community residents was found to be only weakly related to jobs-housing balance. These results suggest that many factors are involved in journey-to-work distances, and that planned communities do not necessarily promote shorter commutes. As discussed early in this section, residential location choice is a complex process in which job proximity considerations may play a minor role.

Jobs-Housing Balance and Wasteful Commuting

Another perspective on the potential effectiveness of jobs-housing balance policy is provided by the urban economics literature. Several recent studies have tested the relationship between commuting distances and the distribution of jobs and housing (*28–30*). The most popular urban economic theory hypothesizes that workers choose residences by trading off commuting and housing costs so as to maximize utility. Workers are willing to commute only to the extent that its cost is offset by housing cost savings. When all jobs are assumed to be located in the center of the city, this optimization process results in a declining density distribution of housing around the center that in turn determines the total amount of commuting (*31*). The total amount of commuting associated with the equilibrium solution is thus a theoretical minimum. In essence, this means that workers (in the aggregate) are located as close as possible to their jobs.

Comparing the prediction of this ideal model with observed commute patterns has indicated that actual commuting far exceeds the predicted amount. This extra or unexplained commuting has been termed "wasteful commuting" (*28*). It is the amount of commuting that cannot be explained by the relative locations of jobs and housing. Hamilton's study indicated that actual commuting was about 8 times as great as that predicted by the model. Indeed, actual commuting was almost as great as that predicted by a completely random distribution of workers and jobs. White (*29*) controlled for the actual distribution of jobs and workers, and Cropper and Gordon (*30*) controlled for differences in housing preferences. Cropper and Gordon's study of the Baltimore area estimated the average required commutes to be about 5 mi, compared to the actual average commute of 10 mi. Simply stated, these studies indicate that a large proportion of all commuting cannot be explained by job access considerations, housing preferences, or other such factors.

Can Jobs-Housing Balance Be Justified as a Transportation Policy Objective?

The available evidence suggests that jobs-housing balance is not a transportation issue. Rather, jobs-housing balance occurs as part of the urban development process. Metropolitan areas expand as households seek lower-cost housing at the periphery; as these new settlements develop, this growing labor force attracts employers. This characterization of the urban development process implies that the outermost suburbs will always be unbalanced, despite policy intervention. Another Southern California example is illustrative. Rancho Santa Margarita is a new planned community located in southeast Orange County. Rancho Santa Margarita suffers from serious transportation access problems. Plans for a future freeway that would traverse the area are in progress, but construction is years away. Santa Margarita developers set out to develop a balanced community, in part to offset transportation problems. The Rancho Santa Margarita marketing program includes an aggressive campaign to attract employers. In contrast, residential building permits are contingent on phased transportation infrastructure requirements, and consequently residential construction is lagging behind demand. Thus, although employment is being promoted and housing production is being constrained, local households far outnumber local jobs.

Similarly, downtown areas will remain unbalanced, primarily because of high land values that make only very high density development economically feasible. Given the preference of many workers for lower-density living environments, even aggressive downtown housing programs are not likely to result in significant reductions in commuting. However, the downtown core represents a declining share of total metropolitan employment, and therefore, from a metropolitan perspective, it is a shrinking part of the transportation problem.

The available evidence also suggests that the relationship between jobs-housing balance and commuting holds only in general terms. Although isolated examples of jobs-housing mismatches have been identified at the community level, there is little evidence suggesting that such mismatches have significantly affected commuting patterns. Regulatory policies aimed at improving jobs-housing balance are thus unlikely to have any measurable impact on commuting behavior, and therefore cannot be justified as a traffic mitigation strategy.

TRANSPORTATION SOLUTIONS FOR TRANSPORTATION PROBLEMS

Jobs-housing balance has emerged from concerns about the lack of affordable housing both in central cities and suburbs, the desire to maintain the economic viability of downtowns, the prevalence of exclusionary zoning practices that have restricted the supply and variety of housing available in suburban areas, and the emergence of employment centers in suburban areas. All of these issues are made more complex by the more generalized concern over growing traffic congestion. Jobs-housing balance puts these problems together and attempts to solve all of them. It is important to note that the concerns that have motivated the current interest in jobs-housing balance are valid. The fact that jobs-housing balance is unlikely to solve transportation problems does not imply that such policies cannot play a role in solving other urban problems. Rather, the point is that these problems are more likely to be solved if separated and dealt with directly. In the case of traffic congestion, this means focusing directly on congestion—on the fact that for many hours each day travel demand exceeds supply.

Travel behavior research shows that travel decisions are made on the basis of cost and convenience (*32*). Because traveling costs both time and money, people choose alternatives that minimize their travel expenditures. They will choose when, where, and how they travel on the basis of the relative cost and convenience of alternatives available. Use of the private automobile is heavily favored under current conditions. It is clearly the most convenient means of travel, and individual travelers do not pay the full costs of automobile trips. Individual travelers do not pay for the congestion or the environmental pollution they cause, and they often do not directly pay for other costs such as parking, street maintenance, and police enforcement. Consequently, like any other consumer good that is priced too low, the single-occupant automobile is used too much, and peak-period congestion is the result.

It is beyond the scope of this paper to provide an analysis of urban congestion. However, to briefly summarize, solving the problem requires either increasing the supply of transportation facilities, increasing their productivity by carrying more people with fewer vehicles, or reducing demand. Much research has been conducted on the issue of urban traffic congestion (*33–36*). Some of the most promising strategies proposed for addressing urban congestion include improved transportation system management (e.g., signal coordination, bypass lanes, and ramp metering); transportation demand management (parking management, alternative work hours, and ridesharing programs); transit and pedestrian-oriented site design; expansion and diversification of public transit services; and congestion pricing.

However, travel behavior research also indicates that the short-run demand for automobile travel is relatively inelastic, meaning that large changes in cost or convenience will initially generate only small changes in demand. Thus effective congestion mitigation strategies are often costly, politically unpopular, or both. It is therefore tempting to focus on indirect (and politically popular) policies like jobs-housing balance. However, solving traffic congestion problems will require direct policies—policies that influence the choices of individual travelers.

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Manufacturers' Views of Transportation's Role in Site Satisfaction

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Over the last several decades, many large manufacturers have moved to North Carolina, or expanded operations there, generating a sort of economic resurgence, particularly in metropolitan areas. Many North Carolina counties still recruit companies from outside—the classic "buffalo hunt" style of economic growth. Concerns about taxes, labor, transportation, and quality of life are often mentioned as factors in the siting decision. However, less is known about these companies once arrived, or companies that sited in North Carolina in earlier years, or their subsequent satisfaction with their decisions. This study reports on a 1989 survey of North Carolina manufacturers that focuses on manufacturing siting decisions and the role of transportation in site satisfaction. A representative sample of 504 manufacturers in North Carolina answered a 5-page questionnaire about present manufacturing inputs and outputs, modes of shipment, company size and unionization, concerns about the present site, and suggestions for policy actions that would improve site satisfaction. Over 93 percent of respondents were satisfied with their present locations; many cited good labor supply, transportation access, lack of unions, and lower taxes as reasons for the choice. Transportation factors also rated high in site satisfaction. Of major concerns, manufacturers were most worried about the quality, trainability, and availability of labor, particularly public school education, work attitudes of workers, crime rates, utility service, and environment. Concern about more transportation access ranked lower on the list of 34 items. The findings varied somewhat by region or industry group, but nowhere did strong concerns for transportation surface. The study concludes that transportation access in North Carolina is presently good in the manufacturers' eyes—a real plus—allowing them to be more concerned about fundamental labor and worker attitude issues, which are seen as a real threat to the competitive economic future of the state.

Over the last 30 years, numerous manufacturers have moved their facilities to the Sunbelt, in search of lower taxes and wages and other amenities. Typical "come-on" recruitment efforts tout the region's quality-of-life, transportation access, low tax rates, and labor costs and availability. Companies from northern rust-belt states are actively recruited in this fashion. Much less is known, however, about postsiting satisfaction of these companies, or earlier movers. A survey of 500 North Carolina manufacturers' opinions about their location is described, and the present transportation and other concerns they now express are discussed.

THE NORTH CAROLINA INDUSTRIAL PATTERN

The structure and geography of manufacturing in North Carolina are based on patterns that were established over many decades. Thus, an understanding of present and likely future trends requires an appreciation of the state's rather unique history of industrialization. Manufacturing has been a major part of the North Carolina economy ever since the late 19th century. After about 1880, numerous textile mills were built throughout the Piedmont area (*1*). The rapid expansion of this industry in cities, towns, and rural areas provided a welcome employment alternative to farming in the post-Civil War era. Cigarette manufacturing and the furniture industry soon followed and, with textiles, formed the "Big Three" as pillars of the state's economy. Textiles and furniture plants were noted for their tendency to locate not in cities but rather in towns and rural areas. This practice was in contrast to the experience of other newly industrializing regions where the clustering of factories provided the basis for the growth of large cities. In North Carolina, both industry and people came to be broadly dispersed and large cities did not emerge (*2*), a pattern called "rurban" (rural-urban blend). By the late 20th century the state was still one of the few to have less than half of its population classified as urban by the census (48 percent in 1980). Yet by 1986, North Carolina ranked eighth nationally in terms of employment, value added, or value of shipments in manufacturing. Furthermore, fully 12.7 percent of the total population had a factory job, the highest such proportion for any state. By that measure, North Carolina is the most industrialized in the nation even though it is still one of the least urbanized.

Recent growth has involved a good deal of diversification. Even though the textile industry lost 26,000 jobs, a host of other industries grew to more than offset the loss in mill jobs (Table 1). During this period of growth and diversification, two major new trends were affecting the state. One was the emergence of the international economy, wherein multinational companies placed production facilities all over the world wherever they could achieve more competitive production costs. A second trend was the appearance of the information processing economy, in which the office replaced the factory as a primary place of work. The modern office tends to locate in clusters that are close labor supplies, business services, and various amenities. Proximity to a major commercial airport is often important; the new office economy is synonymous not just with cities but with large ones. Charlotte has experienced a 10-fold increase in office space between 1970 and 1990. Raleigh, Greensboro, Winston-Salem, and several other cities have had major increases as well. Otherwise, the office space explosion that has been driven by the information processing economy has not extended much to the smaller cities and certainly not to the rural areas. These recent trends have tended to favor growth in metropolitan areas, whereas North

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TABLE 1 MANUFACTURING EMPLOYMENT IN NORTH CAROLINA

Industry (SIC)	Employment (thousands) 1980	1989	% Change 1980-89
Food (20)	44.0	50.5	14.8%
Tobacco (21)	24.2	21.7	-10.3
Textiles (22)	245.8	219.3	-10.8
Apparel (23)	88.0	82.8	-5.9
Wood (24)	35.5	36.5	2.8
Furniture (25)	81.5	87.6	7.5
Paper (26)	21.3	22.9	7.5
Printing-Publishing (27)	20.5	30.3	47.8
Chemicals (28)	39.4	44.0	11.7
Rubber-Plastics (30)	27.1	34.7	28.0
Fabricated Metals (34)	26.0	30.7	18.1
Non-Elec. Mach. (35)	49.5	63.8	28.9
Elec. Equip. (36)	55.3	57.1	3.3
Other Mfg. (29,31,32,33,37,38,39)	61.9	85.9	38.8
TOTAL	820.0	867.8	5.8%

Source: N.C. Employment Security Commission, Labor Force Estimates

Carolina rural counties have experienced slower growth or even economic stagnation. Rural areas are not only losing some of their manufacturing base, but they are not able to attract office complexes or the more high-technology industries that are substantial elements of the information processing economy.

A detailed view of intrastate trends was obtained by using a 14-group classification of counties (*3*). This classification was created by merging five functional classifications that were based on manufacturing specialization, overall economic structure, socioeconomic character of the population, internal accessibility, and external accessibility. Employment patterns of the resulting group of 14 county types are presented in Table 2. Descriptive terms are applied to each group. Suburban are those counties that are close, usually adjacent, to metropolitan counties. Fringe counties are generally a second ring away from the metropolitan areas. Rural groups tend to lack cities of at least 20,000 and are not adjacent to metropolitan areas. Many counties lack towns of over 5,000 people. The unique small-city group contains cities such as New Bern, Greenville, and Fayetteville. They form a distinctive group in the overall classification because they have unusually high proportions in military or civilian governmental employment. The patterns exhibited by the two most rural groupings, fringe and rural, are revealing. In every case the fringe groups have higher proportions in manufacturing, ranging from 28.4 to 41.1 percent, than does the total state. In all cases, manufacturing growth was negative or modest, ranging from a loss of 7.7 percent to a gain of 5.4 percent. In every case, nonmanufacturing employment growth was less than the statewide increase of 33.3 percent, ranging between 15.5 and 27.9 percent. The real disparity in North Carolina thus lies in the fact that the large metropolitan counties are not only growing faster but that the quality of this growth, in terms of income levels, for example, is higher. Perhaps the worst implication of this, as noted by Day (*4*), is that the economic inequalities among North Carolina counties have begun to widen again after years of moving toward parity. The possibility of attracting substantial new industry may be over, but rural areas would do well to hang onto the industry that they have already. In general, it seems to look more closely at current manufacturers to determine how they perceive themselves to be faring in the contemporary economic environment.

RESEARCH METHOD

Manufacturers' opinions of their satisfaction with current locations were sought by sending a questionnaire to a random sample of about 2,600 plants. The sample group was drawn from the 6,800 factories listed in the 1988–89 North Carolina Industry Directory, compiled by the Business-Industry Division of the North Carolina Department of Community and Economic Development

A stratified sampling procedure was used in drawing the sample. The 14-group classification of county types presented in Table 2 was used for this purpose, yielding groups of varying size. In most cases, the names and addresses of 200 units were drawn from each group but in one large group the sample size was increased to 300. Several groups had total populations of fewer than 200, in which cases the entire population was sampled. The probability of selection from each group was proportional to the plant's employment size. This procedure favored the larger plants and ensured that the responses would represent a large proportion of all North Carolina manufacturing workers.

Each questionnaire was mailed with a cover letter that was addressed by name to the top official at each plant as indicated in the industrial directory. The mailing also included a self-addressed, postage-paid envelope. Mail out began in mid-November, 1989, and took about 3 weeks to complete. Returns were accepted until late January, 1990. A total of 504 usable responses were received, about 20 percent of the total. Several companies formally declined to respond, and another 15 questionnaires were returned as undeliverable. A dozen or so came back after the cut-off date and were not used, except for several narrative comments. Most analyses were conducted through the use of the SAS statistical package.

CHARACTERISTICS OF RESPONDENT MANUFACTURERS

Because not all 504 questionnaires included answers to every question, the response rate on any given item was slightly less than 500. Table 3, for example, indicates that 496 respondents provided data on their employment; this totaled 148,860 workers, or 17.2 percent of the North Carolina total in 1989. Mean employment was 300 per plant. About 28 percent of sampled firms employed fewer than 50 persons, smaller than the statewide average of 54 percent (Figure 1). Very large plants, by contrast, made up 1 percent of the sample, but only 0.22 percent of the North Carolina total. In other words, the sample is skewed somewhat in favor of larger plants.

Table 4 presents the distribution of responses according to major industry groups. The four major industry groups described as "traditional labor intensive" were well accounted for with 35 percent of employees, but these industries make

TABLE 2 EMPLOYMENT CHANGE IN TYPES OF NORTH CAROLINA COUNTIES

County Group	No. of Counties	Rural-Urban Index	Non-Agricultural Employment % in Mfg. 1987	% Change Mfg. 1980-87	% Change Non. Mfg. 1980-87	Farm Employment % Total Employment 1987	% Change 1980-87
I. Service-Travel Govt.-Education Economy (Metro Areas) Electronics-Elec. Equip. (Computers Mfg.)							
(1) High Socio Econ. Status/ High Access	(8)	2.3 (Metro)	16.9	3.9	37.4	0.7	-22.5
II. Traditional Manufacturing Economies							
(Textiles, Apparel, Furniture and Food)							
(2) High Socio Econ. Status/ Good Access	(7)	2.9 (Suburban)	38.9%	3.3%	26.5%	1.9%	-25.1%
(3) High Socio Econ. Status/ Fair Access	(4)	5.3 (Fringe)	28.8	-7.7	15.5	4.3	-32.1
(4) Low Socio Econ. Status/ Good Access	(8)	3.8 (Suburban)	41.5	7.7	30.8	4.0	-22.5
(5) Low Socio Econ. Status/ Fair Access	(10)	5.4 (Fringe)	41.1	3.7	27.9	4.7	-23.5
(6) Low Socio Econ. Status/ Low Access	(9)	8.1 (Rural)	36.5	14.3	22.6	8.6	-21.1
(7) Very Low Socio Econ. Status/	(4)	6.3 (Fringe)	32.9	5.4	18.6	6.0	-33.5
(8) Very Low Socio Econ. Status/ Fair Access	(7)	5.7 (Fringe)	28.4	3.6	15.5	10.8	-32.8
(9) Very Low Socio Econ. Status/	(8)	7.6	37.2	11.6	35.9	6.2	-33.1
(10) Socio Econ. Status/Low Access	(3)	8.3 (Rural)	20.8	6.2	33.3	4.5	-23.5
III. Varied Economies, Diverse Mfg.							
(11) Varied Mfg. Socio Econ. Status/ Low, Fair Access	(9)	5.7 (Fringe)	31.4	-0.8	24.6	6.2	-29.7
(12) Non-Mfg. Socio Econ. Status/ Medium, Fair Access	(3)	4.3 (Small City)	10.0	4.5	21.4	1.7	-37.1
(13) Non-Mfg. Socio Econ. Status/ Low, Fair Access	(12)	7.2 (Rural)	7.6	-7.6	34.9	3.9	-26.2
(14) Non-Mfg. Socio Econ. Status/ Very Low, Fair Low Access	(8)	8.4 (Rural)	16.4	-5.7	16.8	17.5	-27.4
North Carolina - All Counties		5.8	24.9%	3.7%	30.5%	3.0%	-27.9%

Note: The Rural-Urban Index is an average for all counties in each group. The integer values are taken from the "Beale Code," by which counties are assigned a code value of 0 to 9 depending on their status. Values of 0 and 1 are counties in MSAs of our 1,000,000 population. There are none of these in North Carolina. Values of 2 and 3 are for counties of smaller MSAs. Categories 4 and 5 are non-MSA counties with at least 20,000 more residents. Groups 6 and 7 have urban populations between 5,000 an 20,000. The first two are not considered to be "rural." The code values used for North Carolina are those contained in Chmura, Christine and Ihrig, Jane, "Changes in Manufacturing Employment in North Carolina Counties, 1980-85," Economic Review, Federal Reserve Bank of Richmond, September-October 1989, pp. 37-46.

up 49 percent of state manufacturing employment. On the other hand, the other durable groups, which account for 27 percent of the actual North Carolina employment total, contributed 40 percent of the employment by responding firms.

About 32 percent of the respondents considered themselves to be occupying rural sites (Table 5); 19.5 percent noted urban and 43 percent, suburban. These statistics reflect the respondents' own perceptions rather than any precise measure or location. Only about 9 percent of all plants reported a union present, but those plants accounted for 15 percent of the total employment. Factories that have a union are relatively large, averaging 562 employees each, whereas the nonunion factories averaged 276 employees.

Table 6 presents the variety of industry groups from which respondent factories acquire their input materials. Each respondent was asked to list the three top materials and the source of each. The chemicals groups, of course, provides an array of products for other industries. Evidently, many of these materials are acquired within the state: fully one-quarter of all input materials come from within North Carolina (Figure 2). This fact suggests that there are many functional linkages among the various plants that operate within the state. This sign of diversity and interdependency within North Carolina's industrial economy is healthy. Figure 2 also projects an image of strong centrality within the eastern seaboard for the state in terms of access to materials sources.

Outgoing shipments also cover a wide area (Table 7). About 15 percent of all shipments were intracompany transfers. This traffic is relatively high in the textiles, apparel, chemicals, metals, transportation equipment, and instruments industries.

TABLE 3 EMPLOYMENT AND SIZE OF SITE REPORTED BY COUNTY GROUP

County Group	Employment: Total No.	Employment: Mean Per Plant	Employment: No. Responses	Acreage: Total	Acreage: Avg. Per Plant	Acreage: No. Responses
1	42,054	609	69	3750	52.8	71
2	13,851	396	35	1178	33.7	35
3	13,688	249	55	1698	30.9	55
4	19.783	471	42	1152	28.1	41
5	15,425	396	39	1703	42.6	40
6	2,339	111	21	865	41.2	21
7	5,092	154	33	1262	37.1	34
8	6,518	197	33	521	17.4	30
9	6,740	170	40	1097	28.1	39
10	793	88	9	172	19.1	9
11	7,158	211	34	1806	51.6	35
12	11,724	317	37	2878	73.8	39
13	2,506	72	35	439	12.5	35
14	1,189	49	14	73	5.6	13
TOTAL	148,860	300	496	18,594	37.4	497

N. C. Total 867,800 in Mfg.

Proportion of N.C. 17.2%

TABLE 4 SURVEY RESPONSE BY INDUSTRY GROUPS

SIC Industry	Percent of Employment by Survey Respondents	Percent of Total N.C. Manufacturing Employment
I. Traditional Labor Intensive Industry		
22 Textiles	18.1%	25.3%
23 Apparel	6.7	9.5
24 Wood	2.4	4.2
25 Furniture	7.7	10.1
Sub-Total	34.9	49.1
II. Other Non-Durable Industries		
20 Food	3.0	5.8
21 Tobacco	2.5	2.5
26 Paper	2.1	2.6
27 Print-Pub.	1.4	3.5
28 Chemical	8.0	5.1
30 Rubber-Plastics	7.1	4.0
29-31 Petroleum/Leather	0.8	0.5
Sub-Total	24.9	24.0
III. Other Durable Industries		
32 Stone Clay Glass	4.7	2.4
33 Primary Metals	1.9	1.4
34 Fab-Metals	2.0	3.5
35 Machinery	12.8	7.4
36 Electric Equipment	11.1	6.6
37 Transp. Equip.	5.4	3.2
38-39 Instruments-Misc.	2.3	2.4
Sub-Total	40.2	26.9
Total	**100.0%**	**100.0%**
Total Employment	**146,850**	**867,800**

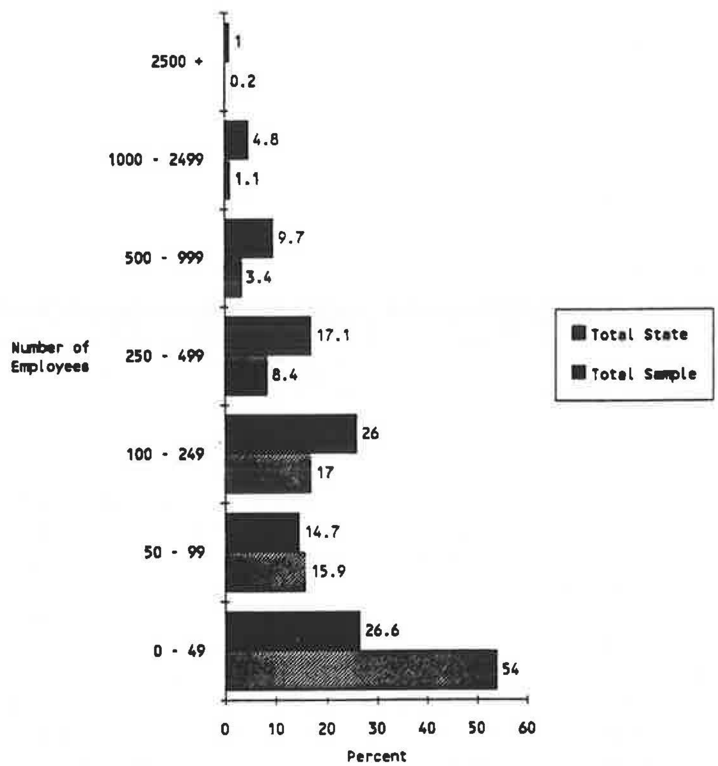

FIGURE 1 Distribution of respondents, by employment size of factors (*top bar*, total state; *bottom bar*, total sample).

TABLE 5 CHARACTERISTICS OF MANUFACTURERS BY COUNTY GROUP

County Group	Location Type*			Union Present	Headquarters at this location	Time to Interstate Hwy (minutes)	Time to Hub Airport (minutes)	Number of Responses
	Urban	Suburban	Rural					
1	25.5%	67.4%	2.3%	18.6%	39.5%	8.4	24.5	71
2	12.0%	68.0%	16.0%	16.0%	36.0%	7.4	44.2	35
3	23.0%	42.3%	26.9%	3.9%	42.3%	39.6	51.2	55
4	23.1%	53.9%	19.2%	4.0%	52.0%	11.6	35.2	41
5	18.5%	29.6%	40.7%	3.7%	29.6%	28.4	58.7	40
6	11.1%	11.1%	77.8%	11.1%	33.3%	51.1	90.6	21
7	21.4%	42.9%	35.7%	7.7%	35.7%	11.4	48.2	34
8	11.1%	33.3%	55.6%	11.8%	41.1%	26.7	48.4	30
9	7.7%	0.0%	84.6%	7.7%	7.7%	49.2	81.9	39
10	0.0%	75.0%	25.0%	25.0%	25.0%	45.5	63.8	8
11	21.1%	47.4%	21.1%	15.8%	31.6%	24.8	40.8	35
12	18.8%	62.4%	18.8%	12.5%	25.0%	36.9	74.7	39
13	33.3%	16.7%	38.9%	0.0%	61.1%	40.9	74.7	35
14	16.7%	50.0%	33.3%	0.0%	33.3%	21.0	47.5	13
Major Groups								
Metro (1)	25.5%	67.4%	2.3%	18.6%	39.5%	8.4	24.5	71
Mfg. Types (2-10)	16.5%	37.7%	41.1%	8.3%	35.0%	28.4	56.4	303
Non-Mfg. (11-14)	23.4%	43.7%	26.8%	8.5%	38.1%	32.9	62.1	122
TOTAL	19.5%	43.4%	32.0%	9.8%	36.4%	26.6	53.2	496

* Do not add up to 100 percent. Not shown are both no responses and "others".

TABLE 6 INDUSTRY SOURCES OF INPUT MATERIALS

Industry Source	Number	Percent
Chemicals	231	15.9
Textiles	134	9.2
Primary metals	132	9.1
Lumber	104	7.2
Farm	59	4.1
Fabricated metals	55	3.8
Paper	50	3.4
Rubber and plastics	50	3.4
Electrical equipment	40	2.8
Stone-clay-glass	33	2.3
Others	213	14.7
Unspecified	351	24.1
Total	**1,452**	**100.0**

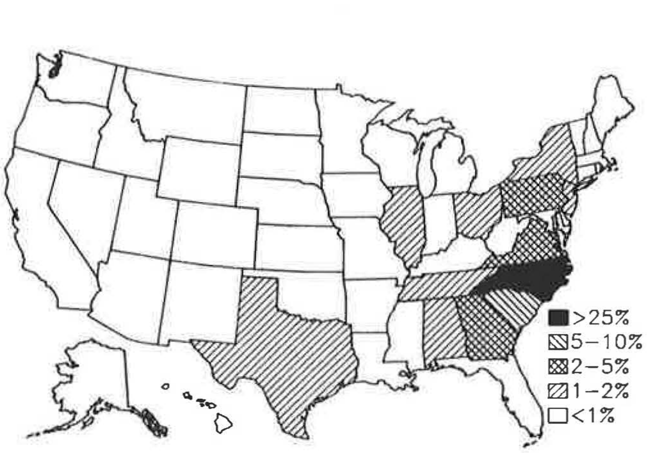

FIGURE 2 State sources of input materials for North Carolina factories.

The fact that 19 of 20 industry groups reported 10 percent or more of shipments going to intraplant transfers demonstrates that North Carolina has a highly interdependent industrial economy.

This fact is reinforced by the data on the geographic destination of shipments. Over one-fifth of all shipments are made within a 50-mi radius of the plant. These local proportions are especially high in the printing-publishing and stone-clay-glass industries. The high percentage in petroleum is explained by the fact that in North Carolina this industry is predominantly involved in making paving and roofing materials. Otherwise, North Carolina factories are region-serving, with over 45 percent of all shipments being sent through either the southeast or northeast. These and the local shipments together account for over two-thirds of the market destinations for North Carolina manufacturers. Tobacco, leather, primary metals, instruments, and miscellaneous products industries have large general national markets, whereas the chemicals and instruments sectors have relatively strong proportions going to international destinations.

Overall, trucks dominate to the extent of nearly 90 percent or more of both types of shipments (Table 8). Among the larger county groups and manufacturing groups, only the other nondurable industries had less than 80 percent of shipments by trucks. This is because of relatively heavy railroad use for materials shipments by the food, paper, chemicals, and rubber-plastics industries. The metropolitan counties also use rail shipments more heavily for inputs and have a substantially higher proportion of air freight for shipments to market.

Nearly 59 percent of all responding factories are within 30 min access of an Interstate highway, and over 86 percent are within 30 min of all types of four-lane highways, including Interstates (Figure 3). In fact, nearly two-thirds are within 10

TABLE 7 DISTRIBUTION OF OUTGOING SHIPMENTS BY INDUSTRY

	Geographic Destinations								
SIC Industry	Within 50-Mile Radius	South-East U.S.	North-East U.S.	Western U.S.	Mid-West U.S.	National	Inter-National	Other Plants of the Same Company	No.
20 Food	34.0%	30.9%	24.8%	0.2%	2.7%	4.3%	3.1%	5.7%	29
21 Tobacco	26.2	17.5	14.3	6.8	7.5	24.9	2.8	7.5	4
22 Textiles	12.3	36.9	23.0	7.1	6.0	12.5	2.2	24.1	53
23 Apparel	15.6	28.7	17.9	6.3	7.1	19.5	4.9	18.5	35
24 Wood	28.9	40.7	14.3	0.8	6.4	3.3	5.6	14.1	31
25 Furniture	5.9	34.3	24.8	6.6	10.3	11.3	6.8	5.6	24
26 Paper	18.9	31.6	23.2	1.1	9.7	7.8	7.7	11.3	17
27 Print/Pub.	66.1	3.5	14.7	1.2	2.2	11.9	0.4	10.7	17
28 Chemicals	15.1	36.6	13.6	2.7	2.7	11.4	17.9	13.8	29
29 Petroleum	55.8	44.2	0.0	0.0	0.0	0.0	0.0	8.3	6
30 Rub-Plastics	19.1	32.2	13.5	3.7	18.8	5.7	7.0	7.1	23
31 Leather	4.0	23.3	16.7	10.0	8.3	34.4	3.3	0.0	3
32 Stone-Clay-Gla.	43.0	21.8	18.7	3.4	8.2	0.6	4.3	10.5	24
33 Prim. Metals	12.7	14.6	11.4	3.2	9.1	47.2	1.8	20.6	11
34 Fab. Metals	29.4	25.8	8.9	4.0	10.8	17.7	3.4	24.5	21
35 Machinery	22.6	15.6	13.9	5.5	11.1	18.7	12.6	16.9	30
36 Elec. Eq.	4.5	10.1	28.5	9.9	19.2	20.3	7.5	15.7	24
37 Transp. Eq.	16.0	23.9	20.5	4.5	17.3	11.7	6.1	18.2	22
38 Instruments	2.2	19.2	11.7	14.5	5.8	25.9	20.9	21.5	6
39 Misc.	12.9	16.4	19.3	0.7	2.9	39.7	8.1	11.4	7
ALL	**21.6%**	**27.5%**	**18.1%**	**4.4%**	**8.6%**	**13.1%**	**6.6%**	**14.9%**	**416**

Note: Geographic destinations account for 100 percent of shipments. The proportions for other plants of the same company are not geographic - specific and are part of the shipments to geographic destinations.

TABLE 8 TRANSPORTATION MODES BY INDUSTRY AND COUNTY GROUPS

(a) Mfg. Industry Group	Assembly of Input Materials				Products Shipped to Market				No. of Responses
	Truck	Rail	Air	Water	Truck	Rail	Air	Water	
Traditional	95.7%	1.6%	0.9%	1.8%	96.1%	1.5%	1.4%	1.0%	171
Other - Non-Durable	79.7	14.8	1.4	4.1	91.7	4.8	2.0	1.5	130
Other - Durable	90.1	3.5	3.5	2.9	89.1	1.8	4.9	4.2	155
All mfg.	**89.3%**	**6.0%**	**1.9%**	**2.8%**	**92.5%**	**2.5%**	**2.7%**	**2.3%**	**456**
(b) County Group									
Metro	82.4%	8.7%	4.9%	4.0%	87.6%	2.8%	7.3%	2.3%	65
Other Mfg.	90.2	5.6	1.7	2.5	93.9	2.3	2.3	1.5	284
Non-Mfg.	90.4	5.3	1.3	3.0	91.0	2.9	2.0	4.1	110
All counties	**89.3%**	**6.0%**	**1.9%**	**2.8%**	**92.5%**	**2.5%**	**2.7%**	**2.3%**	**459**

min of a four-lane highway. In access to one of North Carolina's hub airports (those offering scheduled commercial service), just under half of the responding plants are within 45 min driving time and three-quarters are within 1 hr and 15 min (Figure 4).

SATISFACTION WITH LOCATION

Overall Satisfaction

Figure 5 shows manufacturers' responses regarding their overall satisfaction with their current locations. It is remarkable that only 6.6 percent expressed some degree of dissatisfaction, as opposed to the 28.3 percent that were very satisfied. This high degree of satisfaction did not vary substantially among the major groups of counties or industries. The consistency of this finding is somewhat surprising and unexpected. Of course, there were a few unhappy companies, such as the respondent who commented that "I could bring another of my factories into North Carolina, but refuse to do so because of my experiences here." This suggests that, despite an overall positive evaluation, there are a few disgruntled companies, because of unique local circumstances or problems within the company itself.

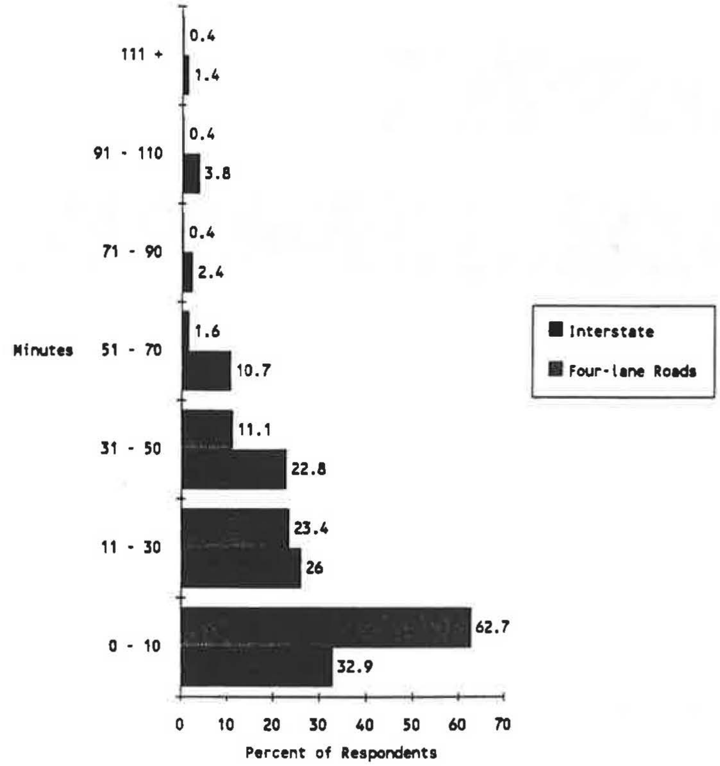

FIGURE 3 Average driving time to Interstate and all four-lane highways by all respondents (*top bar*, Interstates; *bottom bar*, four-lane highways).

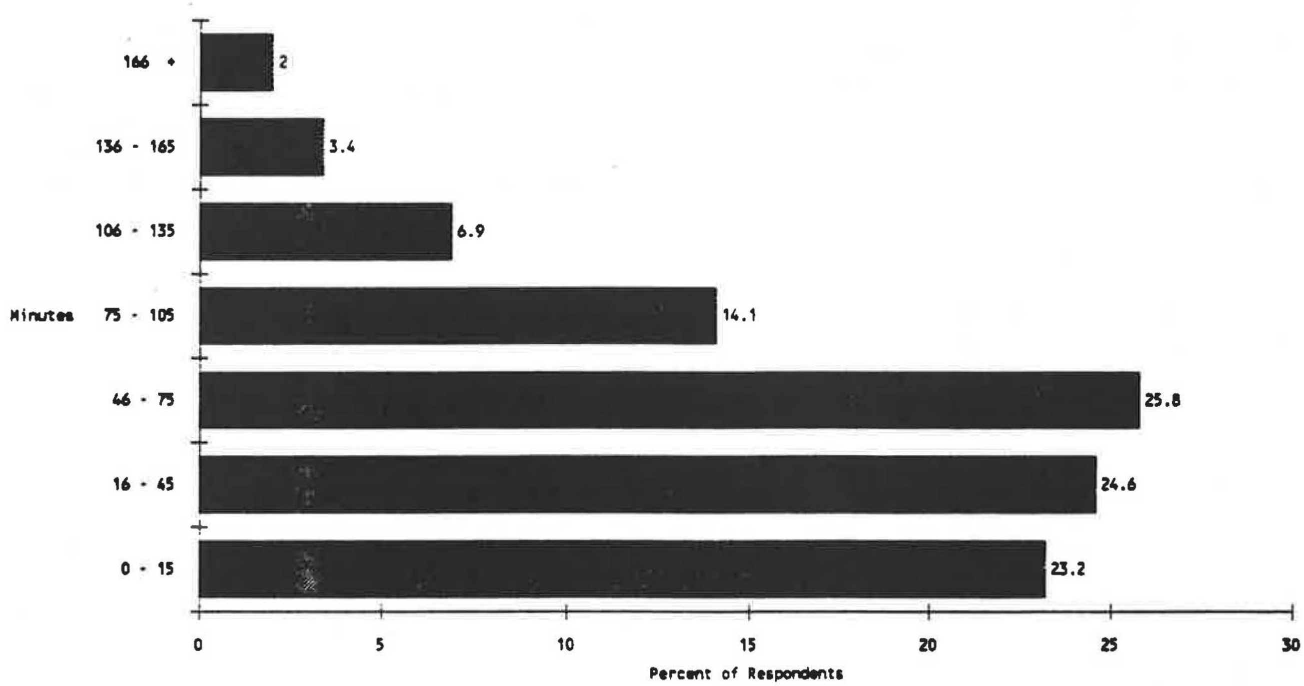

FIGURE 4 Average driving time to nearest hub airport by all respondents.

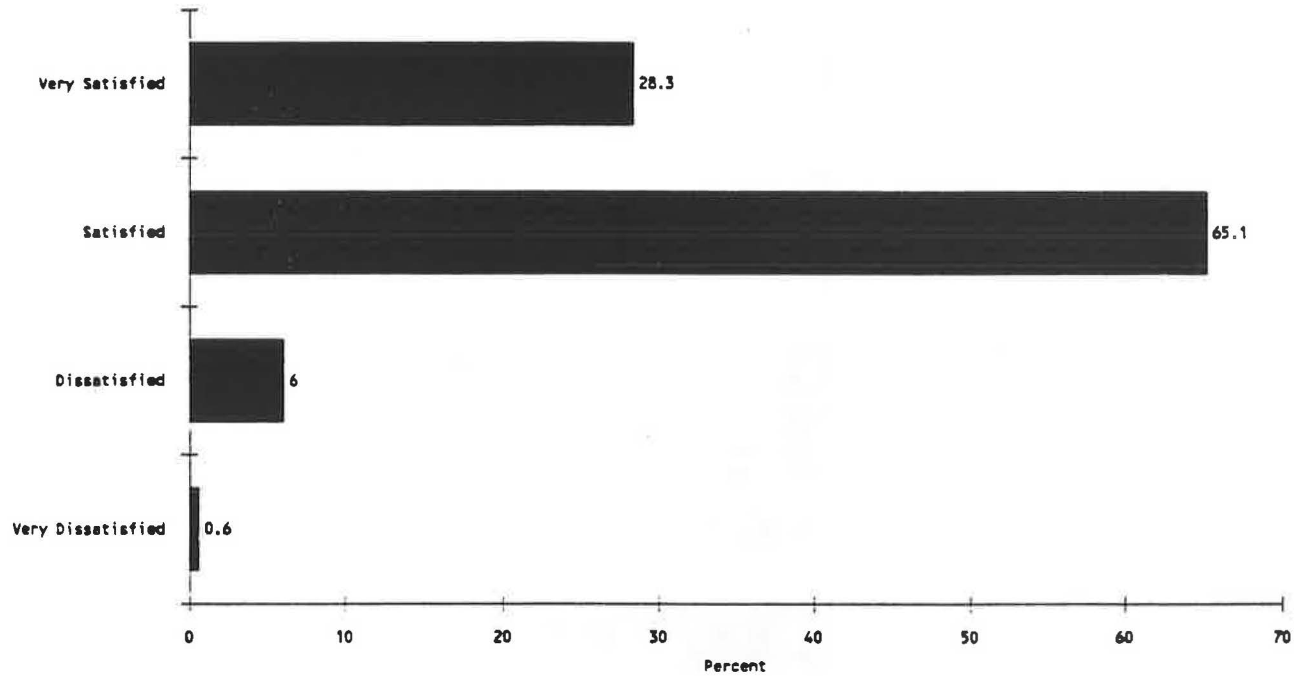

FIGURE 5 Overall satisfaction with location.

In Table 9, responses are divided into specific groups; the table indicates that there is some slight variability in overall satisfaction ratings. The overall average of 3.21 is thus strongly positive: 15 of the 20 industry groups had average ratings of 3.0 or better. The most satisfied industries included tobacco, printing-publishing, chemicals, fabricated metals, instruments, and the miscellaneous group. Least satisfied were transportation equipment, machinery, and leather industries. Among the three major groupings of industries the other durables group expressed somewhat more satisfaction that did the other two but the average values were higher than 3.0 for all three. Ratings are also uniformly positive for each county group.

Positive Location Factors

Another perspective on overall satisfaction was provided by questions in which respondents were asked to list factors that make the current location a good one, and factors that might lead to discounting operations at the present site.

Table 10 presents a summation of the good factors as generalized from the variety of responses. A total of 1,512 factors (3 per respondent) were possible, but 90 companies did not elect to comment, creating a response total of 1,242. A total of 21 factors received 1 percent or more of the responses, topped by labor availability. That and other factors having to do with labor (worker attitudes, skill levels, wage levels, etc.) collectively accounted for over 25 percent of all responses. Transportation and accessibility factors (market access, input materials access, state-to-state access, etc.) followed closely behind at over 23 percent. Assets of the community (good living conditions, good community, etc.) totaled nearly 12 percent.

Discontinuation Factors

Table 11 presents the factors cited that might lead to a decision to discontinue operations. In general, the overall factor cited the most was some sort of labor item (availability, union activity, skill level, etc.), which collectively accounted for over one-third (34.4 percent) of the responses. Far behind (14.4 percent) in second place were economic conditions (decline of business, competition, etc.). Interestingly, the third most frequent response was "none." One respondent, one of those 13.7 percent listing "none," commented simply "I hope none." Another commented "continued dissatisfaction with *local* government." Still another responded by saying "labor shortage—high taxes—too stringent requirements, such as regulations and environmental laws." Apparently, 58 companies could think of no factor that would lead them to discontinue operations. Only 4.2 percent of respondents mentioned accessibility, and that related to input materials.

Satisfaction with Specific Factors

In addition to the overall rating of satisfaction and open-ended comments, the respondents were asked to rate 34 specific factors, all on a scale of 1 to 4, again with 4 indicating high satisfaction (or high importance) and 1 great dissatisfaction (or low importance). The factors were simultaneously rated in terms of their importance on similar scale. Tables 12 and 13 list the factors as listed in the questionnaire along with the headings under which they were placed.

More insight into these factor evaluations can be obtained by comparing the ratings of importance with those of satisfaction. That is, high satisfaction on a factor might not mean much if the factor is considered to be unimportant. Similarly, a slightly negative satisfaction rating is more disturbing if the

TABLE 9 OVERALL SATISFACTION RATING BY MANUFACTURING INDUSTRIES AND COUNTY TYPES

Manufacturing Industry	Satisfaction Rating	County Type	Satisfaction Rating
20 Food	3.09	1	3.25
21 Tobacco	3.20	2	3.26
22 Textiles	3.03	3	3.17
23 Apparel	3.12	4	3.15
24 Wood	2.95	5	3.33
25 Furniture	3.03	6	3.25
26 Paper	2.95	7	3.07
27 Printing-Pub.	3.20	8	3.33
28 Chemicals	3.35	9	3.31
29 Petroleum	3.00	10	3.25
30 Rub.-Plastics	3.00	11	3.11
31 Leather	2.67	12	3.00
32 Stone-Clay-Glass	3.11	13	3.56
33 Primary Metals	3.00	14	3.00
34 Fab. Metals	3.26		
35 Machinery	2.92	**TOTAL**	**3.21**
36 Elec. Equip.	3.07		
37 Transp. Eq.	2.79		
38 Instruments	3.22		
39 Misc.	3.25		
TOTAL	**3.21**		

Industry Group		County Group	
Traditional Labor Int. (SIC 22-25)	3.17	Metro (1)	3.25
Other Non-Durable (20-21, 26-31)	3.18	Mfg. (2-10)	3.20
Other Durables (SIC 32-39)	3.28	Non-Mfg. (11-14)	3.22

Scale:
1 = Very Dissatisfied
2 = Dissatisfied
3 = Satisfied
4 = Very Satisfied

TABLE 10 FACTORS THAT MAKE THE CURRENT LOCATION A GOOD ONE FOR THIS FACILITY

Factor	Percent of Responses	Number of Responses
Labor Availability	12.8%	159
Market Access	8.7	108
Input Materials Access	7.0	87
Existing Location	5.9	73
Good Living Conditions	5.6	70
Local Business Climate	4.8	60
Site Costs	4.2	52
Worker Attitudes	3.9	49
State-to-State Access	3.7	46
Natural Environmental Quality	3.4	42
Skill Levels of Labor	2.4	30
Union Activity in Area	2.3	28
Available Space and Site Size	2.3	28
Local Wage Levels	2.1	26
Good Overall Transportation	2.1	26
Local Tax Rates	2.1	26
Local Access by Road	1.9	24
Labor Costs	1.9	24
Site Image	1.9	24
Good Community	1.7	21
Water and Sewer	1.4	19
Others	17.7	220
TOTAL	**100.0%**	**1,242**

TABLE 11 FACTORS THAT MIGHT LEAD TO DISCONTINUING OPERATION AT THE CURRENT LOCATION

Factor	Number of Responses	Percent of Total
Labor Availability	80	18.9%
None	58	13.7
Union Activity	38	9.0
Decline of Business	30	7.1
Access to Input Materials	18	4.2
Skill Level of Labor	17	4.0
Close Business/Consolidation	16	3.8
Competition	15	3.5
Site Costs	13	3.1
Local Tax Rates	12	2.8
Local Business Climate	11	2.6
Natural Environment Quality	10	2.4
Labor Costs	10	2.4
Others	96	22.5
TOTAL SAMPLE	**424**	**100.0%**

TABLE 12 EVALUATION FACTORS

Factor Type	Factor Description
Labor	
1.	Labor Availability
9.	Skill Level
19.	Local Wage Rates
3.	Work Attitudes of Workers
4.	Trainability of Labor
23.	Union Activity in the Area
Site and Utilities	
20.	Site Costs
6.	Electricity Costs and Supply
22.	Natural Gas Costs and Supply
Quality of Life	
25.	Quality and Availability of Housing
26.	Natural Environmental Quality
18.	Cost of Living
29.	Local Cultural Facilities (libraries, museums, etc.)
27.	Local Recreational Amenities
5.	Crime Rate
7.	Quality of Area for Raising Children
2.	Local Public Schools
31.	Local Private Schools
Transportation	
11.	State-to-State Accessibility by Highway
15.	City-to-City Accessibility Within North Carolina
10.	Accessibility Within Your Local Area by Road Travel
14.	Accessibility to Scheduled Passenger Air Services
33.	Accessibility to Non-Scheduled (corporate plane) Air Services
32.	Accessibility to Rail Freight Services
34.	Accessibility to Port and Water Freight Services
17.	Accessibility to Market
12.	Accessibility to Input Materials
Business Services	
8.	Local Tax Rates
13.	Local Business Climate
21.	State Business Assistance
24.	Local Business Support Programs
16.	Technical Support Programs
30.	R & D Support from Governmental, Private or Institutional Sources, either locally or elsewhere in North Carolina.
28.	Quality of Higher Education Facilities (Universities, etc.)

Note: Numbers represent rank ordering of index of concern, as shown in Figure 6.

TABLE 13 HIGHEST AND LOWEST RATING FACTORS, ALL RESPONSES

(a) Most Important		(b) Highest Satisfaction	
Worker Attitudes	3.73	Local Union Activity	3.28
Labor Availability	3.65	Nat. Environ. Quality	3.14
Public Schools	3.49	Quality of Higher Educ.	3.14
Labor Trainability	3.46	Non-Scheduled Air Service	3.09
Quality for Children	3.40	Site Costs	3.06
State-State Access	3.33	Cost of Living	3.04
Electricity Cost & Supply	3.31	Access to Market	3.02
Access to Input Materials	3.26	Local Wages	3.02
Local Tax Rates	3.24	State-State Road Access	3.01
Local Access by Road	3.21	Water-Port Freight	2.98
(c) Least Important		**(d) Lowest Satisfaction**	
Water and Port Freight	2.01	Public Schools	2.44
Rail Freight Service	2.03	Labor Availability	2.52
Non-Scheduled Air Ser.	2.15	Labor Skill Level	2.54
Private Schools	2.19	Crime Rate	2.59
R & D Services	2.34	Air Pass. Service	2.72
Local Cultural Facilities	2.52	Local Tax Rates	2.74
Local Bus. Support Prog.	2.64	R & D Service	2.74
Local Recrea. Activities	2.65	Electricity Cost & Supply	2.76
State Business Assistance	2.70	Technical Support Program	2.78
Nat. Gas Cost & Supply	2.73	State Business Assistance	2.80

Note: Respondents were asked to rate a factor (1) if very unsatisfactory (2) unsatisfactory (3) satisfactory (4) very satisfactory.

factor is considered to be very important. An index of concern was calculated for this purpose by simply subtracting the satisfaction rating (S) from each factor's importance value I:

Index of concern $= I - S$

Negative values result when satisfaction exceeds the level of importance. Those factors with high positive index values (importance exceeds satisfaction by a large margin) are the ones of greatest concern for policy makers and economic development officials.

The results of this calculation for the entire sample are presented in Table 14, in descending index values. Figure 6 shows the data in graphic form. What emerges is a clear picture in which labor-related factors are of dominant concern. This concern is made up of a combination of concerns over labor availability, attitudes, supply and trainability, and public schools. Despite the overall high satisfaction levels noted earlier, the respondents are concerned about supply and quality of labor over the long term. Some volunteered comments by respondents illustrate these concerns:

- "Train school children in the work ethic."
- "Don't graduate students who are illiterate."
- "Companies in this area are exporting work or importing labor from Asia while teenagers won't work at a job."
- "Better education, better education, better education!"
- "Better elementary schools."
- "We hire mostly untrained employees and then train them. Reading job applications will just make you cry over the education our kids are leaving school without, even when they have graduated."

The foregoing quotes were included in responses from 10 widely scattered counties. They represent the mountains, piedmont, and coastal plain regions; rural and metropolitan areas; printing, furniture, electronics, and other industries. Thus the concerns over labor and education span a broad range of situations.

Additional analysis was performed on the data using Automatic Interaction Detector (AID). This program examines the relationship between several independent variables and one dependent variable. The program splits the data into two groups that explain the greatest percent of variance in the dependent variable. These groups are determined by grouping together observations that have the same values of the independent variable. All the values of the independent variable are then split into two groups, which partitions the whole data set.

The attitude variables analysis indicated once again that the satisfaction and importance of local public schools is the key important factor influencing the respondents' overall satisfaction with their location. One result stated that those with an average satisfaction with location of 3.00 had rated public schools with a 1 or 2, compared with the average of 3.27 for those who rated public schools with a 3 or 4. Another run of AID indicated that those respondents with an average location rating of 3.30 were less concerned with cultural activity in their area, but were satisfied with the skill of the labor; those with an average satisfaction of 2.72 were less satisfied with the housing and the skill of the labor. Overall, the attitude variables that explained the most variance of satisfaction with location were the importance of input materials and the satisfaction with public schools (Figure 7).

TABLE 14 IMPORTANCE AND SATISFACTION EVALUATIONS, ALL RESPONDENTS

Factor		Importance	Satisfaction	Index of Concern
1	Labor Availability	3.65	2.52	1.13
2	Local Public Schools	3.49	2.44	1.05
3	Work Attitudes of Workers	3.73	2.84	0.89
4	Trainability of Labor	3.46	2.83	0.63
5	Crime Rate	3.16	2.59	0.57
6	Electricity Costs & Supply	3.31	2.76	0.55
7	Quality of Area for Raising Children	3.40	2.90	0.50
8	Local Tax Rates	3.24	2.74	0.50
9	Skill Level (labor)	3.02	2.54	0.48
10	Local Access by Road	3.21	2.84	0.37
11	State-State Highway Access	3.33	3.01	0.32
12	Access to Input Materials	3.26	2.96	0.30
13	Local Business Climate	3.16	2.95	0.21
14	Scheduled Passenger Air Service	2.90	2.72	0.18
15	City-City Access within N.C.	3.03	2.87	0.16
16	Tech. Support Programs	2.85	2.78	0.07
17	Accessibility to Market	3.09	3.02	0.07
18	Cost of Living	3.09	3.04	0.05
19	Local Wage Rates	3.06	3.02	0.04
20	Site Costs	2.98	3.06	-0.08
21	State Business Assistance	2.70	2.80	-0.10
22	Natural Gas Costs & Supply	2.73	2.83	-0.10
23	Local Union Activity	3.17	3.28	-0.11
24	Local Business Support Programs	2.64	2.77	-0.13
25	Quality-Availability of Housing	2.80	2.95	-0.15
26	Natural Environmental Quality	2.95	3.14	-0.19
27	Local Recreation Amenities	2.65	2.88	-0.23
28	Quality Higher Education	2.88	3.14	-0.26
29	Local Cultural Facilities	2.52	2.82	-0.30
30	R & D Support	2.34	2.74	-0.40
31	Local Private Schools	2.19	2.82	-0.63
32	Rail Freight Service	2.03	2.91	-0.88
33	Non-Scheduled Air Services	2.15	3.09	-0.94
34	Port-Water Freight Services	2.01	2.98	-0.97

Policy Implications

North Carolina manufacturers are generally satisfied with their current locations. But, there is wide agreement among North Carolina manufacturers that poor education in the public schools and poor work attitudes are looming threats to continued economic viability. If there are "Shadows in the Sunbelt," they are the shadows of poor education and lax worker attitudes, not foreign competition. This statement suggests that the time has come to balance the policy focus between

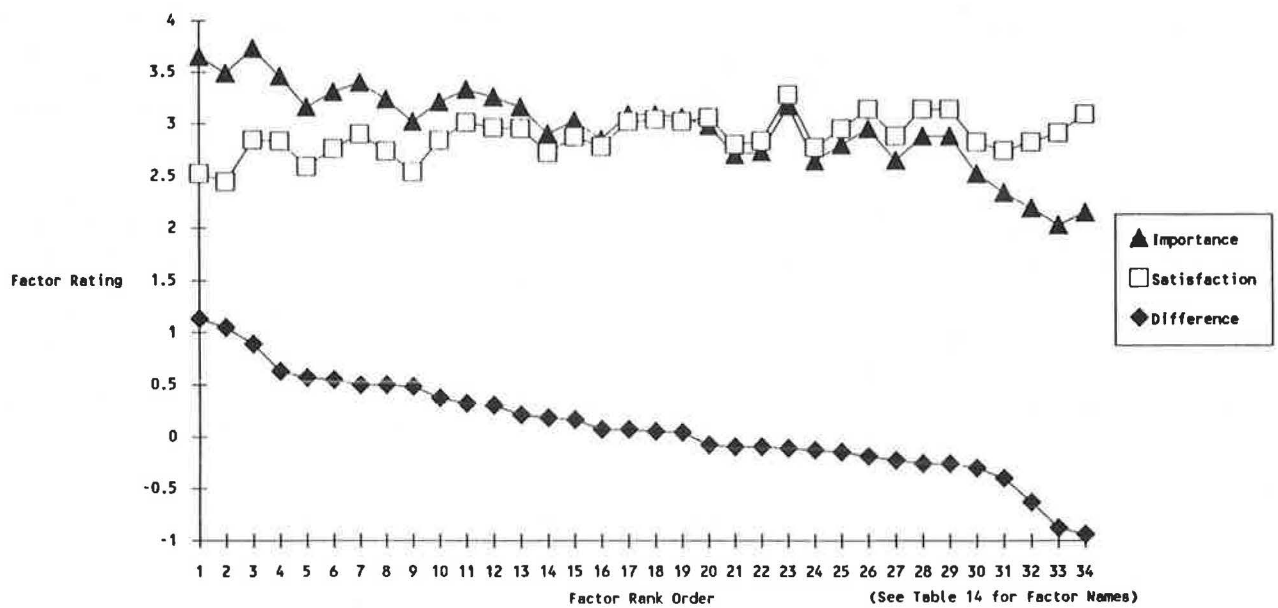

FIGURE 6 Importance and satisfaction evaluations, all respondents.

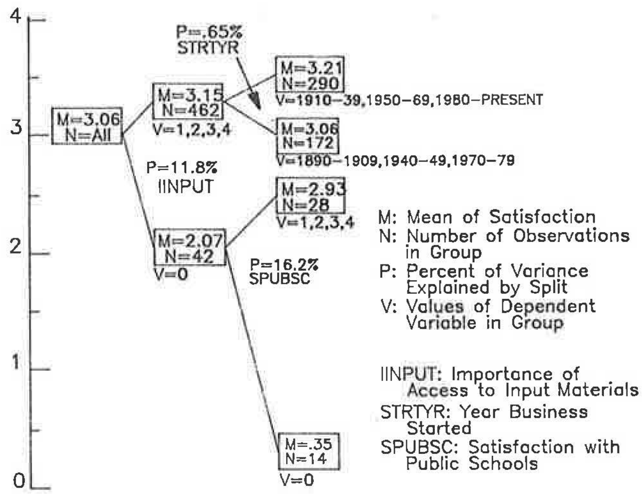

FIGURE 7 Main components of variance of satisfaction with location statistic.

these issues, even if they present difficult and expensive problems.

Another conclusion from the present survey of manufacturers is that transportation access is important in overall satisfaction ratings, but is less important in retaining industry than are labor and other factors. Transportation access was noted as a key reason for coming to North Carolina, and for overall high satisfaction, but it is not a key reason for staying. Airport, port, and rail access are perceived as satisfactory, but less important by manufacturers. Air service and ports may become more important in the future for foreign or import-export businesses, but for now highways are the vital aspect of accessibility, and manufacturers are generally satisfied with the situation.

The survey results do not support the idea that rural industries might be more inclined to leave than those in urban areas. Rural areas still remain more heavily dependent on their manufacturing sectors, and they still have high proportions in declining, labor-intensive industries, but, for now, their satisfaction levels are also high. However, rural economies may be enjoying only a temporary interlude between the declines of the late 1970s and early 1980s and some future downturn. Declining dollar values on world markets may have helped decrease international competition, but a sluggish economy in 1990, associated with chronic high interest rates, may be pointing toward future losses for many industries. Current high satisfaction levels could mean that rural manufacturers do not realize their precarious position in the new global economic environment.

The long-term perspective may be less pleasant than the present, because of educational deficiencies, a perceived worsening of worker attitudes, and a demographic blip in which the number of people in the young-adult, "post-baby boom" groups will decrease or grow slowly for a few years. Comparison of the results of the present study with others show that industrial location factors may have changed in recent years as part of a long-term trend. Late 1970 surveys (*5*) revealed that transportation, proximity to customers, unskilled labor, energy supply and productivity were the top concerns, in that order. Another national survey, taken in 1982 (*6*), suggested that an increase in concern over labor factors had occurred, but that they were not the top considerations. A survey of manufacturing firms that had located plants in North Carolina, South Carolina, or Virginia during the 5 years prior to 1982 (*5*) revealed that the top factors were (a) state-local business climate, (b) labor productivity, (c) transportation, (d) land availability or room for expansion, and (e) cost of land and construction. The emphasis on site considerations reflects the fact that these were initial location decisions, rather than evaluations of existing locations by currently operating concerns. The high priority given to business climate and transportation in the late 1970s and early 1980s, when a number of new plants were opened, differs from the current survey results. Labor factors rated fairly high in the earlier survey but they did not get the emphasis that the present survey revealed. Furthermore, in 1982 the educational system was regarded as the top quality of life factor, but that category generally was rated as substantially less important than were business-economic factors.

The opportunity to compare the results of the earlier survey with the present one is limited by the differing emphasis of each and by differences in the phrasing of questions. Nonetheless, it does appear that the high priority given in the present survey to labor supply and quality, and especially to primary and secondary education, is new. There is not much that the state or local communities can do directly to increase the labor supply. In fact, there may be plenty of people available. What can be done is to ensure that workers have an adequate education to make them trainable and employable.

The trends of a worsening of labor and education factors are national, and not unique to North Carolina. However, they may be more acute in rural areas because historically the factor that has drawn industry to rural areas has been labor. It would not be overly dramatic to assert that North Carolina's economic future depends on how successful the state meets the looming labor and educational crises.

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Calmer, Not Faster: A New Direction for the Streets of Los Angeles

JOEL WOODHULL

As Los Angeles nears the end of its road-building era, it turns toward schemes for increasing traffic flow on existing roadways. People want less traffic, yet want to travel faster. The inherent conflict in these desires goes unrecognized as the political process continues to favor efforts to expand mobility by improving traffic flow. The counterproductive nature of measures taken to free up traffic are described in terms of two central districts of Los Angeles. Conflicts between place and path can be resolved by concentrating population while reducing numbers of vehicles. Tools of traffic control can be applied to cause vehicles to travel at slower and more uniform speeds. Mobility can be maintained with fewer vehicles by better use of in-vehicle capacities. The Los Angeles correction depends on changing the goal of street management from traffic maximization to traffic calming. This means balancing and integrating land uses to make it possible to walk from one activity to another; giving priority to environmentally preferable modes of travel; basing traffic flow decisions on person flows; and reducing vehicle density where there is high population density.

While Los Angeles was becoming one of the large and influential cities of the world, it also became the epitome of the automobile-dominated city. People in other cities struggling to avoid the Los Angeles fate of endless sprawl, traffic congestion, and bad air now warn of "Los Angelization."

Los Angeles is also known for spurring innovation. The fact that it is beginning to deal with some of its persistent air quality problems is being noticed around the world. The people of Los Angeles have realized that they can't simply build more roads to decongest traffic, and have affirmed tax expenditures for future rail service. Proposals for traffic relief in the near term are focused on improvement of traffic flow on existing roadways. Plans include conversion of a number of streets in central Los Angeles to one-way operation, and use of automatic traffic surveillance and control (ATSAC) systems.

On the basis of the fact that a vehicle traveling at a constant optimal speed produces less polluting emissions per mile, traffic flow improvements have been incorporated into plans for reducing air pollution. These approaches are well liked because they seem to offer a win-win situation—faster driving and cleaner air; and no one loses property, because the existing roadways are used. Yet consideration of the higher-order effects—cumulative effects caused by network feedbacks—would indicate that actions to increase traffic speed will normally worsen air quality and increase emission of greenhouse gases, because these actions increase vehicle miles traveled (VMT) (*1*).

Southern California Rapid Transit, 425 South Main Street, Los Angeles, Calif. 90013.

IMPROVING TRAFFIC FLOW

Tools of Traffic Control

Although new freeways are seldom proposed today, there are still hopes that less extreme means of easing traffic flow will not only reduce congestion, but will reduce energy and pollution costs as well. Residents exhibit a growing resistance to road widening, but still seem to accept ways of increasing traffic flows that can be applied without widening the roadway—various traffic engineering measures, including electronic control of signals, and alterations of vehicle flows within the roadways.

Of the many tools for enhancing the capacities of streets and street systems, conversion of two-way streets to one-way operation is one of the oldest means of squeezing additional flow capacity from a given network of streets. One-way streets facilitate greater flows because signals can be timed for any desired speed, and left-turn waits can be eliminated. One of the newest tools is the automatic traffic surveillance and control (ATSAC) system, by which vehicle movements are monitored in real time, and signal timing is adjusted to increase link or intersection throughput. While either one-way streets or ATSAC can be used independently of the other, the greatest gains in vehicle throughput can be made when they are used jointly. This outlook heightens the traffic engineers' desire for one-way streets.

Conflicting Goals

Traffic engineers ply their trade on behalf of a public that wants to go faster. Almost universally, people believe they should be able to live in a nice neighborhood and travel easily to all other places. The fact that these two personal goals are in conflict when they are shared by many other people is seldom contemplated. When a few people living along a narrow street object to its widening, they are thought to be selfish, unwilling to make a reasonable sacrifice for the greater good of the community. After all, the number of people passing through is likely to be far greater than the number who live along the section to be widened.

This greater good argument prevailed for a number of years in the building of freeways. Today there is great resistance to construction of more freeways, particularly in urban areas. People seem to perceive that more freeways means more time spent on freeways, rather than the easier travel that was promised.

The greater good argument is still made on behalf of vehicle flow enhancements because people don't analyze intensity of interest—that the resident spends many hours at home, whereas the person traveling past has only a fleeting interest in that neighborhood. Because people don't simultaneously occupy and travel through a place, they tend not to reconcile their dual roles as place occupier and traveler. In effect, people have dual personas—one as the place occupier, and the other as the traveler. The same person that objects to the car drivers speeding through his neighborhood becomes another person with another viewpoint while traveling through another neighborhood. The other neighborhood may not even be viewed as a neighborhood, but as a commercial district.

Links and Networks

There is still a collective wish to speed the flow of traffic because the reasons for doing it are more apparent than are the reasons for slowing it down. The primary reason for fast travel is so simple—wanting to be somewhere else and not wanting to waste time in getting there. This simple objective is supported by rationalizations such as faster travel reduces air pollution and helps the economy.

The chief obstacle to continually expanding mobility is the finiteness of the urban transportation network. People don't normally think in terms of networks. It is easier to understand one's direct interactions with the environment than to know about individual or collective relations to higher-order network effects. People don't think about how their presence on a network is contributing to the congestion of the network. Because they don't think much about the long-term collective impacts of their actions, they seldom realize that improving the traffic flow capacity at one location may lead to more traffic congestion, more energy consumption, and air pollution in the aggregate.

Even when people do think in terms of networks, they make gross simplifications. For example, places are represented in transportation models by nodes, or points. When places are reduced to points, it makes it easier to disregard them in favor of the facilities constructed for travel. When people act as decision makers to intervene in these complex networks, and change the nature of some of the links or nodes, it is generally with meager knowledge of the overall long-run consequences to the network, and especially the impacts on places in the network (*2*).

In spite of these complexities, there is growing public recognition that there are limits to mobility. In a general way, most people understand that there are system feedbacks that invalidate the simple extrapolations of the effects of easier travel along specific links. This understanding is manifested in the steadily increasing importance given to EIR's, public hearings, and development moratoriums. In a recent survey, Glickfeld and Levine (*3*) found that traffic is the single most important reason leading to the appearance of growth management measures on the ballot in California cities. These measures are evidence of the public desire to more carefully consider the consequences of interventions, whether the interventions are in the travel network or in the places served.

SOME CONSEQUENCES OF TRAFFIC IMPROVEMENTS

Although the term "traffic improvement" is used here in its usual sense, the central point of this paper is to call into question the unquestioning pursuit of traffic flow capacity, because of unintended and often unrecognized side effects. Among these effects are the increase in VMT and consequent impacts on air quality, energy security, and global warming; worsening of transit effectiveness; and neighborhood degradation.

Increase in Travel Volume

All else being equal, higher total traffic flow (i.e., higher VMT) means more energy use and more emissions. So, it would be nice if efforts to eliminate bottlenecks and congestion did not result in more VMT. There are two schools of thought on the effect of traffic flow improvements on total traffic volume. The traditional view, held by many traffic engineers, roadbuilders, and others, is that raising vehicle speeds toward their design optimums will reduce emissions and fuel usage. An opposing view that has arisen in the last 10 years is that the ability to go faster translates over time into decisions to go farther; to live farther from work, to range farther for shopping, education, entertainment, etc. This tendency is thought to neutralize any gains that might have been made initially, and ultimately to reestablish the congestion.

The pioneering work on this topic has been carried out over the last decade by Newman and Kenworthy and their associates, who took two different approaches. After first using instrumented vehicles to investigate driving cycles (*1*), they acquired and analyzed gross scale data from 32 large cities throughout the industrialized nations (*4,5*). Their work demonstrated that where people live and work at lower densities, and where workplaces are decentralized (e.g., in places like suburbs as well as low-density cities), the vehicle trips are longer and more frequent. They found that "free-flowing traffic does not lead to savings in fuel or time, or lowering of emissions in a city overall."

More recently, Holtzclaw (*6*) used actual mileage records of vehicles owned by residents of high- and low-density areas in the San Francisco Bay area to determine the relation between VMT and urban density. He found a consistent relationship, that per capita VMT is reduced 30 percent by a doubling of population density.

There are other views on these matters. In a response to Newman and Kenworthy, Gordon and Richardson said that "decentralization reduces pressures on the CBD, relieves congestion, and avoids 'gridlock'. . . . nationwide, most commuting is now suburb-to-suburb." They said that data from the 1977 and 1983–1984 Nationwide Personal Transportation Study (NPTS) "shows that there is no relationship between city size and trip lengths, times, or speeds; moreover, average commuting speeds did not decline" (7). In another paper, Richardson and Gordon stressed the importance of nonwork travel:

> The concept of the CBD-dominated metropolis became obsolete as both households and firms moved into the suburbs. Suburbanization made possible shorter work trips and generated more opportunities for nonwork travel, especially in larger metropolitan areas where the most dramatic changes in land use patterns occurred. The ubiquity of a wide range of commercial and service facilities in today's suburbs has created more efficient settlement patterns that save travel time and thus provide an opportunity for more leisure pursuits that involve more travel.

Lowry (8) sees both residences and work places dispersing into sprawling low-density patterns. In supporting the theme of Gordon and Richardson, that nonwork trips are becoming the preponderant concern, he notes that other local travel "depends heavily on private vehicles because in a low-density residential environment, distances are too great for pedestrians and volumes are too low to support public transit. . . ." He sees the need for expanding capacity on suburban streets and arterials, yet says that "however much capacity is expanded, congestion will not be far behind; it is the equilibrating factor that limits travel demand."

Using the same NPTS data used by Gordon and Richardson, Pisarski (9) agrees that the shift in commuter patterns toward suburb-to-suburb commutes has produced shorter trips, but he notes an opposing trend, that the suburb-to-suburb and center-city-to-center-city . . . (trips) are growing rapidly in length. "This suggests that the trip distance advantage of suburb-to-suburb travel may not last as the pattern becomes more pervasive."

A study by Cervero (10) also found that work trips in the suburbs may actually be growing in length, as suggested by Pisarski. In a population of 57 suburban employment centers, the employees commute an average of around 11 mi, taking around 24 min, which is farther and slower than journeys to work made by the typical suburban employee in 1980. He attributes the change to the increase in congestion and the widening jobs-housing imbalance (housing costs not matching incomes) found around suburban employment areas since 1980.

In the main these writers seem to agree on what is happening, but disagree on what, if anything, should be done about it. The depth of disagreement on normative issues is illustrated by a suggestion of Gordon and Richardson (7) that Newman and Kenworthy would perhaps "be well advised to seek out another planet, preferably unpopulated, where they can build their compact cities from scratch with solar-powered transit."

Gordon and Richardson, Lowry, and to a lesser extent Pisarski, give the impression of approving of sprawl development. Lowry (8) says

> Planners had better get used to Sprawl City, precisely because the American people invariably choose it as the better way to live. Whatever the case with water and sewer service, fire and police protection, Sprawl City is not necessarily less efficient than Compact City with respect to local travel. The critical factor in local travel is the collocation of daily destinations: home, work place, school, grocery, fast-food outlet, movie theater, bank. The evidence from daily travel surveys is that as residences, work places, and retail establishments have dispersed, they have mutually located in ways that reduce travel rather than increase it. On the other hand, as local travel becomes easier, people do more of it, so that congestion is a perpetual problem, however efficient the spatial organization and the transportation system."

There does appear to be considerable agreement that cities are still suburbanizing, that the overall densities of cities are still declining, that people are making more and more of their trips in cars. One side says it is because that is their free choice, and planning interventions are undesirable. The others would say that there could be other, equally desirable choices, but they will not be possible without intervention.

Impact of Traffic Flow Improvements on Transit

It is often claimed that bus transit is assisted by raising the speed of the entire traffic stream. Although it is true that higher transit speed means lower cost per vehicle-mile, the incentive to use transit is diminished by a general speed-up, and the overall effectiveness of transit is worsened. This is because the incentive to use transit is based on its performance relative to the automobile, and its relative performance worsens as traffic speeds increase.

In order to explain how speeding the general flow of traffic harms transit's relative performance, the time components of a trip must be examined. For a trip in the automobile, it is essentially just the time spent in the traffic stream. With the bus, it is the time in the traffic stream, plus the time spent waiting for a bus, plus the delays incurred while the bus is picking up other passengers along the route. Frequency of service can be improved somewhat by faster traffic speeds, but passenger-induced delay is not. Thus, by whatever factor automobile trip time is reduced, transit trip time is reduced by a smaller factor. It is not mere coincidence that transit is most productive in the cities (and in districts within cities) where traffic moves the slowest. Some evidence of this effect of traffic speeds on bus productivity is provided by SCRTD bus line data. Consider data on productivity (average boardings per bus-hour) as a function of average traffic speed where the line operates. Traffic speed is estimated from average bus travel speed by applying a passenger delay factor equal to 3 sec per passenger boarding:

$$V_T = \frac{D}{H(1 - Bd)} \tag{1}$$

where

V_T = estimated average traffic speed,
D = total daily in-service miles of the bus line,
H = total daily in-service hours of the bus line,
B = average boarding rate for the bus line, and
d = boarding delay per passenger (hr).

Data from 99 local bus lines yield the linear regression relationship shown in Figure 1:

$$\hat{B} = 167.0 - 7.14\ V_T \tag{2}$$

with $r^2 = 0.606$. This fit is artificially high because V_T is based

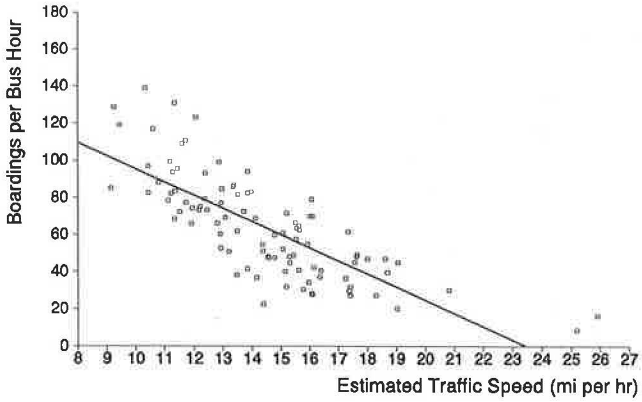

FIGURE 1 Bus line productivity as function of traffic speed.

partly on B. Without the boarding rate adjustment in the traffic speed calculation, r^2 is 0.52. The point here is not to be precise, but simply to illustrate a phenomenon that many traffic engineers choose not to believe.

This is not to suggest that the way to make bus lines productive is to slow them down! The point is that bus transit is more effective under land use and transportation equilibrium conditions that result in slower traffic. Of course, transit is even more effective if it is given a speed advantage without raising the general traffic speed, by means such as reserved bus lanes. Unfortunately, a practice more widespread than reserved bus lanes is bus turnouts. These are often touted by traffic engineers as an advantage for transit, even though their primary function is to raise average automobile speeds by lowering average bus speeds.

Aside from the general speed effect, transit is also harmed by the circuitous routings dictated by one-way streets. Walk distances are increased and route confusion is intensified. Passengers can't make a return trip by reversing course; they must find a corresponding stop on another street. The return route could be on either side of the arrival route.

Bicycles are negatively affected both by high automobile speed and by circuity. High speed differentials are dangerous and intimidating. The circuity sometimes forces cyclists to use streets on hilly terrain that they otherwise could avoid. Bicycling can never be a serious mode of nonrecreational travel until treated as if it is.

Impact on Residence Location Decisions

One of the proposed means of reducing VMT is the balancing of jobs with housing. As initially introduced in the Los Angeles region, the concept addressed only the gross balance at the subregion level. There has been much ensuing discussion, but generally the basic idea of having housing convenient to workplaces has become a well-accepted principle. Los Angeles has been actively encouraging housing construction in the central area, and a planning program has established a goal of 100,000 residents in the downtown area.

This goal is subverted by plans to increase roadway capacity for commuter traffic through the same central area, in corridors that roughly parallel the first two rail lines. Faster traffic and higher traffic volumes diminish the desirability of an area for residential use. The impact of traffic on neighborhoods was described by Appleyard et al. (*11*):

> Paired one-way street systems expanded the impact of former arterials into the neighborhoods, broadening the bands of traffic impact and the number of houses subjected to traffic. It may well be that more residences were negatively affected by conversion to one-way systems than by the freeway systems. But eventually it was the freeways that became the targets of protest. The taking of homes and jobs was more traumatic and visible than the slow incremental intrusion of traffic on residential streets.

Normal practice is to allocate high traffic volumes and higher speeds to commercial streets and lower volumes and speeds to residential streets. Unfortunately, there is too much traffic volume and not enough commercial land use for this allocation to be workable. Without enough commercial activity to line the arterials and take the abuse of heavy traffic, a large portion of the land fronting high-volume streets is used for what might be called "sacrificial residential."

The mechanisms for the long-term detrimental effects of traffic improvement are complex, but conform to common sense. In the simplest terms, the attempt to accommodate automobiles without directly charging the users for the cost they incur results in overuse, in the form of heavy traffic. The traffic negatively impacts adjacent land uses, causing people to migrate to lower-impact locations. Lower-income people and less desirable land uses take their place. The heavy traffic remains or worsens because the additional people now at the urban periphery impose an additional traffic burden on the central area.

Traffic gradually increases as measures are taken that favor through traffic over local access travel. When used to speed traffic, one-way streets are a prime example of an action that favors through traffic over local access. Their greater circuity differentially affects the people making short trips, because more of them are seeking access. The greater inconvenience of local travel adds to the incentives of local residents to relocate, whereas the greater capacity aids people passing through, and encourages more through trips. The trips passing through are longer trips, that add more VMT to the region's travel.

POLICY AND PLANNING CONFLICTS

The attempts to provide for more traffic, even as concerns about neighborhood traffic impacts grow, are a result of conflicting policies. Inconsistent policies coexist in part because most network impacts develop over a long time. The effort to ease a congestion problem by speeding and enlarging the flow of vehicles discourages uses like housing and neighborhood services, and ultimately results in migration, longer trips, and more congestion.

Politicians are placed in the middle. It is easy for people in their residential personas to demand that the politicians do something about neighborhood automobile impacts, while in their automobile-driver personas they insist on free-flowing thoroughfares. The politician can't reasonably be blamed for support of conflicting policies when heated demands for resolution are hopelessly in conflict.

There are many examples of these developing conflicts, but they are most acute in the high-activity areas. Two specific cases in Los Angeles will serve to illustrate the problems created by attempts to speed traffic.

The Central Business District

The CBD (Figure 2) provides the best illustration of the embarrassments of successful traffic engineering. Over the years the flows have been improved, but the primary result has been more cars, not more people. The number of people entering downtown has only increased 5 percent since 1955 but the number of automobiles entering has increased 23 percent (*12*). This modest increase in the number of vehicles has had a disproportionate impact on congestion because of the automobile's demand for street space and storage.

In the past, when faced with congestion, the standard approach has been to expand street-carrying capacity, either by expanding the streets themselves or by redesign. Accommodating more vehicles has only aided the spread of automobile use. In 1939, the number of passengers per car entering downtown was 1.51; in 1955 it declined to 1.46 and in 1984 it declined to 1.36.

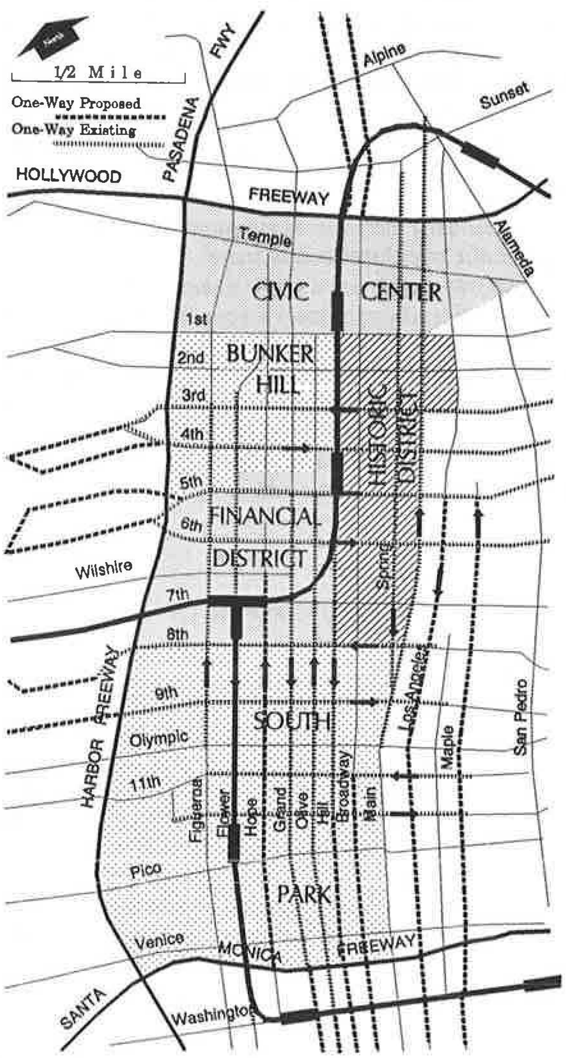

FIGURE 2 Los Angeles CBD.

The CBD is seeing massive development of new office space, and the beginnings of an advance toward downtown housing. There is a formal interagency effort to plan for access and circulation, with some hopes for avoiding the pedestrian-hostile environments created years earlier in the renewal of Bunker Hill.

Yet here is where the movement toward one-way streets continues to be both strong and—except for Broadway—seemingly unquestioned. Some of the one-way streets have been in place for many years. Subway construction provided the excuse to add some more (Hill, Figueroa, and Flower Streets). Although one-way streets were justified as ways to cope with subway construction, they are unlikely to return to their former two-way operation once the construction is complete. To the contrary, the goal is to extend the one-way operations, far beyond the CBD in some cases (*13*).

Support for Rail Investment

Until now, downtown employees have had a limited choice: either overcrowded buses or underutilized automobiles, all running together in a gradually slowing stream of traffic. The rail lines now being constructed will provide an alternative means of access to the CBD for a large number of workers. How effective the rail lines turn out to be will depend in large measure on how well supported they are by governmental and private sector policies.

Local supportive actions for rail transit are a prerequisite for federal funds. In 1978, the U.S. Department of Transportation (DOT) came out with its Policy Toward Rail Transit. Under the heading, "Controlling the Cost and Increasing the Effectiveness of Rail Transit," the policy stated the following:

> Localities proposing to build rail transit with Federal assistance will be required to commit themselves to the development and implementation of a program of local supportive policies and actions designed to enhance the proposed system's cost-effectiveness, patronage and prospect for economic viability (*14*).

Among the supportive measures that DOT considered appropriate were "pricing, regulatory or traffic control measures aimed at managing the peak period use of automobiles with[in] rail corridors (e.g., traffic metering, tolls, higher parking fees, elimination of employer-subsidized parking)."

There is a serious question as to whether this investment in rail transit is going to be adequately supported by local actions, as required by DOT policy. It is inconceivable that the traffic control measures anticipated in the federal policy could include adding automobile capacity in the same areas served by the rail transit. If the rail service is properly supported, it would make additional automobile capacity unnecessary. If the automobile capacity is there, it will be taken up by additional through traffic, and rail effectiveness will be weakened. Yet plans for saving the historic core include construction of five multistory parking structures, in an area that is still heavily transit oriented.

The current plans of continual roadway widening and traffic flow enhancement are simply a continuation of practices that began in the 1920s. However, even then planners knew that "even if a city doubled the width of its streets, traffic would eventually rise to its previous level of intensity. . . . It was improbable . . . that the city could increase the capacity of the streets beyond the ability of the public to purchase automobiles" (*15*).

Wilshire Center

In the Wilshire Center area (Figure 3), a cooperative planning process developed an approach to traffic and development in keeping with the larger goals of the region. The Wilshire Center Plan (*16*), a concept plan produced with private funds in cooperation with the City Planning Department, proposed a variety of transportation management measures intended to accommodate development by reducing trip rates rather than by increasing flows.

But this plan is not the only one for the area. The traffic engineering proposals produced by the Los Angeles Department of Transportation would convert Sixth Street to one-way east in order to create a high-volume through route. Seventh Street would provide for one-way west travel, assuming that it will also be pushed through the Ambassador Hotel site, where it deadends. This plan conflicts with the Wilshire Center Plan, which envisions Sixth Street as having the role of an intensive pedestrian, local shopping, and restaurant area to complement Wilshire. Where the Wilshire Center Plan tries to foster local access, controlled traffic flow, and encouragement of pedestrian activity, the traffic engineering plan attempts to develop an efficient conduit for travel through the area, ensuring more noise and fumes for adjacent businesses, and greater barriers to pedestrian crossings. The Department of Public Works is already in the process of widening the Sixth Street roadway at the expense of the sidewalks, and to the detriment of recently completed adaptive restorations of local retail establishments that would cater to pedestrian traffic.

This is an example of how local travel is often thwarted in order to make regional travel easier. If people making local trips are unable to travel west on Sixth Street, they are unlikely to go to Seventh Street for the westbound trip. They may travel on Wilshire instead, or cut through the adjacent high-density housing areas, creating "rat-runs" of major proportions. How buses are to be routed, when a one-way street pair straddles a two-way street, is not clear. If good bus service was a real objective, these kinds of proposals would never be made.

On another set of streets, the same traffic proposal also illustrates the undeclared degradation of residential areas by traffic management decisions. One way to take advantage of spare capacity of a low-use street when it is adjacent to a heavy traffic street is the creation of a one-way pair. By dividing the flow equally, greater flow is permitted overall. Plans to make Eighth and Ninth Streets a one-way pair would be a classic illustration of Appleyard's caution about one-way streets. The traffic currently carried by a busy commercial street (Eighth Street) would be divided, to inundate a high-density residential street (Ninth Street) with traffic. It would be surprising if any of the residents of the multistory apartment houses along Ninth Street have any inkling of these plans, or if they do, what the impact on their lives would be if the plans were to be implemented. Over the years, the owners of the affected properties have bought and sold in conditions of relatively low traffic. The coupling of the residential street with a major arterial will clearly be harmful to residential property values, but the owners will not be compensated.

SOME ALTERNATIVE WAYS OF DEALING WITH TRAFFIC

Do Americans really choose sprawl as the better way to live, as Lowry suggests? Could there be a better choice, or at least alternatives for those who would choose them? Even if sprawl

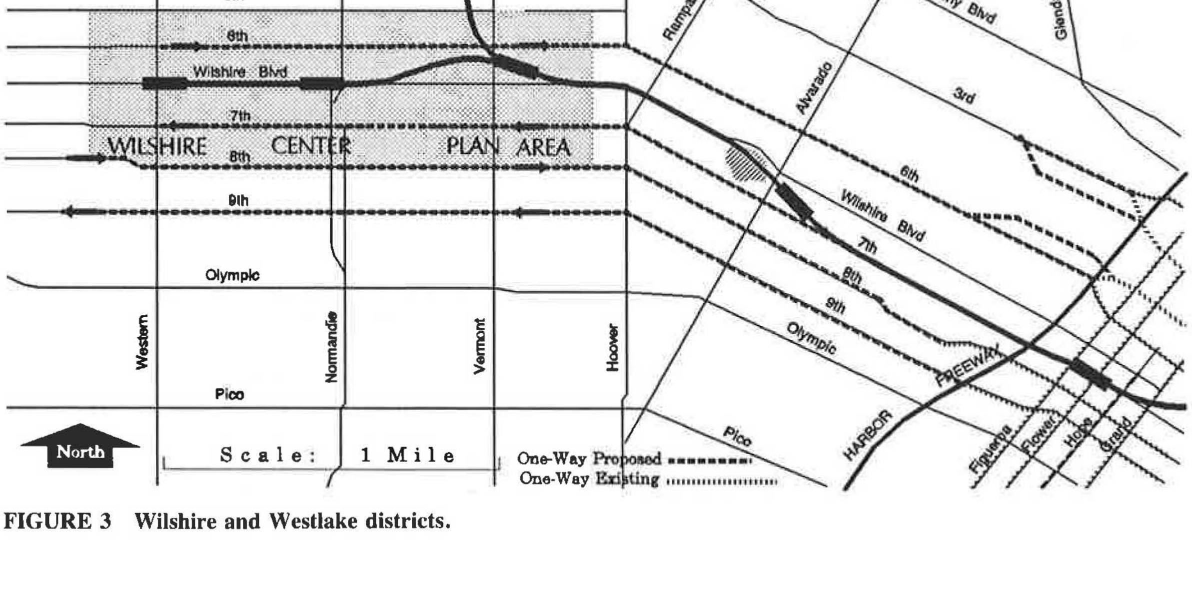

FIGURE 3 Wilshire and Westlake districts.

is the collective preference, how long will Americans retain the freedom to use energy at 5 times the world average rate, and contribute to global warming in similar disproportion? At this juncture in world history, it might behoove Americans to begin thinking seriously about sustainable urban form, i.e., what arrangement of land use patterns would be viable when people are limited to their per capita share of the world's diminishing resources? Sprawl does not appear to be an acceptable option under this fundamental ground rule, although a multicenter urban form could be. Clearly, there are policy conflicts in current approaches to land use and transportation. Some programs support enhanced livability of central areas, whereas other programs would sacrifice the quality of central areas to speed traffic to outlying areas. The policy conflicts have arisen because of changing goals. Some people embrace containment and concentration of urban development, whereas others continue working toward earlier goals of easy mobility, which leads inexorably to sprawling development.

If we are trying to reduce VMT by making higher density central city living more acceptable, the slow incremental intrusion described by Appleyard (*11*) should concern us. There may be no more freeways built in Los Angeles, but there are many plans for widenings, channelizing, conversions to one-way streets, "smart streets," and "superstreets." Whether through creation of one-way streets or by advanced methods of traffic control, these will have a serious negative impact on the willingness of people to live in high-density neighborhoods.

If society's goals include energy efficiency, air quality, and reduced traffic stress, and if sustainable urban form is one of the means to those ends, policies should promote population concentration and reduced automobile dependence. Concentration of people and automobiles is untenable. Elsewhere in the world, in the United States, and even elsewhere in California, there are examples of populations living by choice in high-density urban areas. Where we have attempted to concentrate people and automobiles, the environment deteriorates; people with choice move away and people with less choice replace them.

If we are to move toward attainment of these three related goals, we could begin with a new direction for transportation: focus on the pedestrian. We have to go back and look at the kinds of urban development and transportation decisions that encouraged people to get into their cars for the most modest of trip purposes. We have to ask how new decisions can reverse this process while avoiding perceptions that life quality is being further eroded. The fact that the ultimate goal will take many years to attain is no reason not to start in the right direction.

Encouragement for Pedestrians

People will walk more when walking is made safer and more pleasant. Enhancements of traffic flow almost always degrade the pedestrian environment, by increasing danger and by making walking inconvenient.

Most of the concerns about pedestrian safety in this country are manifested as "pedestrian control," a euphemism for keeping people out of the way of vehicles, rather than keeping vehicles from running into pedestrians. This subtle but important distinction results in such measures as: traffic light buttons that the pedestrian must push to get a walk signal; the walk signal itself, which limits the portion of the green phase available to the pedestrian; and the pedestrian bridge or tunnel, which requires the pedestrian to climb up and down stairs to let the cars travel through without hindrance.

Other practices discourage walking. The emphasis on off-street parking leads to numerous conflicts on the sidewalk. Even though pedestrians have the legal right of way on sidewalks, they are commonly ignored by drivers either wishing to hurry out of the traffic stream, or into it. The provision for right-turn-on-red is good for traffic flow but endangers the pedestrian. The wide streets that look so good to an automobile driver can be a formidable obstacle to a pedestrian trying to cross. But turnouts not only reduce bus speeds, but have the effect of lengthening the crosswalks and reducing the width of the sidewalk at the location where people stand to wait for the bus, thus further narrowing the effective sidewalk width for pedestrians. The elimination of crosswalks at nonsignalized intersections, based on a single study which concluded that they result in pedestrian overconfidence, leads to further driver disregard for the pedestrian.

Children are arguably the primary victims of the deteriorated pedestrian environment. This result has put pressure on families with children to abandon the central city if they are able. Even in the suburbs, the dangers of street crossings and the distances to the locations of children's activities have caused parents to become chauffeurs, creating automobile trips that would be completely unnecessary in an environment that is less hostile to pedestrians.

The safety of children is the central reason for the pioneering work in Holland on the woonerf, begun in Delft in the mid-1970s. Appleyard (*11*) provides a description:

> A "woonerf" is a residential area where traffic flows are generally between 100 to 300 vehicles per hour during the peak period. The design features of the "woonerf" are:
>
> 1. The sharing of the street space between vehicles and pedestrians. To this end curb distinctions between the sidewalks and street pavement are eliminated.
> 2. Conveying the impression that the whole street space is usable by pedestrians. To this end abrupt changes in path direction, vertical features, surface changes, and plantings and street furniture are all designed as obstacles to vehicle travel and to create a residential atmosphere.

While the woonerf addresses the immediate environs of the dwelling, other actions will be needed to enable pedestrian access to everyday needs, e.g., shopping for groceries and other merchandise, going to school, and local recreation. The most basic change that is required is the reduction of the distances between these primary activities. An emphasis on mixed-use zoning will help, but if the requisite change in land use pattern is to be extensive enough and rapid enough, ways must be found to permit mixing in currently unmixed areas, in addition to mixing uses in new developments. This is not likely to be easy.

Where traffic engineering choices must be made between facilitating through traffic or local traffic (often having to do with restrictions of turning movements), an emphasis on local travel will bring reduced speeds, and will be more friendly to pedestrians. Lanes will not be added, because fewer lanes mean less risk in crossing streets.

Traffic Calming

By using some of the many available techniques to divert and slow traffic in residential areas, the "rat-running" through those areas will be curtailed. Although some traffic will disappear, some of it will be pushed back onto the arterials and they will become more congested. Traffic on the arterials will have to be addressed.

Whereas traditional traffic engineering practitioners would remedy the increased congestion with more arterial capacity, the Germans have taken a different approach. They recognized that spot applications of the woonerf can create inequities for nonincluded neighbors, either in adjacent residential zones or on heavier traffic streets, and concluded that a more comprehensive treatment of wide areas was needed. They have carried the philosophy of the woonerf higher in the hierarchy of travel networks, by a program of area-wide traffic restraint. They call it Verkehrsberuhigung, which translates as "traffic calming" (*17*).

Although the Los Angeles approach to traffic congestion is presently oriented to boosting traffic flow, it could be reoriented toward traffic calming. Rather than see how much traffic can be squeezed through traffic lanes and intersections, the new philosophy would be to determine how many vehicles are acceptable at all times and places, and use the tools of traffic control to limit the numbers of vehicles accordingly. In their resident personas, most people recognize that high speeds are more of a problem than congestion, and that enforcement is a weak option for curtailing high speeds. Traffic engineering techniques should be used in combinations for smoothing the flows of traffic, while avoiding provision of more capacity. The goal should be to allow traffic to move at a relatively constant speed, with a minimum of queuing and stops and starts, and with higher speeds inhibited at all times. The determination of the levels of traffic and the speeds to be allowed should be made at the appropriate community or neighborhood level through democratic processes. Such questions are not a matter for traffic engineers or transportation organizations to decide.

Transit Capacity Enhancement

Clamping down on excessive traffic would have the effect of reducing mobility, if no compensatory actions were taken. Mobility can be maintained while reducing the numbers of vehicles, if the capacity in vehicles is increased.

In the central part of the Los Angeles region today, an awkward situation exists, in which transit vehicles are filled to capacity on roadways that are at their vehicle flow capacity. People can't get out of their cars and into transit vehicles because the capacity can't be provided, because the funds are unavailable. The single-occupant vehicle (SOV) drivers are unable or unwilling to share rides in automobiles. So we talk about squeezing a little more vehicle flow onto the roadways by electronics or one-way streets.

Where existing transit capacity is already fully used, the most cost-effective solution would be to transfer funds heretofore available for increasing vehicle flows, to build transit capacity at the same locations. Ideally, the funds would come from the vehicle users, through a congestion fee. Less ideal means may have to suffice for awhile, but no additional vehicle flow capacity should be contemplated without first considering the possibility of using the same funds for enhancing transit capacity. Having the SOV driver pay for building up the capacity of transit is justified on several grounds: that the remaining SOV drivers benefit directly from having others switch to transit, that the subsidization of the automobile has been the primary cause of the thinning of transit service, and that the SOV driver is responsible for most of the pollution and congestion.

One of the potential sources of funds for transit capacity enhancement is the trip fee imposed on projects that burden the transportation system. Too often such fees are conceived as a way of purchasing additional capacity for automobiles, further exacerbating the problems they are intended to solve, and further weakening transit. If the stated purpose of the fee is to provide road capacity, the fact that construction of additional road capacity is likely to result in a worsening environmental problem in the long run makes it difficult or impossible to demonstrate a nexus between a fee imposed on development and a remedy that the expenditure would provide. In other words, if there would be only a temporary improvement, followed by a consequent worsening of regionwide traffic, the fee designated for road capacity is ultimately only a penalty.

One option for a trip fee is to capitalize the future cost of transit service to the site and contract for a perpetual level of service. Something on the order of $5,000 would provide the transit subsidy required to service that trip in perpetuity, on the basis of some reasonable assumptions:

$$C_P = 2C_b N_T \tag{3}$$

where

- C_P = total public cost of all future trips represented by the daily arrival and departure of one person via transit,
- C_b = average public cost (subsidy) per one-way (linked) transit trip, and
- N_T = trip accumulation factor, the number of all future trips represented by one daily trip.

Using RTD figures, the subsidy per one-way trip, C_b, is given by

$$C_b = (\text{cost per boarding}) \times (\%\ \text{subsidy}) \times (\text{boardings per linked trip}) = \$1.27 \times 0.55 \times 1.3 = \$0.91.$$

The trip accumulation factor, N_T, is just like a present worth factor used to convert a stream of income into a single present value. By using a discount factor, the time value of money is accounted for, as well as uncertainties or risks. Here, the total term is 25 years, and the discount rate is 10 percent. Each daily trip corresponds to about 300 annual trips. These assumptions give N_T a value of 2,785 trips.

Therefore, using Equation 3, the public cost of all future round trips is

$$C_P = 2 \times \$0.91 \times 2{,}785 = \$5{,}070.$$

Designating the fee for continual future transit service has some advantages over the trip fee that is either undesignated or slated for road enhancements:

- For each tripmaker to be accommodated by transit, the developer can avoid the cost of a parking space (if permitted by parking codes to make this substitution);
- The community would benefit because transit service would be more frequent; and
- Additional cars, and the need for additional road capacity, would be avoided.

One disadvantage of designating a fee in this way is that a decision may be required at the time a project is undertaken about which entity should provide the service and the nature of the service itself. For that reason, it might be better to have an undesignated fee (i.e., a tax). San Francisco is an example of a city that imposes a fee on new development to support transit service. At $5 per square foot, the San Francisco fee appears to be too low to cover the added cost of future service, but it is a step in the right direction.

Land Use Balance

Encouragement of pedestrians, calming of traffic, and increasing transit capacity are all ways of accommodating trips that will be generated. We must also pay attention to the way the trips are generated. Land use arrangement is the key to the numbers and lengths of vehicle trips likely to occur. A closer coupling of complementary land uses would foster more foot travel, bicycle, and transit riding, and thereby reduce the number of motor vehicle trips.

Job-housing balance is important; the attention it has received recently is justified. But it will be ineffective in reducing vehicle trips unless carried out at the neighborhood and community scales (in areas of, say, no greater than 4 square miles). Although subregional balance (the current emphasis) has the potential of reducing the lengths of some of the automobile trips, it is unlikely to reduce their number as long as people still have to jump in their cars to get a loaf of bread. To the extent that jobs are put in the suburbs where housing is in excess, there is no reasonable assurance that average automobile trip lengths would decline at all, if Pisarsky (*9*) is correct in contending that any favorable trip distance advantage obtained when jobs follow residences to the suburbs is only temporary. The most likely result would be continued expansion of housing into rural lands, to take advantage of the additional suburban jobs and the lower cost of undeveloped land still further out. Transit ridership will be significant.

The gradual formation of land use patterns to accommodate the automobile has solidified the need for the car, primarily by making walking trips impractical. If an individual can't make many necessary trips conveniently on foot or on bicycle, and those trips add up to a justification of car ownership, a car is bought and then used for virtually all trips, because the incremental cost of a single automobile trip is so low. In Los Angeles, this may be a first car, but more likely a second car.

There is more to be balanced than jobs and housing. Most trips (81 percent in the region) don't even connect jobs to housing. Just as housing was, over the years, separated from job sites, commercial and retail activity has tended toward consolidation in megacenters. The accumulation of businesses that once served neighborhoods into region-serving specialty centers (e.g., lumber and hardware sales) has come about partly because the general public pays such a large portion of the cost of goods distribution (when customers travel long distances over subsidized roads). Because these costs aren't paid either by the seller or the customer, the seller can disregard them.

In order to foster more optimal arrangements of land use, the emerging trend toward mixed-use zoning should be accelerated. Insofar as possible, all of the costs of transportation should be made tangible to the user, as well as avoidable via choice of mode.

Applying Holtzclaw's (*6*) result (that per capita VMT is reduced 30 percent by a doubling of population density) in the Los Angeles basin, if new development is located in areas of 12,000 persons per square mile density, rather than 3,000, there will be a 40 percent saving of VMT. Holtzclaw also concludes that allowing jobs to concentrate at the center will also help to reduce VMT, a conclusion that suggests reconsideration of certain aspects of the current job-housing balance policy of the Los Angeles basin. This result says that it is far more advantageous to an air basin to have infill development than to permit development to occur on open land at the perimeter.

Traffic Engineering Objectives and Practices

In spite of big plans to reduce emissions, the reality is that the Los Angeles region is still making every permissible effort to increase vehicle flows and accommodate the automobile. Such notions as getting the most traffic flow through available street widths, running cars at higher speeds "to reduce emissions," and eliminating bottlenecks, are still in regional plans ostensibly aimed at attaining higher air quality. Now that there is to be consideration of global warming in the region's air quality measures, there is even more reason to question actions that would increase vehicle flows.

Transportation departments and traffic engineers operate within a framework of expectations prescribed by local government officials, and they in turn respond to their constituents. In their driver personas, the citizens expect the engineers to make traffic go faster. Traffic engineers could just as well work toward an alternative set of goals, if asked. Their tools, such as one-way streets, roadway geometrics, physical control devices, and ATSAC, can be used just as easily to adjust traffic flows to desired levels instead of maximum levels.

A more up-to-date set of goals and objectives is needed. By focusing on the pedestrian, and on improving neighborhood environments, new traffic engineering objectives can be specified. The objectives would be based on how much vehicle traffic is acceptable—the more people in a given area, the fewer vehicles per capita. At some point, the absolute number of vehicles should decline.

One way of giving due consideration to the pedestrian is to focus on the person-capacity of intersections, rather than the vehicle capacity. If pedestrians, cyclists, and transit riders were to be considered as the equivalent of car drivers at each intersection, there might well be intersections where maximum flows would be achieved with no cars at all. In effect this is what has been done in most of the other large cities outside the United States. It has become quite common to reserve most of the street space in the centers of the cities for pedestrians, with high-capacity transit for getting people to and from those areas.

Instead of generally speeding traffic, ATSAC should be used in conjunction with measured or expected pedestrian and transit passenger movements, to limit vehicle flows to acceptable levels. This is likely to require shorter traffic cycles for encouraging transit operation and bicycle and pedestrian flow.

The use of one-way streets should be reexamined. They have merit for limiting automobile traffic in sensitive areas, but their use for increasing street capacity is questionable. A research report by Harwood (*18*) notes that earlier beliefs that one-way intersections were more efficient, which were included in the *1965 Highway Capacity Manual*, were later contradicted by opposite findings. Harwood further notes the circuity effect that increases total traffic volumes and consequently increases air pollution levels.

There should be no one-way operation of transit service. One-way automobile lanes should be used only to provide acceptable street conditions for transit and bicycle operations, not to allow more cars to move faster. They are useful for limiting traffic in residential neighborhoods.

In areas where pedestrian cross-traffic is desirable, the pedestrian barrier factor of the vehicle stream should be considered. Transit has the potential for providing a high level of access to a site without destroying the pedestrian environment. A bus coming every minute with 40 people is much less a barrier to pedestrian cross-traffic than its equivalent, one car every 2 sec. This principle is one reason why the Denver bus mall is so successful. Even though buses run at frequent intervals, pedestrians cross the bus way freely, and the accident rate is nil.

CONCLUSION

Street improvement doesn't have to mean more traffic, more vehicle miles, more noise and more air pollution. Streets are a multipurpose resource. The rights of way of a city belong to its people, not to its automobiles. The fact that cars and trucks have gobbled up a steadily greater portion of the region's land area for the past 70 years does not mean the process cannot be reversed.

The reversal can come about by changing the goal of street management from traffic maximization to traffic calming. We do want to get the most out of our investment in street space, but most doesn't mean the most cars.

The most important actions to be taken are the following:

- Balance Land Uses. Make it possible to walk from one activity to another. When there is a goal of improving the balance between housing and jobs, we should no longer think of some areas as commercial, and thus subject to higher traffic levels. Allow fine-scale mixing of land uses, based on direct accounting for impacts.
- Give the Advantage to the Environmentally Preferable Modes of Travel. Priority should be given to pedestrians, then bicyclists, then transit, then multioccupant vehicles, and only then to SOVs.
- Determine How Much Traffic is Acceptable Before Applying Traffic Engineering Methods. Determine how much traffic should be allowed at each location, and make sure traffic control measures support that amount and no more.
- Base Traffic Flow Decisions on Person Flows, Not Vehicle Flows. In general, on streets with more pedestrians than vehicles, sidewalks should be widened and roadways narrowed.
- Above a Certain Population Density, Reduce Vehicle Densities. Higher combined residential and employment population densities present an opportunity for good transit service. Accommodating additional automobiles only prevents all modes from being effective.
- Direct Project Funding Toward Moving People. Rather than increase vehicle flow by adding lanes or by use of electronics, raise transit-carrying capacity and reduce the number of vehicles, using the same funds that would otherwise be available to increase vehicle flows.

The scourge of pervasive, intrusive motor vehicle traffic can be conquered, even in Los Angeles. The most difficult part of the task is the reorientation of thinking and expectations. The cost and the personal adjustments required will be less onerous than what would be required of us if we continue on our present course.

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Evaluation of Transportation Demand Management Programs at Residential Developments

CHRISTINE WOLF AND CY ULBERG

Over the last decade, local jurisdictions and transportation agencies have increasingly used transportation demand management (TDM) programs to manage the traffic impacts of new commercial and retail developments. More recently, however, King County and the cities of Kirkland, Redmond, and Seattle, Washington, have introduced TDM programs for residential developments or origin sites. The objectives of the evaluation were (a) to document the implementation of home-end TDM strategies, and (b) to evaluate their effectiveness in mitigating the number of vehicle trips generated by residential development. Because few projects had been built and occupied by the time the evaluation concluded, quantitative evaluation was limited, and the success or failure of residential TDM programs could not be determined. However, it was possible to gain an understanding of the nature and reasons for the implementation problems encountered through qualitative means. These means included interviews with jurisdictional staff, developers, and managers and a focus group among residents. The analysis pointed out problems related to (a) the decision process leading to the imposition of mitigation requirements, (b) the institutional memory of requirements, (c) monitoring, (d) enforcement of compliance, and (e) the adequacy of mitigation measures. Recommendations to mitigate these implementation problems are suggested.

Over the last decade, local jurisdictions and transportation agencies have increasingly used transportation demand management (TDM) strategies as a means of managing the traffic impacts of new commercial and retail developments. TDM programs are developed for a specific development project to mitigate the transportation impacts associated with it by discouraging single-occupant vehicle (SOV) trips and encouraging travel by high-occupancy vehicle (HOV). They serve the site-specific needs of tenants and are designed to reduce SOV trips and parking demand at a development site.

In the past, these efforts to discourage SOV commutes and encourage HOV modes of transportation have almost exclusively been focused on destination sites—office buildings, industrial or office parks, and office or retail developments. Since 1987, however, King County and the cities of Kirkland, Redmond, and Seattle, Washington, have introduced the concept to residential developments, or origin sites, in an attempt to mitigate the transportation impacts of these developments through promotion of HOV use among residents.

Before the onset of this study, no data on residential projects using TDM strategies had been collected, nor had an evaluation been conducted of the TDM programs and the various mitigation measures attempted. An objective assessment of these programs seemed appropriate. Thus, the original objectives of this project were to (a) document the implementation of home-end TDM programs and (b) evaluate their effectiveness in managing the transportation impacts of residential developments on freeways and adjacent arterials. These objectives were meant to identify the effect of home-end TDM programs on HOV use by residents and to identify specific effective actions.

The researchers intended to combine a number of different methodologies, including surveys of project residents, surveys of ridematch and vanpool applicants, interviews with project developers and managers, and comparisons of vehicle counts between TDM program sites and control sites.

However, in the early stages of the project it became clear that the scope envisioned was not appropriate for the available data. Thus, the success or failure of TDM programs on residential developments was not determined. Rather, the scope of the project was extended to gain an understanding of the nature of the problems encountered in implementing these programs and to develop approaches to minimize these problems while gathering as much information relating to the original goals of the study as possible.

PROJECTS IN KING COUNTY, KIRKLAND, REDMOND, AND SEATTLE WITH TRAFFIC MITIGATION REQUIREMENTS

Locations of TDM Projects

The researchers established a list of developments with TDM requirements from files maintained by the Municipality of Metropolitan Seattle (Metro), the region's transit operator. As part of the State Environmental Policy Act (SEPA) process, each jurisdiction informs Metro about major projects with a potentially high impact on transportation. Because, with the exception of the city of Seattle, jurisdictions have generally required developers to negotiate any TDM measures with Metro, its files were relatively comprehensive.

In all, 57 residential projects with TDM requirements were identified and analyzed. Of these, 47 were located in unincorporated King County, 3 in the city of Kirkland, 2 in the city of Redmond, and 5 in the city of Seattle. Thus, almost all projects, and the focus of the study, were in suburban environments. According to the research conducted at the

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outset of this study, none of the other jurisdictions in the region had started to require TDM measures from residential developments. Ten of the projects, all located in unincorporated King County, were single-family lot developments; therefore, a comparative analysis of TDM programs implemented for single-family projects versus multifamily projects could not be carried out because of the small sample size of single-family projects. For 12 projects, the information obtained was too limited or outdated, and the developers or managers for these projects could not be contacted. Nine of these projects were within the jurisdiction of King County, and three within the city of Seattle. Two projects, both in unincorporated King County, had been withdrawn and would not be built, 25 were either still in the approval process, not started, or partially built. Only 18 had been built and occupied by May 1990.

Types of Home-End TDM Requirements

Twelve different measures encouraging mode shift have been imposed on residential developments in the Puget Sound region. They can be grouped into four types, including (a) the provision of physical structures that encourage mode shift, (b) the distribution of transit and rideshare information, (c) the collection of information on commute behavior, and (d) transit subsidies. No more than eight measures were required from any single development. Twenty projects were listed with unspecified TDM program requirements, other than sidewalk improvements (see Table 1).

The provision of physical structures included the requirement of fully connected sets of sidewalks on the project and along adjacent streets in 14 cases (25 percent), bus pads and shelters in 4 cases (7 percent), and secure bicycle storage in 6 cases (11 percent).

The distribution of transit and rideshare information was required for 23 of the projects (41 percent). In 7 cases (13 percent), this included installation of a commuter information center (CIC) on site. Seventeen developers (30 percent) were required to provide a transportation coordinator (TC) on the project. Periodic promotion of transit and ridesharing options was requested in 4 cases (7 percent).

Information on commute behavior, accomplished through surveys of residents, was to be made available on request of the jurisdiction by seven of the projects (13 percent). Five development owners or managers (9 percent) were to submit regular reports to the jurisdiction.

Transit subsidies in the form of a free monthly bus pass to first-time residents were required of 24 developments (43 percent). One project (2 percent) was to provide peak-hour shuttle services to the nearest park-and-ride lot. Originally, two developments, both large multifamily projects, had had this requirement, but it was implemented on only one of them.

KNOWLEDGE OF AND COMPLIANCE WITH TDM REQUIREMENTS

Figure 1 shows a breakdown of projects by knowledge of TDM requirements and compliance.

Knowledge of the Requirements

The developers or managers of 12 of the 45 projects (27 percent) for which contact could be made acknowledged awareness of at least one TDM requirement. Out of 21 projects in which more than one requirement was imposed, developers of 8 projects were aware of the requirements. However, two companies owned six of the projects. In all, only six companies in the area paid serious attention to the requirements. The two companies with more than one project with TDM requirements were among the biggest developers in the region and had a political and economic stake in successful relations with the jurisdiction. They were willing to comply with requirements they considered minor to preclude negative public opinion and higher mitigation costs. All four developers contacted who had both a sidewalk requirement and a generic TDM program requirement knew only about the sidewalk. Three projects reviewed had the single obligation to provide a free bus pass to first-time residents. Managers or developers of these projects were aware of the requirement. It is possible that in some cases developers claimed no knowledge of TDM requirements to cover their unwillingness to comply with them. In cases in which the researchers suspected this, they could not establish whether the requirements were just considered minor and thus ignored until the developer was questioned about their implementation or whether the TDM concept itself was not considered worthwhile. None of the 20 developers of projects with unspecified TDM program requirements was aware of any requirements.

Compliance with the Requirements

While the existence of TDM requirements on projects could be determined with Metro lists, no sources other than the developers themselves were available to establish compliance for all but two of the projects. Thus, compliance had to be determined by interviews with developers.

Of the 12 projects for which developers acknowledged the requirements, only 9 projects (75 percent) had been built and occupied by May 1990. Of these nine, the requirements of eight (89 percent) had been implemented at least in part. As stated earlier, four of them had only a single requirement, three to provide monthly bus passes, one to provide sidewalks. Four other developments, each with a different set of requirements, belonged to the two previously mentioned major development companies. At the time this study was conducted, two of them were just starting to implement the measures because they had been occupied only recently. One developer acknowledged the requirements in an interview and stated that they were minor both in costs and personnel, even though five different measures were required. However, he had not implemented them.

PERCEPTIONS OF DEVELOPERS AND MANAGERS

The information presented discussed in the following paragraphs was gained through informal interviews with devel-

TABLE 1 RESIDENTIAL PROJECTS: TDM MEASURES, KNOWLEDGE OF TDM REQUIREMENTS, AND THEIR IMPLEMENTATION

	Project			Amenities				Transit/Rideshare				Data		Subsidies		Developer		
Name	Units	Type	Built	Wal	Pad	Shel	Bik	Info	CIC	TC	Pro	Sur	Rep	Bus	Shu	Cont	Kno	Impl
The Park at Forbes Crk.	496	mf	X					X	X	X				X	X	X	X	X
Ballinger Commons	485	mf	X				X	X	X	X	X	X	X	X		X	X	X
Redondo Beach Club III	298	mf	X	X				X	X	X	X			X		X		
Riverview Apts	266	mf		X												X		
Emerald Glen II	261	mf			X	X		X		X			X	X		X		
Remington	260	sf	X					X		X		X				X	X	X
Emerald Glen	257	mf	X	X	X	X		X		X				X		X		
Glen Park I	250	mf	X		X			X	X	X	X			X		X	X	
Shadow Brooks	247	sf						X		X		X				X		
Timberline Ridge	242	sf						X						X		X		
Colony at Bear Creek II	238	mf	X				X	X						X		X		
Evergreen Heights	200	mf						X						X		X	X	
Newport Crossing Apts	192	mf		X				X		X	X	X	X	X		X	X	
Kenmore on the Park	180	mf		X												X		
Redondo Reach	167	mf						X		X		X		X		X		
Riverside Apts	150	mf	X											X		X	X	X
Cascade Terrace	144	mf	X											X		X	X	X
Kenmore	140	mf		X												X		
Westview Village	137	mf		X				X		X		X	X	X		X	X	
Silver Shadow Apts	132	mf	X	X		X		X		X				X		X		
White Gate	124	sf		X												X		
Juanita Shores	112	mf					X	X						X		X		
East Empire Gardens	103	mf		X					X									
High Point Park	100	sf					X	X	X	X				X		X		
Salmon Creek Apts	100	mf		X												X		
Westchester Estates	100	sf	X					X		X		X				X		
Terrace View Apts	78	mf					X	X						X		X		
Valley Faire	75	sf		X		X		X		X			X					
Hendrikson Apts.	62	mf							X									
Rainier Meadows Apts	62	mf	X	X												X	X	X
Campus Highlands	53	sf	X					X		X				X		X	X	X
Coal Creek	49	mf					X	X		X				X				
Waterfront Apts	44	mf	X											X		X	X	X
Johnson Court Apts	42	mf						X						X		X		
Queen Anne Apts	17	mf												X				
3515 Wallingfd. Ave N	8	mf												X				

LEGEND

Project: Units = Number of units; **Type** = type of development (sf = single family, mf = multiple family); **Built** = Indicates that project has been built

Amenities: Wal = sidewalk, **Pad** = bus pad, **Shel** = bus shelter, **Bik** = bicycle storage

Transit/Rideshare (Distribution of Information): **Info** = information distribution; **CIC** = commuter information center; **TC** = transportation coordinator; **Pro** = promotion

Data: (Collection of Information on Commuter Behavior) **Sur** = survey residents; **Rep** = report

Subsidies: Bus = bus pass; **Shu** = shuttle

Developer: Cont = Contacted by investigators; **Kno** = developer knows about requirements; **Imp** = developer has implemented requirements

opers and managers of a small number of residential projects. It is qualitative rather than quantitative and cannot be considered representative of all residential projects. It ranges from general data about the projects and their target clientele to more specific information on TDM program requirements.

New multifamily developments in the region for which this information had been gained were geared toward the middle- or upper-middle-class income range. None of the projects contained low-income housing. Background checks on prospective tenants of a sample of these developments, conducted at most new projects, exhibited average incomes between \$36,000 and \$43,000 per apartment. The turnover rates ranged between 5 and 10 percent per month, or around 75 percent per year, and were considered normal by their management.

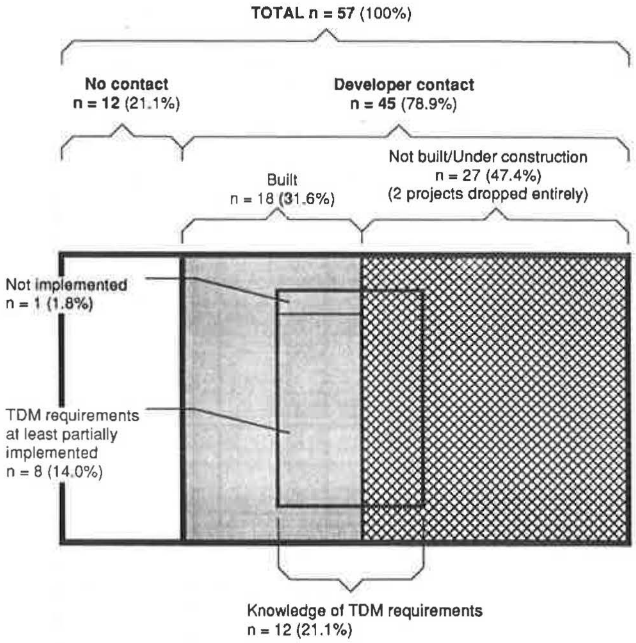

FIGURE 1 Breakdown of projects by knowledge of TDM requirements and compliance.

With the exception of the few projects within the city of Seattle for which the parking ratios were around 1.2 per apartment, the parking ratios on the suburban projects ranged from 1.6 to 2 spaces per apartment.

In general, the representatives of the development community were not interested in the TDM requirements on their projects. They did not consider them important and, for the most part, seemed either to be unaware of them or to be ignoring them. The only exceptions were two of the major companies in the area and developments in the city of Seattle, where all contacted developers complied with their requirements. Transportation issues such as access to transit or proximity of park-and-ride lots were not decision criteria in siting projects. Those developers who were aware of the requirements for their projects tended to be skeptical about the actual success of these programs.

None of the developers considered the requirements to provide information, a commuter information center, a bus pass, or a transportation coordinator a problem. Although no developer had kept track of the actual costs for these requirements, both financial and personnel costs were considered minor or negligible in comparison to the overall costs of the project. This was true both for projects where these TDM measures were implemented, with estimated costs in most cases below $1,000, as well as for projects whose developers were asked to estimate the potential costs of the above requirements for their projects. (A one-zone pass cost $26, and the distribution of information and passes was easily incorporated into the work of the project manager.) The only exception was the shuttle at the Park at Forbes Creek, where the ridership did not justify the expense. The shuttle was operated during peak hours and made two to three runs during each peak time. However, on average only five or six people per day had used it. According to the developer, operating costs were about $3,000 per month, and the resale value of the project would have decreased by $400,000 if this expense had continued.

However, much more concern was expressed about the high costs of physical requirements such as sidewalks and bus pads, which can run up to several tens of thousands of dollars. In one case, the requirement for a sidewalk along the project was at first overlooked by the developer but later enforced by the county. The company refrained from going to court only because of plans for a second project in the neighborhood of the first one. None of the developers who acknowledged the existence of requirements had any problems understanding or implementing them.

With one exception, all representatives of developers who actually contacted Metro to negotiate or implement its requirements were pleased with the support Metro staff had given them. Metro response was considered timely and adequate.

PERCEPTIONS OF RESIDENTS AND TENANTS

Previously unpublished surveys were conducted by Metro of residents of The Park at Forbes Creek and Ballinger Commons, two projects with TDM requirements, a focus group meeting, and comments from managers and developers. The limited number of cases did not warrant distinguishing of projects by external factors such as the level of transit service available or density around the projects.

Interviews with managers of multifamily developments revealed that the interest of residents in transit and carpool and vanpool options was small. If residents asked for transit information at all, which they rarely did, questions about directions and distance to the closest park-and-ride lot prevailed. To the knowledge of the developers and managers, there were no tenants who did not own a car and were thus dependent on transit. As the manager of one of the projects put it: "People who move here expect to use their cars."

The experience with the shuttle service at The Park at Forbes Creek confirmed this attitude. Here, the developer was required to provide free peak-hour shuttle services to the closest park-and-ride lot. Although The Park had close to 500 units and an occupancy rate of 95 percent, only five residents rode the shuttle on a regular basis. The shuttle service was discontinued after 9 months.

According to the manager, only 5 percent of Park residents took advantage of the substitute offer, a free 1-month, two-zone bus pass. For five other projects with a bus pass requirement, a similar response rate was reported. Although no figures on the actual number of requested bus passes could be obtained, the managers of these projects estimated that between 5 and 10 percent of the residents had asked for the passes. In most cases, the tenant was informed about the offer personally or through an information package on moving in. The only exception to this was Remington, a single-family project, at which about 40 percent of the residents had requested a bus pass. In that case, however, the offer was made at the project's well-attended first home owners association meeting, after the transportation management requirements had been introduced. Residents just checked their name on a list. At Ballinger Commons, the one project at which this information was available, survey results indicated that the bus passes were used an average of 19 times during that month.

One other requirement on large multifamily projects was the provision of a commuter information center (CIC). According to the Ballinger Commons survey, despite the fact that 65 percent of the respondents knew about the existence of the CIC, only 11 percent had ever looked at it (n = 190). At The Park, 55 percent (n = 76) of the respondents had considered it very likely or somewhat likely that they would commute by bus, carpool, or vanpool if a CIC were available. However, The Park had a CIC and the management had gone to great effort to inform residents about the shuttle and other transit and ridesharing options, but only 23 percent of the respondents actually had used one of these modes of transportation. The manager even used the closed-circuit TV system of the project for promotion without, according to him, any success.

Participants of the focus group meeting at the single-family development stated that they would be more likely to take notice of transit or rideshare options if the information were provided in a regular newsletter, e.g., the monthly publication from the home owners association. They suggested the transportation coordinator on the project could be responsible for listing project residents who were interested in carpooling or vanpooling in the newsletter, including information from the ridesharing agency in the area, as well as transit information and updates.

Residents were asked about the likelihood that they would change their mode of transportation if someone at the residence would help them plan their commute. At The Park, where the shuttle service was provided, 38 percent of the respondents answered they were very likely or somewhat likely to change their commute behavior. At Ballinger Commons, 24 percent considered it very or somewhat likely. Interestingly, both projects had a TC requirement, and at both sites a representative of the management served in that position at the time the survey was conducted.

Several projects were required to provide secure bicycle storage facilities. When asked whether they would change their commute if bicycle facilities (bike paths, storage for bikes, and free loaner bikes to ride to a nearby park-and-ride lot) were provided, 38 percent of the respondents at The Park considered it very likely to somewhat likely. At Ballinger Commons, 7 percent considered it very likely or somewhat likely.

For reasons stated earlier, very little can be said about the effectiveness of different TDM measures on residential projects. It seems clear, however, that most residents are not interested in using HOV modes of transportation at projects without low-income housing. It is also not apparent to what extent people's stated willingness to change behavior will match their actual behavior over time. Studies carried out in other parts of the country that suggested that the location, size, and demography of the development can be important factors in the success of TDM programs, as well as land use patterns and zoning policies (*1,2*), were supported by the research for this project. However, further investigation is necessary to gain a clearer understanding of the relationship between those factors and the success of TDM measures and to enable jurisdictions and regions to develop packages of policies complementary to these factors.

IMPLEMENTATION PROBLEMS WITH EXISTING RESIDENTIAL TDM PROGRAMS

Because the original intent of the research could not be carried out because of the small number of developments with TDM programs, the researchers tried to identify reasons for this failure. In the process of research for this project, a number of problem areas were uncovered related to (a) the decision process that leads to TDM program requirements for residential projects, (b) institutional memory about the requirements, (c) monitoring, (d) enforcement, and (e) adequacy of the measures. The following is a description of these problems.

Decision Process Leading to the Imposition of Requirements

All projects listed in this study were assigned requirements under a case-by-case negotiation process as part of the State Environmental Policy Act (SEPA) review. Interviews with staff indicated that as of May 1990 none of the jurisdictions had established administrative guidelines or an ordinance imposing TDM requirements on residential developments, although efforts were under way to establish ordinances in all four jurisdictions. No performance goals had been established by any of the jurisdictions, either for the overall effect of TDM strategies on residential projects or for specific projects or classes of projects. King County, Kirkland, and Redmond usually required the developers of projects to contact Metro to negotiate the set of TDM measures appropriate for that project or to fulfill the requirements. However, procedures varied among jurisdictions.

Kirkland used a rule of thumb to decide on requirements for particular projects and had not established a coherent set of criteria or a consistent process. In Redmond, a project generally had TDM requirements if it contained more than 100 units. If it was close to a bus line, it was required to provide a bus pad and shelter as well as pedestrian access to that shelter. Further requirements were the distribution of information on transit and ridesharing options and a free 1-month bus pass over a varying period of time. However, the process was not well established and staff were not operating on a decisive set of criteria.

In the city of Seattle, residential projects with 20 or more parking spaces had TDM requirements. The Department of Engineering looked at the permit application for each project and could require further information. If deemed necessary, it might ask the Department of Construction and Land Use to request a traffic impact study. After review of all available information, the Department of Engineering would, in close cooperation with Metro, propose requirements such as bus passes or CICs, but the Department of Construction and Land Use was responsible for imposing the requirements. The department was not required to follow the Department of Engineering's suggestions. This process was followed for all types of projects within the jurisdiction of the city of Seattle under SEPA, including nonresidential land uses.

Unincorporated King County had tried to establish a process for assigning requirements to residential developments. In general, when a project was large enough to be required to conduct a traffic impact study under SEPA, a special review process to include transportation demand management was triggered. The county then tried to ensure that Metro received a copy of the study. In turn, Metro was supposed to put together a set of requirements to recommend to the county. Because of a lack of an established procedure, this process collapsed. From then on, Metro was usually notified as part of the regular SEPA procedure for the project. Metro would work out a set of requirements in negotiation with the developer and send it to King County's Building and Land Development division to be included in further permit review and approval.

These processes allowed for a great amount of flexibility and thus enabled the planning staffs in each jurisdiction to set requirements for a project according to the unique situation of a site. This flexibility can be advantageous when new TDM measures are tested; however, it can also create a set of problems.

During the initial review, insufficiently trained staff may be unable to recognize the significance of a project because of inexperience with TDM programs on that type of project. They may use their discretion and decide that the project does not need mitigation, while it actually has unrecognized or underestimated impacts that justify TDM requirements. Although such requirements can still be imposed at a later stage, that is not likely to happen.

If there is no established process, implementation of TDM program measures is open to irregularities and—unintended—equity problems. As shown in Figure 2, there was no relation between the size of the project and the type or number of requirements imposed on that project, despite the fact that Metro, a single agency, established the requirements for the majority of developments in suburban areas. There were no clear thresholds for any given mitigation measure.

A further problem lay in the need to use SEPA procedures. First of all, only projects considered for SEPA review were considered for TDM requirements. Second, if a project had a large enough impact to justify transportation mitigation measures, they could be implemented in two ways: (a) if the project was considered insignificant under SEPA for all other issues, it had to receive a determination of insignificance that included the mitigation for transportation impacts; or (b) if a project was expected to have a significant impact under SEPA, an Environmental Impact Study would be required and transportation mitigation measures would result from that process. At the time that this paper was written, no process had been established to ensure that mitigation would occur.

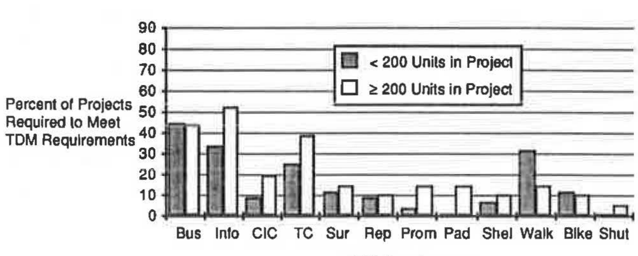

FIGURE 2 Relationship between TDM requirements and percent of projects required to meet those TDM requirements.

An additional problem was posed by the fact that the use of SEPA tended to curtail regional mitigation. Although one project by itself may not have a significant traffic impact, it can create problems if it is combined with other projects nearby. SW Campus Drive in Federal Way is a case in point. Campus Drive was a major development area in which several of the projects analyzed in this paper were located. In at least three cases, TDM measures were required for developments with more than one building phase, but only one of the phases had TDM requirements. One single-family development had five divisions totaling over 300 houses, but only one of its divisions, with about 60 houses, had TDM requirements. On at least one project, of about the same size as its neighbors, no requirements were imposed. SEPA theoretically requires consideration of cumulative impacts, but administratively, it is difficult to impose mitigation measures based on cumulative impacts. This difficulty was apparent in cases in which no procedure had been established, such as in the residential projects analyzed here.

In the Puget Sound region, the decision process using the case-by-case approach has proved to be too flexible. To ensure predictability and continuity, an ordinance must be developed that structures the requirements for residential developments or sets clear performance goals for the TDM program on the residential project. However, the development of an ordinance requires a certain amount of commitment by the jurisdictions to TDM requirements on residential projects. They need to decide what they want to achieve with the policy, relate it to their overall transportation goals, and determine how much staff and money they are willing to commit to the effort.

Institutional Memory of the Requirements

According to officials, none of the jurisdictions that had residential developments with TDM requirements had a compliance tracking system at the time that this paper was written. Thus, information on requirements on developments could and did get lost. Even for the city of Seattle, which had a process to determine the significance of applications, information proved to be incomplete. A representative of the county conceded that under the present system, information on transportation mitigation requirements could get lost when the application went through the subsequent stages. Thus, Metro could have projects on file that were supposed to implement TDM measures, but the county did not have notice of any requirements on the same project.

As described earlier, only a small percentage of the developers contacted claimed awareness of the requirements on their projects. Although some lack of knowledge can be explained by the lack of a jurisdictional tracking system and active enforcement, there were other reasons for this phenomenon. At the developer's office, the person who guided a project through the permit application process was not necessarily the person who would be responsible for it when the time came to implement the requirements. This problem could be true even within the same company. Interviews with developers indicated in at least three cases that the agent responsible for a project changed during the course of this investigation. Even though the first respondent had been aware of the requirements imposed on the project or was in the process of negotiating them, the next person did not know about them. In another case, the respondent said that he had just taken over the project, had found reference to the mitigation requirements only by chance, and was starting to negotiate them.

Further complicating the transfer of information is the fact that, commonly, development companies hand a project over to a management company once it is occupied. Although the agent in the developer's office may be aware of the requirements, on-site management may not be informed. In at least one case, the researchers observed that information on requirements was lost in the transferral process. One developer mentioned that a 1986 change in tax law complicated the process of information transmission. The law made it more profitable for developers to sell their projects shortly after they were finished and occupied and thus increased the percentage of projects being sold shortly after completion.

Institutional memory is an important factor in ensuring compliance with TDM requirements. The analysis of existing projects and requirements indicated that both the staff at the jurisdictions and the developers, managers, and owners of residential projects often did not know about the requirements of the project (or in the case of the developer or manager, claimed not to know about them).

In order to ensure that the information does not get lost both at the jurisdiction's and the developer's offices, the TDM ordinance should have clearly defined objectives and requirements. It is important to tie the requirements explicitly to the land, independent of ownership or control of the project.

Monitoring Compliance

A monitoring mechanism is needed to ensure compliance with the mitigation measures and to determine whether the developer has made a "good faith" effort to implement the mitigation measures within a reasonable time frame and at an acceptable level of quality. Furthermore, monitoring is particularly important for a new set of rules and requirements (such as transportation mitigation measures for residential developments) to enable the jurisdictions, Metro, and developers to examine the usefulness of the measures or sets of measures and to modify them accordingly.

At the time that this paper was written, monitoring of compliance with mitigation measures in the Puget Sound region was limited. This lack of attention could explain in part why so few developers responded that they knew about the measures. None of the jurisdictions had established a process of monitoring compliance, nor was any of them monitoring projects with TDM requirements on an informal basis. However, there were a few exceptions.

In the case of The Park at Forbes Creek, the developer had completed the negotiation process with Metro and complied with all requirements, including the shuttle, and the project had been monitored by Metro. Without Metro's interest in the shuttle and its ridership problems, and without the developer's desire to make the project work, Metro would not normally have monitored it so closely. According to the developer, one staff member of the city of Kirkland, where the project was located, made "a few informal phone calls." None of the other four projects with requirements belonging to that company had been closely monitored.

Apart from that, monitoring occurred only when mitigation measures required physical structures such as sidewalks or bus pads and shelters, or, as in the city of Seattle, CICs. In one case in the city of Seattle, compliance with a CIC requirement was monitored when the Certificate of Occupancy was issued, but there was no follow up.

None of the jurisdictions in the Puget Sound area effectively monitored the projects, except when physical structures such as sidewalks were required. Thus, neither the effectiveness of the existing mitigation measures nor compliance with the TDM requirements could be established.

Enforcement of Compliance

Enforcement of mitigation measures should not be necessary if the developer makes an earnest effort to comply with them and make them work. However, jurisdictions need to establish a legal basis for enforcement so that violations can be pursued.

Because none of the jurisdictions had effectively monitored compliance with TDM requirements on residential developments or established any performance goals, it is not surprising that none of the jurisdictions in the Puget Sound area had established penalties for noncompliance when this analysis was conducted. Again, the only exceptions seemed physical structures such as sidewalks and the shuttle at The Park at Forbes Creek. The shuttle at The Park was the only requirement for which performance goals had been established on any of the projects.

However, in order to set performance goals for the traffic mitigation measures on a residential development, the jurisdiction must first decide what it wants to achieve with its residential TDM programs; that is, it must establish its role in achieving its overall transportation goals. It then must determine how close to achieving these goals it can come, given its financial, personnel, and political situation, and adjust them accordingly. Only if a realistic and feasible balance between the goals of mitigation measures and the administrative capacity is achieved can transportation mitigation requirements be monitored and enforced effectively and the credibility of the program be ensured.

Adequacy of TDM Requirements

Even if the developer makes a good faith effort to implement the requirements imposed on the project, they will not necessarily result in a significant or recognizable change in commuting habits. The experience with the free shuttle service at The Park at Forbes Creek, where the developer made every effort to make it work, is a case in point. Obviously, it was not the appropriate measure, given the location of The Park and the demographic composition of its residents. Other examples include projects located on Campus Drive South West in Federal Way. Campus Drive South West is a new development area with about 3,000 new apartments and houses. It does not have walking access to a bus line, only driving access to a park-and-ride lot. However, three of the projects with TDM requirements had a bus pass requirement.

Other factors, such as the proximity and convenience of transit service; the destination and length of commute trips; transportation and parking management at the work site; size, design, and lay-out factors at both the residential site and work site; as well as land use and zoning decisions are important determinants that can potentially overwhelm all incentives resulting from the mitigation measures. As authors such as Robert Cervero (*1*) demonstrate, land use and zoning policies are also important factors in a successful TDM program.

RECOMMENDATIONS

This section provides four different approaches to designing TDM ordinances for residential developments that mitigate the implementation problems presented earlier. Both a study on existing TDM ordinances, including requirements from residential developments in other parts of the country (*3*), as well as information from personal communication with staff from these jurisdictions are included here.

The first step for each jurisdiction considering TDM requirements on residential developments should be to decide what it wants to achieve with that policy. The policy must be consistent with the overall transportation goals for the jurisdiction and the region, and the land use and zoning laws. Once the jurisdiction has decided to implement TDM measures on residential developments, it must make the commitment to follow through. In addition, the jurisdiction needs to ensure that the costs of the TDM strategies for the developer are scaled to their potential impact. The local jurisdiction should be able to afford the administrative costs to monitor compliance with requirements and to enforce them. The next step is to balance all of the factors against the political climate in which the jurisdiction operates and to decide on a policy. The research for this report has illustrated the results when jurisdictions have not taken these steps carefully enough.

Four different approaches to a TDM ordinance for residential developments appear possible after consideration of these issues. The first one is to develop an ordinance requiring minimum size thresholds for increasing sets of requirements. The bigger the project is, the larger is the number of requirements and the higher the costs. The developer is not required to meet any performance goals apart from the implementation of the measures themselves. This approach is appropriate for jurisdictions where transportation problems are heavy enough to warrant action, but not heavy enough to demand more stringent requirements. It is also most appropriate for small projects and is used for commercial developments by many jurisdictions in the country. It ensures predictability and continuity and is fairly easy to monitor. Because the requirements are clearly stated for each size of development, the information on them cannot get lost. However, this approach cannot ensure that the requirements are adequate for that particular project, and enforcement may prove difficult in particular if the requirement is not quite appropriate. North Brunswick, New Jersey, applies this approach to residential developments (*3*).

In order to avoid the problem of potential inadequacy of required TDM measures on a residential development, the jurisdiction may, in a second approach, decide to put the choice of the TDM program measures into the hands of the developer. Although a basic set of measures should be carried out for each project, the developer must then choose further measures from a list of additional requirements to tailor the TDM program as closely to the development as possible. This second approach is particularly appropriate for larger developments. The jurisdiction reviews the TDM program, approves it if it is considered appropriate for the project, and issues a transportation special use permit. The permit is tied to the land; therefore, the information on the requirements cannot get lost. It can be revoked if the jurisdiction finds that the development's TDM requirements are not carried out adequately. This mechanism is used in Alexandria, Virginia, for residential projects of 250 or more units (*3*).

In order to ensure compliance under both approaches, the jurisdiction may decide to require the developer, manager, or owner to pay an annual fee for each unit into a fund or performance bond. The developer can then use the fund to comply with the requirements, for example, buy bus passes. Should the jurisdiction determine that compliance is inadequate, it can use the funds to finance TDM programs. If the developer is found to have made a good faith effort, he or she may be allowed to incorporate the remaining funds into the next year's program. The policy may also allow the developers to organize themselves into Transportation Management Associations in coordination with commercial areas in order to pool resources and efforts.

The third approach is a variation to the second approach. Implementation of this approach is dependent on the severity of transportation problems in the area and the political feasibility of even stronger requirements. The jurisdiction sets performance goals and leaves the choice of TDM measures up to the developer.

A fourth approach, even more stringent than the previous ones, is to require the developer to mitigate the projected traffic impact of the development before it has been built by devising and implementing a TDM program on an already existing project. The developer does not receive a building permit before the performance goal for the TDM measures has been reached. This approach requires a high degree of commitment from the jurisdiction and is politically feasible only if the transportation system in the jurisdiction or region cannot be eroded any further. To simplify the monitoring process for the jurisdiction, each TDM program's process has to be reported to the jurisdiction on a regular basis. To ensure the correctness of these reports, a process that requires the developer to pay for an independent audit mechanism in addition to the self-monitoring process is an appropriate solution. This method is successful in Montgomery County, Maryland, despite the fact that it creates equity problems (*4*).

CONCLUSION

The quantitative evaluation of TDM requirements on residential projects in suburban Puget Sound proved difficult, because only a small number of projects had implemented these measures. However, the analysis of available quantitative and qualitative information pointed out implementation problems related to (a) the decision process leading to the imposition of mitigation requirements, (b) institutional memory of requirements, (c) monitoring, (d) enforcement of compliance, and (e) adequacy of mitigation requirements.

The research presented indicates the dilemma many jurisdictions face. The case-by-case approach to transportation demand management on residential projects used by King County, Kirkland, and Redmond leaves both the staff of the jurisdictions, as well as the developer, with too many uncertainties about their respective responsibilities and creates equity problems. It does not send a strong enough signal of commitment on the part of the jurisdictions and allows developers to ignore or overlook their responsibilities. On the other hand, the evaluation of existing projects with implemented TDM measures has proved the importance of tailoring requirements to that particular development, as well as the area in which it is located.

Transportation demand management at residential projects, like any other policy, needs clearly defined and measurable goals and commitment by the local jurisdiction. It has to be integrated in a wider framework of local and regional transportation planning, balanced with the land use and zoning policies of the jurisdiction and the region, and it has to account for the financial and personnel capacity of the jurisdiction. A stringent and well-considered TDM ordinance for residential developments is worthless if it cannot be monitored and enforced, if it is not linked to land use and zoning policies, or if the political climate does not allow for the level of commitment on the part of the jurisdiction necessary to make the envisioned residential TDM policy feasible. Thus, it is necessary to make a decision between the need for clear thresholds, a well-structured ordinance, and the particular requirements of the project, while keeping the tradeoffs between them in mind. The success of development, imposition, monitoring, and enforcement of TDM measures on residential developments is not only dependent on the quality of the implementation of these strategies but also on other factors such as land use and zoning policies. However, in implementing TDM ordinances for residential projects jurisdictions have a number of options for mitigating the implementation problems.

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Attracting Minorities to the Transportation Profession: Perspective of Historically Black Colleges and Universities

MOGES AYELE

The extent of minority underrepresentation in professional and managerial positions in the transportation industry is discussed. Historically black colleges and universities (HBCUs) have been involved in the recruitment and training of minority transportation professionals, but these institutions have not been adequately used as a source of trained professionals for the transportation industry; future efforts to attract minorities to the transportation field should include active support for programs in these institutions. Two successful programs were designed to increase minority participation in the field of transportation. The first program is the FAA's Airway Science Program, which has already established FAA-approved academic programs in seven HBCUs. The second program is Morgan State University's Career Development and Training Project (CDTP), which carries out a variety of activities including recruitment, counseling, providing financial aid, placing students in internship or co-op programs, and conducting workshops.

> None of the challenges in transportation can be met unless individuals working in the field have the quality education and background to take on the professional responsibilities. . . . In preparing the next generation of transportation professionals, particular attention must be given to attracting and retaining minorities and women and socially and economically disadvantaged individuals, who have not been well-represented in higher level educational programs and among transportation professionals in the past. (*1*).

Transportation has always been a critical factor in the economic, social, and cultural development of man. Historically, the density of many nations and cities had been influenced, to a great extent, by the presence or absence of adequate transportation systems. The role that transportation plays in the modern world is equally significant. In the United States, transportation occupies a unique position in the national economy. Transportation and related industries account for approximately one-fifth of the gross national product. According to the U.S. Department of Transportation (DOT), in 1987 about 11.8 million people, that is, about 10 percent of the U.S. civilian labor force, were employed in some aspect of transportation—automobile and transportation manufacturing, retailing, repairing, fuel sales, transportation facilities construction, motor carrier vehicle insurance, federal and local government programs, or the transportation of passengers and freight. The total U.S. freight and passenger transportation expenditure for 1987 was over $815 billion (*2*).

Besides providing physical mobility to passengers and goods and fostering economic development, transportation is a dynamic force with major impacts on the environmental, social, cultural, and political life of the nation. It has considerable impact on social mobility, locations of housing, patterns of urban development, quality of the natural environment, and other related issues.

Despite the vastness and significance of the transportation industry, the representation of minorities in the industry continues to be minimal. If each segment of the transportation industry is examined, the story is the same with regard to minority representation. Minorities are almost totally excluded or are seriously underrepresented in management and professional positions.

Historically, the powerful unions in the railroad industry excluded blacks from membership. This policy was often explicitly stated in their constitutions, which made it difficult for blacks to hold important positions in the railroad industry.

Until the late 1950s, blacks did not advance beyond unskilled positions in the aviation industry. For instance, the first black stewardess was hired in 1957. Even though the situation has improved to some extent, the underrepresentation of blacks in managerial and professional positions continues to be a serious problem. Fortunately, the FAA's recent initiative to develop academic programs in selected historically black colleges and universities (HBCUs) will contribute toward the alleviation of the problem.

In the maritime industry, the situation is similar to other sectors of the transportation industry—minorities have some representation in the unskilled or semiskilled jobs but almost no representation in management positions. A study conducted by the Center for Transportation Studies (CTS) of Morgan State University, under a grant from the Maritime Administration, revealed that the industry needs to take major steps to attract Blacks to its professional and managerial ranks (*3*). Another study conducted by CTS analyzed minority participation in the Coast Guard and confirmed the serious shortage of minority commissioned officers (*4*). (This study was designed to identify the problems facing minorities in the Coast Guard and to develop specific recommendations to increase the minority Coast Guard officer population. The Coast Guard has adopted the study's recommendations and is currently in the process of implementing them.) In 1987, out of a total of 5,079 commissioned officers only 197 (3.8 percent) were minorities. With only 86 commissioned officers, blacks made up only 1.7 percent of the total commissioned officers in the Coast Guard, which is part of the U.S. Department of Transportation.

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Although current statistics on racial backgrounds of owners and employees in the trucking industry by job categories are not available, it is a well-known fact that minorities are not well represented in influential positions within the industry. According to an Interstate Commerce Commission (ICC) report, out of a total of 22,000 carriers regulated by ICC in 1981, only 314 (i.e., 1.4 percent) were minority-owned carriers (*5*).

The low level of representation of blacks in professional and management positions in highway-related fields is also evident. The fact that only a handful of blacks attend the national conferences and meetings of AASHTO, ITE, and TRB reflects the low level or representation of blacks in highway-related professions. A report by the TRB task forces on Minorities' and Women's Involvement in TRB and Transportation indicated that out of a total of 2,719 individuals who attended the 1986 and 1987 committee meetings (including both members and nonmembers) only 142 (i.e., 5 percent) were minorities (*6*). (These data were gathered from records received from TRB committee chairs. Sophisticated studies are not always needed to determine the extent of black representation.)

The situation is better in the urban transit industry which has been relatively more accessible to blacks. Increasing number of blacks are occupying important positions as board members, general managers, administrators, and planners. Historically, the urban mass transit industry has played an important role as a source of employment for blacks in many cities throughout the nation (*7*). (Jeffress presents a detailed historical account of the employment of blacks in the transit industry.) As a result of the shift from private to public ownership of urban transit systems, the blue-collar nature of transit work, the greater concentration of blacks in major urban centers, and civil rights legislations barring discrimination in employment, blacks' share in urban transit jobs has continued to grow. During the same period, the proportion of black urban transit users has also increased substantially.

However, a close look at the type of jobs that blacks hold in the industry reveals that they have not been sufficiently represented in managerial and professional positions. With exceptions, a majority of black transit employees in urban areas have been restricted to menial, unskilled, and semi-skilled jobs. Few blacks hold middle- or upper-management jobs. Most transit managers have advanced through the ranks, often having begun as operators or trainmen. Even though the situation has improved in the recent past, Blacks have been historically barred from promotion past certain levels.

The participation of minority businesses in urban mass transportation is also minimal. This problem is articulated in a study conducted by One America, Inc., under the sponsorship of UMTA. On the basis of analysis of a sample of 21 transit properties, the study concluded as follows:

> Minorities make up a disproportionately large percentage of the transit dependent, so that as customers they are major supporters of public transportation systems. Minorities also make a major contribution to the local financial support of transit systems as taxpayers. Yet ironically, minority businesses have experienced to date only the most minimal participation in planning, development and implementation of transit systems and system improvements, despite the advocacy of UMTA Office of Civil Rights (UCR) (*8*,p.2).

Even though the study is fairly old, the finding of the study is generally valid today. In short, the absence of blacks in professional and management positions in various sectors of the transportation industry has unfortunate consequences. It denies the industry the opportunity to use the talents available in the black community. It also deprives blacks from influencing decisions that directly or indirectly affect their lives. Blacks exert little influence on important transportation decisions such as the allocation of resources for the various modes of transportation, the character and quality of transportation services in urban and rural areas, how the transportation systems should be operated, the prices charged for various types of services, how the systems are regulated, the types of services that underprivileged groups (the handicapped, the elderly, low-income central city residents) receive, the employment and personnel policies, and the extent to which government should be involved in the delivery of services.

DEMOGRAPHIC TRENDS AND MINORITIES

Demographic trends indicate that the U.S. labor market may be increasingly dependent on minorities after the next decade. *Workforce 2000*, the widely discussed study by Hudson Institute, projects that in the year 2000 more than 15 percent of the workforce will be nonwhites as compared with only 11 percent in 1970. Nonwhites will make up 29 percent of the net additions to the workforce between 1985 and 2000 (*9*,p.89).

The same report revealed that the new jobs that will be created in the coming years will be substantially different from those that have been traditionally available for minorities. The new jobs will require higher levels of education and skills in language, mathematics, and reasoning. The rising educational and skill requirements of the job market present serious challenges for minorities who are already acutely underrepresented in professional and managerial positions. Because minorities are the most disadvantaged in terms of their access to good education, their ability to take advantage of this market is limited. The negative impact of the changing job market on minorities will be serious unless the nation takes major actions to counteract the problem by providing good education that enables minorities to acquire the skills demanded by the new job market. The Hudson Institute report emphasized the need for improving educational opportunities by making resources available for training and education of minorities. It called for a renewed emphasis on "education, training and employment assistance for minorities." It also concluded that "these investments will be needed, not only to insure that employers have qualified workforce in the years after 2000, but finally to guarantee the equality of opportunity that has been America's great unfulfilled promise" (*9*, p. 114). Although the findings of the Hudson Institute Study are based on the national economy in general, they are equally relevant to the transportation industry. The transportation industry should recognize these trends and develop appropriate programs to attract minorities to pursue careers in transportation. These programs may include, among other things, recruiting minorities for transportation programs both in minority and nonminority institutions, strengthening transportation-related programs in HBCUs, developing cooperative and internship programs in which minorities can participate, and providing financial aid to minority students. A successful career development project, which is currently being conducted by Morgan State's Center for Transportation Studies, will be discussed later.

ROLE OF HISTORICALLY BLACK COLLEGES AND UNIVERSITIES

TRB's study of the need for transportation professionals (*10*) recognized the seriousness of minority underrepresentation in the transportation industry and recommended that "transportation professionals in universities must encourage further development of programs to attract women and minorities to transportation." The conference on surface transportation education and training held in Williamsburg, Virginia, in October 1984 also recognized the problem and recommended that educational "programs at both minority and mainstream institutions" should be enhanced and supported.

Although minority transportation professionals should be trained at both minority and nonminority institutions, HBCUs can play increasing roles in providing well-trained professionals to the transportation industry because they have unique resources and capabilities for recruiting and training of minorities that should be used by the transportation industry.

Any serious national effort to increase the pool of minority transportation professionals in this country should not fail to include the enhancement of programs at HBCUs. These institutions continue to play a significant role in the higher education. According to the National Association for Equal Opportunity in Higher Education (NAFEO), a Washington-based organization representing about 115 minority higher education institutions, since the inception of this country over 70 percent of black graduates have been produced by HBCUs—resulting in a supply of about 300,000 college graduates every 10 years. They have educated 50 percent of the nation's black business executives and elected officials, 75 percent of black Americans with doctoral degrees, 75 percent of black military officers, 80 percent of black federal judges, and 85 percent of black physicians. About 18 percent of black college students are enrolled in HBCUs, and yet over 40 percent of blacks who complete their baccalaureate degrees in this country receive them from the HBCUs. In 1986–1987, more than 11 percent of black engineers graduated from only six HBCUs—Tuskegee, Howard, Southern, North Carolina A&T, Tennessee State, and Prairie View A&M Universities (*11*, p. 6). With the establishment of engineering programs in other HBCUs in recent years, the contribution of HBCUs in supplying engineers has become even more significant.

TRANSPORTATION EDUCATION AT HBCUs

Recent developments in HBCUs in the area of transportation education are encouraging. Before 1980, there were no HBCUs offering graduate degree programs in transportation. Currently, there are two institutions offering comprehensive graduate curricula in transportation. In 1981, CTS began offering the M.S. program in transportation planning and management. Initially, the Morgan State program placed special emphasis on urban and passenger transportation. In 1984, it expanded its program by introducing a new specialization in physical distribution and logistics. In 1989, Morgan began offering a joint degree program—M.B.A. and M.S. in transportation. Students enrolled in the joint degree program receive both an M.B.A. and an M.S. on the completion of a minimum of 60 or maximum of 90 graduate credit hours.

Morgan State's M.S. program provides interdisciplinary training to enable students to attain balanced knowledge required in the planning and management of transportation systems. It offers 17 graduate courses in transportation and also draws from a wide variety of supportive courses offered by other graduate programs in the university including business management, urban and regional planning, economics, geography, and architecture.

Since its establishment in 1981, a total of 89 students have received an M.S. in transportation from Morgan State. Many of these graduates are holding positions as planners and managers in transportation-related organizations throughout the country and overseas.

In 1984, Texas Southern University in Houston also began offering an M.S. in transportation, a multidisciplinary program similar to the one offered at Morgan State. Texas Southern has been successful in attracting minority students and in establishing close relationships with the transportation community in Texas, particularly in the Houston Metropolitan Area.

In addition to the degree programs at Morgan State and Texas Southern Universities, Florida A&M University in Tallahassee offers a graduate program in human resource management with courses in transportation. It is also considering developing a degree program in transportation. North Carolina A&T in Greensboro, which has a long history of active involvement in transportation research through its Transportation Institute, has developed a graduate degree program in transportation that it hopes to implement in the near future. Alabama A&M also has interest in developing a graduate program in transportation planning within its Department of Urban Planning.

There are also encouraging developments on the undergraduate level. Besides North Carolina A&T, which has been offering transportation within the School of Business for many years, a number of HBCUs have recently established or have plans to develop transportation programs. They include Florida Memorial College, Hampton University, Virginia State University, Norfolk State University, Lincoln University in Pennsylvania, and Southern University in New Orleans.

HBCUs with engineering schools can also be a source of trained minority transportation or traffic engineers. Even though a large majority of HBCUs are liberal arts colleges, increasing numbers of them are offering engineering programs. Currently, the following institutions offer civil engineering programs accredited by the Accreditation Board for Engineering and Technology (ABET): Howard, Tennessee State, and Prairie View A&M universities and the University of the District of Columbia. A few other HBCUs have recently established new engineering programs that are not yet accredited. With some help and encouragement from the transportation community, these institutions can offer transportation engineering courses or can establish degree programs in transportation.

Even though these developments are encouraging, the level of participation of HBCUs in transportation education continues to be minimal. A great deal of work needs to be done to use effectively the full potentials of HBCUs. The institutions that have already taken the initiative to develop a transportation curriculum should be encouraged and supported. Perhaps, everyone can learn from the experience of the FAA, which has been successful in establishing academic programs in airway science at a number of HBCUs. FAA's Airway Science Program at HBCUs is likely to have a lasting impact on minority representation in the aviation industry.

FAA'S AIRWAY SCIENCE PROGRAM

In 1982, recognizing the need for well-trained manpower to support the National Airspace System of the future, the FAA, a modal administration of the U.S. Department of Transportation, established the Airway Science Curriculum designed to prepare the next generation of aviation technicians and managers. The program is developed with the basic assumption that with the support and guidance of the FAA, higher educational institutions are best suited for recruitment and training of a new cadre of aviation technicians and managers who can cope with the vastly expanding national airway system and rapidly growing technological change in the aviation industry. Federal funds are made available to higher education institutions that adopt an airway science curriculum that is approved by the University Aviation Association. Congress has appropriated funds for allocation to colleges and universities participating in this program. Essentially, the Airway Science curriculum is a comprehensive undergraduate degree program emphasizing critical thinking, analytical, management and communication skills in addition to the specialized knowledge in aviation (*12*). A student enrolled in the program is required to take courses in liberal arts, mathematics and science, computer science, management, aviation, and in the area of specialization that the student chooses to pursue. There are five area options in which a student can specialize:

1. Airway Science Management. This option prepares students for a variety of positions within FAA and in the private sector including air traffic control specialist, air carrier manager, airport manager, and general aviation operations manager.
2. Air Computer Science. This option provides training for operating computers used in aviation including flight navigation, communications, and information processing.
3. Aircraft Systems Management. This option is designed to prepare professional pilots, aviation safety inspectors, and flight operations managers.
4. Airway Electronic Systems. This option provides training in electronic theories as they relate to aviation and prepares individuals to serve as electronics technicians.
5. Aviation Maintenance Management. This option provides training both in practical and in theoretical aspects of air frame and power plant maintenance.

In accordance with the presidential executive order on historically black institutions that directed the active participation of HBCUs in federally sponsored programs, the FAA has made serious effort to involve HBCUs in the Airway Science Program. Of the $45 million appropriated by Congress for the Airway Science Program since 1982, $11 million (i.e., 24.4 percent) was awarded to HBCUs. The following seven HBCUs have an FAA-recognized airway science curriculum: Hamptom University in Virginia, Florida Memorial in Florida, Texas Southern in Texas, Edward Waters in Florida, Delaware State in Delaware, University of Maryland Eastern Shore, and Jackson State in Mississippi. Four other HBCUs have submitted proposals for gaining recognition and support from the FAA to offer the program (G. B. Thomas, unpublished paper).

The FAA has also made funds available for HBCUs to conduct research in high-priority areas of aviation including aviation security, aircraft systems fire safety, airport pavements, and automation service.

Like FAA, other modal agencies within the U.S. Department of Transportation need to recognize and use the valuable resources of HBCUs for recruiting and training your talents to help meet the manpower requirements of the transportation industry in the 21st century. It is unlikely for HBCUs to play a significant role in transportation education without outside support from the federal government or the transportation community. A CTS study revealed that there are a number of barriers that prevent effective participation of HBCUs in transportation education and research (*13*). [In 1984, the Center for Transportation Studies of Morgan State University received a contract from the U.S. Department of Transportation to examine the capabilities of HBCUs to conduct research and training in transportation and to identify the major barriers they face in developing transportation research and training programs. The project involved 15 HBCUs located in Maryland, Virginia, Pennsylvania, Delaware, and the District of Columbia. The principal source of information for the study was a questionnaire mailed to administrators and faculty members in selected departments (e.g., Business Administration, Urban Studies, Geography, Economics, Engineering, Public Administration, and other transportation-related disciplines).] These barriers include, among other things, lack of awareness about opportunities in the transportation industry, inadequate libraries, and inadequate computer facilities. However, at the root of most of the problems and barriers cited in the study lies the serious problem of financial constraints facing HBCUs. The development and implementation of transportation education programs require adequate funding to attract good faculty and students, to improve the facilities, to develop good transportation libraries, and to acquire up-to-date equipments for research and instruction. Unfortunately, most HBCUs find themselves in difficult financial situations and are unable to allocate the needed financial resources to support such new and innovative programs. Thus, they have no alternative but to seek external sources of funding to ensure the establishment of transportation programs.

CAREER DEVELOPMENT AND TRAINING PROJECT

The task of attracting minorities to enroll in transportation education programs requires aggressive recruitment effort, counseling, and financial aid to deserving students. In this section, a career development project developed by CTS will be described in the hope that others may learn from the experience. The project has been successful in attracting significant numbers of students to enrollment in Morgan State's transportation program.

In September 1988, CTS, a member of the Mid-Atlantic Universities Transportation Center (MAUTC), was awarded a DOT contract through Pennsylvania State University to conduct the Career Development and Training Project (CDTP). The CDTP had been developed with the view that recruitment should not be restricted to engineering programs. This was consistent with the report of the TRB Task Force on Women's and Minorities' Involvement in TRB and Transportation, which concluded that "current recruitment efforts are too narrowly focused on civil engineering. Business, economics, planning, and public administration are all examples of the disciplines that could provide abundant talent to mitigate the projected shortage of transportation management personnel." Although it was similar to the career development efforts of ITE and AASHTO in some respects, Morgan State's CDTP was different in two areas (*6,14,15*):

1. Unlike AASHTO's and ITE's projects, which were designed to attract students to pursue transportation and traffic engineering, Morgan State's project attempted to recruit students to enroll in its interdisciplinary M.S. degree program in transportation planning and management.
2. Morgan State's project was particularly designed to help alleviate the acute shortage and underrepresentation of minorities in professional and managerial positions in the transportation industry.

CTS is conducting a variety of activities to accomplish this goal. The major activities include: (a) recruiting minorities; (b) providing internships and training; (c) serving as a resource center for minority students; and (d) conducting workshops and presentations.

Recruitment

Considerable amount of time was spent on the recruitment component of the project. A packet of written materials was prepared for distribution to potential students. It included information on Morgan's transportation program, the CDTP, brochures and articles on career opportunities in the various sectors of the transportation industry, cooperative and internship programs, financial aid, and educational institutions offering transportation programs and other related materials. The CTS developed a detailed recruitment plan that included visiting HBCUs, advertising in local newspapers, mailing out information, participating in career fairs or days, making presentations, conducting workshops, and providing counseling and financial aid to the students who decide to enroll in Morgan State University's M.S. degree program. During the first year, the project director and coordinator visited 11 HBCUs in the mid-Atlantic region and 2 nonminority institutions in the Baltimore-Washington area, with fairly large numbers of minority students. The visits provided opportunities to establish contacts, to discuss and disseminate literature about the CDTP, to solicit support for the project from faculty members and administrators, to interact with students either through seminars, workshops, classroom lectures, or career days and fairs.

Advertisements and announcements in the local media were also used as a recruitment tool. Advertisements and articles on the CDTP appeared in the major Baltimore papers, including the *Baltimore Sun*, the Baltimore *Afro-American Newspaper*, and the *Baltimore Times*. The project coordinator participated in an hour-long radio talk show "On Career" and discussed career opportunities in transportation in general and Morgan's program in particular.

Packets of information were mailed out to 350 students on the graduate record examination minority locator list (nationwide), 800 Morgan State University graduates, 20 predominantly black churches, and over 150 students from other institutions throughout the country. Special posters (with mailback cards), which were sent to HBCUs throughout the country, have generated inquiries from potential students. Interested students fill out the form on the card requesting various types of information and mail them to the center. The appropriate information is mailed to the interested students.

Another important part of the project's recruitment effort was offering financial aid to deserving students. In the fall of 1989, the university's School of Graduate Studies and the CDTP provided financial aid to 41 students in the form of scholarships, assistantships, fellowships, and tuition waivers. The financial aid from the CDTP was given in the form of tuition waivers primarily to new students who met the admissions requirements of the M.S. program in transportation.

Internship/Cooperative Program

Perhaps, the most exciting aspect of the CDTP is the internship/cooperative program component. Selected students enrolled in Morgan's transportation program are placed as interns/cooperative students at various transportation agencies in the Baltimore-Washington Region.

Morgan State reached an agreement to establish an internship program with the Maryland Department of Transportation in 1987. During the 1988–1989 academic year, the Maryland Department of Transportation allocated $65,000 to cover salaries and fringe benefits for the interns in addition to the administrative costs of the program. For the fiscal year 1990, the Maryland Department of Transportation allocated a total of $67,320 for intern salaries and benefits (leave and health insurance). The amount allocated does not include program administration costs.

The Maryland Department of Transportation Internship Program was created to provide students with real-world experiences and training in various transportation agencies within the Maryland Department of Transportation. The program allows the participating student to work on a full-time basis during the summer and on a part-time basis during the academic year in any one of the modal agencies within the Maryland Department of Transportation. In general, the intern would work as a junior level analyst or planner, under the direct supervision of a section manager or senior staff member. The assignments would range from serving as a member of a staff team responsible for a Department of Transportation function to independent research on a specific transportation issue. The work and progress of the intern are monitored and evaluated not only by the supervisor in the agency but also by a faculty member from the CTS at Morgan State University. The students are also enrolled in a special internship course designed to help them evaluate and integrate their academic work at Morgan State University with the real-world experience.

Students are selected for the program on a competitive basis. In November, a selection board composed of five representatives from Maryland Department of Transportation and two faculty members from Morgan State review the applications of several students and select students to participate in the internship program beginning the following spring semester. The students are selected on the basis of the following criteria:

1. An indicated interest on the part of the student to pursue a professional transportation career.
2. The availability of assignments in the Maryland Department of Transportation that match the skills or interests of students.
3. The students' academic performance in their respective baccalaureate college or university or as students in the transportation program.
4. Willingness of the applicants to enroll in Morgan's program on a full-time basis.

Every year, at least five interns are placed in agencies within the Maryland Department of Transportation—the Maryland Port Administration, the Mass Transit Administration, State Highway Administration, State Aviation Administration, State Railroad Administration, Motor Vehicle Administration, and the Maryland Department of Transportation Headquarters. The interns begin their assignments in January with an orientation session that includes meeting Maryland Department of Transportation officials and participating in presentations about the agency and its career opportunities.

In 1988, an internship program was also established with the Baltimore City Department of Transportation (BCDOT). The program was designed to provide minority and female college students with work experience to prepare them for upper-level management positions. The BCDOT uses essentially the same type of competitive student selection process and program cycle as the Maryland Department of Transportation program.

The internship program is the first of its kind for the BCDOT. Six students have participated in the program since its inception in 1988. The students have been assigned to the agency's Interstate Highway, Highway Maintenance, and Traffic Engineering Divisions. The program has placed the interns in an advantageous position to secure permanent positions on completion of their graduate work at Morgan State.

Although the major internship programs of the project are with the Maryland Department of Transportation and the BCDOT, a number of students have participated in internship programs at other transportation agencies.

Resource Center

The third major task of the project is the development of a resource center for minorities seeking guidance and information about the manpower needs of the transportation industry, career opportunities, educational programs in transportation, internships, cooperative programs, and other related issues. The project staff assembles and organizes such information to make it easily available to students. The center maintains contact with the USDOT, UMTA, American Public Transit Association (APTA), FHWA, Maryland Department of Transportation, higher education institutions, and other organizations to build the information base and to identify resources that may be useful to potential recruits.

The resource center receives numerous announcements from local, regional, and national transportation organizations about employment opportunities, training, and cooperative programs and scholarships for interested students. These announcements are logged in the center's employment book or posted on the center's bulletin boards.

The resource center has acquired videos from Virginia Department of Transportation, Maryland Department of Transportation, American Public Transit Association, National Council of Negro Women/UMTA, ITE, and Council of Logistics Management. These videos are used to acquaint current and potential students with career and business opportunities within the transportation industry.

The *CTS Network Newsletter*, which is mailed to HBCUs, businesses, transportation organizations, students, and Morgan's faculty, is also designed to help achieve the objectives of the resource center. It contains articles related to the project, CTS students and faculty, and other related activities.

The resource center also provides individual counseling to students. The project coordinator spends considerable time counseling and meeting with students individually to discuss with them a wide variety of issues designed to increase their awareness about opportunities in transportation and the serious shortage of minority transportation professionals. The aim is to inspire minority students to seriously consider transportation as a career option and to encourage them to pursue graduate education in transportation at Morgan State University or other institutions offering transportation programs.

Workshops and Presentations

During visits of HBCUs, the project staff makes presentations on careers in transportation and Morgan's program to groups of interested students. The presentations are often arranged with the help of a faculty contact from the host institution. These sessions provide opportunities to disseminate information to students and faculty, and to interact with and identify interested students for follow-up work.

During the spring semester, the center hosts an open house and conducts a series of workshops focusing on career opportunities in transportation. The program includes video presentations, dissemination of packets of information, meetings of potential students with faculty and staff, and formal presentations by guest speakers from various transportation organizations, both public and private. It also includes panel discussions or presentations by graduates from Morgan State's Transportation program currently working as transportation professionals.

The series of workshops conducted in April 1989 and 1990 featured speakers from a variety of organizations, including

CSX Transportation Corporation, Virginia Department of Transportation, Maryland Department of Transportation, Atlantic County Transportation Authority, Washington Metropolitan Area Transit Authority, Wilbur Smith and Associates, A/E Group, Parsons Brinckerhoff Quade and Douglas, Inc., Baltimore City Department of Transportation, Long Island Railroad, and Fairfax County Department of Planning.

The participants in these workshops are primarily students and faculty from Morgan State University and higher education institutions in the Baltimore region. The workshops also attract people who are already in the transportation industry and are considering graduate education to enhance their professional growth. The workshops serve as a forum for students and professionals to come together to discuss careers, training, job opportunities, and minority representation within the transportation industry.

Accomplishments of the CDTP

The CDTP is a 4-year project that will be evaluated after the end of the fourth year. The full impact of the project is difficult to evaluate at this point, 1½ years after the program was launched. However, it is possible to make a preliminary assessment on the basis of the experience of the first year.

On the basis of the enrollment data from Morgan's School of Graduate Studies (see Tables 1 and 2) and the increase in class size in many of the program's courses it is evident that the recruitment effort has been successful. According to the School of Graduate Studies, 61 students enrolled in the program during Fall of 1989–1990 compared to the 37 during the fall of 1988–1989. This increase represents more than a 64 percent increase in enrollment. The increase in enrollment is reflected in the class sizes that changed from approximately 6 to 10 students per class during the 1988–1989 academic year to an average of 20 students during the fall 1989 semester. Over 90 percent of the students enrolled in the transportation program during the fall 1989 semester were women and minorities. Another indication of the effectiveness of the recruitment activities was the number of inquiries that the center received that increased significantly after the project was put in place. The increase in enrollment is attributed to a combination of recruitment activities described earlier, particularly the visits by the coordinator and the director to HBCUs, placement of advertisements in local newspapers, and the open house and workshops.

Another successful aspect of the project is the internship/cooperative component. The success of the program is made possible by the continued support received from the Maryland Department of Transportation and the BCDOT. They have demonstrated their commitment not only by providing funding for the interns' salaries but also by actively participating in the selection, placement, supervision, and evaluation of the interns. The interns participating in the Maryland Department of Transportation and BCDOT Internship Programs have been enthusiastic about the program and are gaining valuable real-world experience while they are enrolled as graduate students in the transportation program. Evaluation reports of the Maryland Department of Transportation interns by their supervisors reveal that the agencies have been satisfied with the performance of the interns and that they (the agencies) are also benefiting from the works of the interns. As indicated earlier, because of the limited number of Maryland Department of Transportation internship positions and the competitive nature of the selection process, only the highly qualified students are selected.

SUMMARY AND CONCLUSIONS

This paper attempted to summarize the extent of minority representation in various sectors of the transportation industry. Even though there are no recent systematic and in-depth studies on the subject, there are clear indications that minorities are seriously underrepresented in professional and managerial positions in transportation. As noted by ITE (*16*), no single group by itself can provide a solution to the problem. Solving the problem requires serious and concerted efforts by transportation agencies on federal, state, and local levels, educational institutions, professional organizations such as ITE, ASCE, AASHTO, TRB, and other members of the transportation community.

TABLE 1 TRANSPORTATION ENROLLMENT BY SEX

	1984-85		1985-86		1986-87		1987-88		1988-89		1989-90
Sex	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
Male	21	16	31	31	33	29	33	31	32	26	36
Female	19	17	12	12	8	5	7	6	5	6	25
Total	40	33	43	43	41	34	40	37	37	32	61

Source: Morgan State University School of Graduate Studies

TABLE 2 TRANSPORTATION ENROLLMENT BY RACE

	1984-85		1985-86		1986-87		1987-88		1988-89		1989-90
Sex	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
Male	3	3	4	3	4	2	1	1	1	0	6
Female	37	30	39	40	37	32	39	36	36	32	55
Total	40	33	43	43	41	34	40	37	37	32	61

Source: Morgan State University School of Graduate Studies

HBCUs can contribute towards the alleviation of the serious underrepresentation of minorities by recruiting and training talented young blacks for the industry. These institutions have unique resources and capabilities that have not been adequately used by the transportation industry. More specifically, a national effort by the transportation community to attract minorities to transportation professions should include the following actions:

1. Supporting existing transportation programs in HBCUs and developing new programs in selected HBCUs. The FAA's Airway Science Program can serve as a model. Support should also be given to HBCUs with engineering programs to develop transportation courses and possibly concentrations in transportation and traffic engineering.
2. Carrying out aggressive recruitment in HBCUs similar to the activities of the Career Development Project of Morgan State University. The aim should be to attract students not only to transportation and traffic engineering programs but also to programs emphasizing an interdisciplinary approach, planning, or management.
3. Providing financial aid to minority students sufficiently attractive to encourage them to pursue transportation as a career. Minorities often rely on financial aid to enroll in colleges and universities.
4. Supporting internships and cooperative programs in which minority students can participate. Such programs enrich the educational experience of the students through hands-on training and allow them to gain work experiences that will place them in better positions when they are ready to compete for jobs.

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FEEDS: An Innovative Approach to Continuing Education and Professional Development

LON-LI DAVID SHEN AND DEBRA J. SHERIDAN

One-third of this nation's professional engineers in state, county, and city transportation agencies will retire during the next decade. To counter this problem, innovative approaches to transportation engineering continuing education and professional development must be developed. The use of tutored videotape instruction technology such as the Florida engineering education delivery systems (FEEDS) is a low-cost and effective approach for a continuing education and professional development program. FEEDS has demonstrated the success of one relatively inexpensive state system that allows access to the combined strength of seven engineering colleges in this area of scarce resource.

The Florida engineering education delivery system (FEEDS) is a cooperative effort of the following six colleges of engineering: Florida International University (FIU), Florida Atlantic University (FAU), University of Central Florida (UCF), University of Florida (UF), University of South Florida (USF), and Florida State University/Florida A&M University (FSU/FAMU). The other two state universities, the University of North Florida (UNF), and the University of West Florida (UWF), are participating in the delivery of the engineering programs.

FEEDS has been developed in response to the needs of engineers working in industry and government for access to quality graduate continuing education and professional development programs. It is recognized that ready access to the highest quality engineering education by people all over Florida will play an important role in the growth of the economy in the state. FEEDS is to provide this access. The innovative use of television, live and recorded, and computer-aided communication brings students and teachers together intellectually regardless of location (*1*).

Because of recent trends reflecting an alarming decline in the number of transportation engineering students entering and graduating from our colleges and universities (*2*), it is critical to find new and innovative approaches to transportation engineering continuing education and professional development programs. FIU's experience in using FEEDS to successfully reach practicing transportation engineers all over Florida is examined.

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BACKGROUND

FEEDS was developed as a result of efforts by leaders from industry and government, working closely with the State University System (SUS). The people who produced FEEDS are committed to effective university-industry interaction to foster lifelong learning for engineers and scientists all over Florida. They are involved in the development of a "new pattern of engineering education intended to meet the needs of a world characterized by rapid technological change and by engineering systems of growing complexity. In such a world, creative, responsive, and broadly knowledgeable engineers are a most precious resource whose quality cannot be replaced by quantity" (the MIT plan, *Lifelong Cooperative Education*, presented at the MIT Centennial, October 1982).

The state universities with graduate programs in engineering (FIU, FAU, UCF, UF, USF, and FSU/FAMU) are known as primary centers and other universities (UNF and UWF) as cooperating centers. The organization of FEEDS is shown in Figure 1. Figure 2 shows the geographical location of the various FEEDS primary and cooperating centers throughout Florida (*1*).

In 1985, the FIU College of Engineering began its graduate engineering degree program and was able to join FEEDS as a primary center. Complete master's degree programs are offered in Civil/Environmental, Electrical, Mechanical, and Industrial Engineering. FIU is currently delivering courses by tutored videotape instruction (TVI). Regular (live) class sessions are videotaped on ¾-in. videocassettes at FIU University Park Campus in Miami. These cassettes are then shipped to the TVI classes at the industrial site (*3*).

A FEEDS class usually consist of four to eight students and a tutor/facilitator. The main purpose of the facilitator is to lead the class discussion. It is best if the facilitator not be an authority on the subject being reviewed, but rather someone who has taken a FEEDS course before, or who works in the disciplinary area of the class subject. This during-class discussion does lengthen the class time. A typical 50-min class should be allowed at least 75 min. FIU live classes are 75 min long and should be allowed at least 105 min for review and discussion.

Another important task for the facilitator is to be the professor-TVI class liaison. The facilitator keeps the professor up to date on the class progress. If there is a problem on campus, it is usually easier to contact the facilitator rather than each individual student (*3*). The facilitator and FEEDS

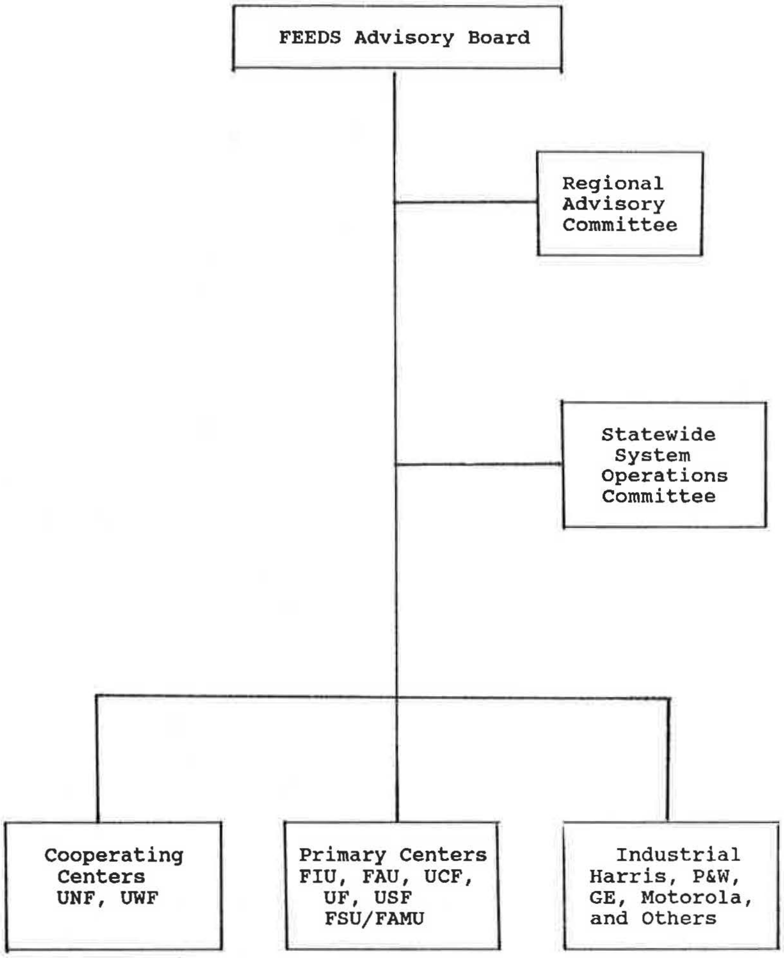

FIGURE 1 Organization of the Florida engineering education delivery systems (FEEDS).

FIGURE 2 Location of FEEDS primary and cooperating centers (1990).

students both have access to the professor on campus by the telephone and FAX.

FEEDS FACILITIES

FIU FEEDS classes are taped in two studio classrooms controlled by the Division of Instructional Media Services. One studio has three Ikegami ITC-730A cameras. The second, and newer studio, is equipped with three Sony DXC 3000 AK cameras. One camera is used to cover textbook references, samples, illustrations, etc., and the other two cameras cover the action. There are three Sony VO–5600 U-Matic video tape recorders (VTRs). All FIU courses are taped on ¾-in. U-matic videocassette tapes; however, in special circumstances a course can be taped on the ½-in. VHS Panasonic VTR.

FIU, as well as most of the other primary centers, delivers all tapes and materials by United Parcel Service. This procedure has greatly improved the TVI delivery by reducing the time gap between the professor's live class and the industrial site. The use of videotapes allows maximum flexibility for students and the FEEDS center. In addition, videotapes are available for students to review or to view missed class sessions caused by meetings, travel, illness, etc.

THE PROBLEM

A recent National Science Foundation study found that over the next 5 years, the college-age population will decline and the supply of engineers graduating from college will also decline, perhaps quite markedly. This decline is occurring in the face of a growing need for transportation engineers in state, county, and city transportation agencies. In state highway agencies alone, the need for civil or transportation engineers, who make up almost 75 percent of the professionals hired, is projected to grow at the rate of about 4.5 percent per year (*4*).

In addition to this growing demand, one-third of this nation's professional engineers in state, county, and city transportation agencies will retire over the next decade (*5*). In 1976, about 47 percent of all engineers were over age 40 (*6*). By 1986, that age group had increased to 59 percent. Young people are not being attracted into the profession. To complicate this already tight situation, the rate of retirement will be much greater than in past years. During the 1950s and 1960s, government agencies hired rapidly as the nation's highway programs expanded; those same professionals are now at retiring age (*6*).

Most transportation engineering professionals are a product of a civil engineering education. Although some have a transportation minor at the undergraduate level, many have little transportation education. In a study of the current shortage of graduates interested in transportation engineering, it was found that the shortage occurs at all levels of education, from the B.S. and M.S. degree level at the transportation industry level of interest and with Ph.D. at the university faculty level (*6*). It is critical that engineering educators address this important transportation engineering education problem. FEEDS seems to be an ideal approach to educate M.S. degree level engineers and to provide continuing education and professional development to those engineers who normally will not have this chance.

THE FEEDS SOLUTION

An engineering student or a practicing engineer can register for a FEEDS-delivered course at all major cities or towns in Florida. All students registering for one or more courses offered on FEEDS must be admitted to one of the primary universities as a degree or nondegree student. Application may be made directly to the registrar or through the Division of Continuing Education.

In general, there are three student classifications supported by FEEDS: (a) graduate, (b) postbaccalaureate, and (c) transient. Within the graduate status, an admitted student may be further classified as regular or provisional (or conditional). Student classifications (b) and (c) are considered to be nondegree-seeking status. Figure 3 shows the flow chart of how FEEDS works for a prospective student interested in the program.

FIU's master of science in civil engineering (transportation) program requires 36 credits and a thesis or research report. Between 2½ and 5 years are required for completion of all requirements by the average FEEDS student. More than 100 students have taken FEEDS transportation engineering courses since FIU started to offer them in 1985. Those FEEDS stu-

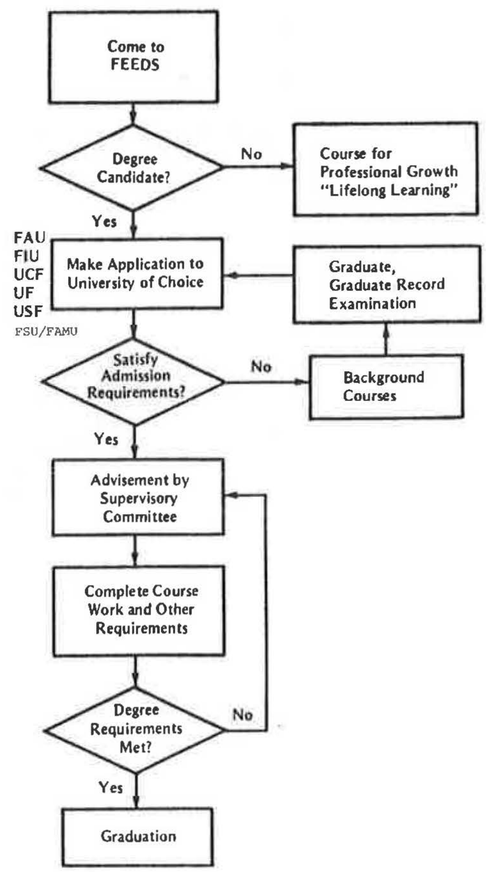

FIGURE 3 Flowchart of the FEEDS program.

dents are spread all over the state, from Jacksonville to the Florida Keys, from Pensacola to West Palm Beach. Table 1 presents the transportation engineering courses and their enrollments offered by FIU over the years.

A survey conducted in 1990 indicates that over 90 percent of the FIU FEEDS (transportation engineering) students are non-degree-seeking students. Their primary interest in taking the course is to advance their job skills and professional development. This again confirms the success of using FEEDS as an innovative approach to the continuing education and professional development program. Table 2 presents the average age, education, professional registration, and place of employment for FEEDS students and their counterparts on campus. A typical FIU FEEDS (transportation engineering) student is a white male, 34 years old, with a professional engineer (PE) or engineer-in-training (EIT) certificate, and previous work in a middle-sized engineering consulting company.

Table 2 indicates that FEEDS students are generally older and have more professional experience than regular on-campus students. However, as the Stanford University experience demonstrated, and the results at FIU confirm, that with the help of TVI, off-campus FEEDS students perform as well or better than students on campus taking the same course, especially in those design-oriented courses. Through TVI, the FEEDS students have access to the same high-quality graduate engineering courses that are available on campus. The experience in Florida clearly indicates that FEEDS provides an effective means of delivery, tolerant of the problems associated with fulltime employment such as travel and project deadlines. There is no doubt for anyone who is involved in FEEDS that it is an extremely effective and efficient approach to the transportation engineering continuing education and professional development program.

THE FUTURE

Transportation engineering education in 2010 will be highly technology oriented. The computer-video technology classroom will be the standard classroom used for transportation engineering courses. FIU is exploring the use of microwave relay delivery or instructional television fixed service (ITFS). This low-power microwave television broadcasting system would send audio and video signals to the class site during real time or as the class is actually being taught. The class would have an audio signal sent back to the professor at the live class. This gives the ITFS class the feeling of being in the live class and is well suited for larger classes (*3*). This delivery method would minimize travel and shipping expenses and would reduce the need for a tutor or facilitator. FIU would work directly with the human resource person at the company to coordinate administrative business.

The goal of the engineering college at FIU is to meet the needs of the South Florida area by making the graduate degree programs more accessible to industry and different government agencies within the area. The response has been overwhelmingly positive. With the help of FEEDS, FIU's transportation program is one of the most successful programs in the state. From 0 to more than 100 students in just 5 years—

TABLE 1 TRANSPORTATION ENGINEERING FEEDS COURSE ENROLLMENT AT FIU

Year	Semester	Course Name	Enrollment
1986	Spring	Pavement Design	11
1986	Summer	Advanced Highway Geometric Design	5
1986	Fall	Advanced Highway Capacity Analysis	12
1987	Spring	Urban Mass Transit & Transp. Planning	2
1987	Summer	Pavement Design	8
1987	Fall	Advanced Highway Geometric Design	12
1988	Summer	Urban Mass Transit & Transp. Planning	4
1989	Spring	Airport Planning & Design	5
1989	Summer	Advanced Highway Capacity Analysis	13
1989	Fall	Urban Traffic Characteristics	12
1990	Spring	Advanced Highway Geometric Design	3
1990	Summer	Advanced Highway Capacity Analysis	8
1990	Summer	Traffic Control Systems	6
1990	Summer	Urban Mass Transit & Transp. Planning	6

TABLE 2 STATISTICS OF STUDENTS TAKING TRANSPORTATION ENGINEERING GRADUATE COURSES AT FIU

Average Age	Education		Professional Registration			Place of Employment	
	BSCE	Other	PE	EIT	Other	Gov't	Industry
FEEDS Students							
34	71%	29%	42%	14%	44%	20%	80%
On-Campus Students							
32	79%	21%	8%	46%	46%	25%	75%

from Miami to Jacksonville, from Naples to Pensacola—the diversity of the students speaks for itself.

In order to prepare for the 21st century, new and innovative technologies will be installed in our FEEDS classroom in the future. FIU is currently exploring use of the following hardware (*2*):

1. Large-screen projection system (VGA),
2. Super VHS editing VCR,
3. Video disc player,
4. Live color overhead projector display system,
5. Amplifier and speaker system,
6. Overhead projector with software,
7. Large VGA color monitor, and
8. Computer networks in the classroom.

The benefits of a dedicated computer-video FEEDS classroom for transportation engineering education are as follows:

1. Emphasis placed on computer use by demonstrated commitment of the engineering college.
2. Demonstration to include state-of-the-art instructional technology.
3. Increased efficiency in instruction of transportation engineering courses that are oriented to computer applications.
4. A much larger target area can be reached through the use of FEEDS, thus making the investment more efficient and cost effective.

The application of instructional endeavor will embrace and support this technology, demonstrating increased use as the industrial demand and expectations for computer literacy continue to increase. In addition, computer-aided design and drafting (CADD) applications in highways, airports, ports, and mass transit systems can only be demonstrated in such an environment.

SUMMARY

The use of FEEDS for transportation engineering continuing education and professional development program is promising, as FIU's success has clearly indicated. However, the transportation engineering profession faces serious personnel and training problems in the coming decade. The use of TVI technology such as FEEDS is a low-cost and effective approach for a continuing education and professional development program. Florida's experience with FEEDS can definitely be duplicated in other states. FEEDS has demonstrated the success of one relatively inexpensive state system that allows access to the combined strength of seven engineering colleges in this area of scarce resource.

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Approach to Increasing the Representation of Women in Nontraditional Professional Fields

ADRIENNE A. SCERBAK AND LOUIS PIGNATARO

Women in Engineering, Science, and Technology (WEST) will be established at New Jersey Institute of Technology to facilitate the transfer of women from 19 community colleges in New Jersey to engineering, science, and technology programs at 4-year colleges and universities on completion of their 2-year curricula. During its first year, the WEST office will work with some of the community colleges with which articulation agreements already exist. Special efforts will be made with urban-based colleges with a high percentage of minority and economically disadvantaged students. After its first year of operation, WEST will expand its efforts to include other community colleges in the state. The goal is to recruit at least 200 women per year to the career days and seminars. Fifty-two of these recruits will later be enrolled in the telecourse offered by the Center for Precollege Programs and Distance Learning or in the Educational Opportunity Program. The objectives are to increase by 10 percent each year the number of community college women transferring to 4-year colleges and universities to pursue majors in engineering, science, and mathematics; to encourage women with undeclared majors at community colleges to select preengineering and science curricula; to help the community colleges recruit more entering women students to the preengineering and science curricula; to evaluate the model after its first year for the purpose of improvement and dissemination to other 4-year colleges during its second year; and to expand the scope of activities of the WEST program to other community colleges after its first year of operation.

In December 1989, the Task Force on Women, Minorities, and the Handicapped published its final report, *Changing America: The New Force of Science and Engineering*. This report and the Task Force's interim report published in September 1988 systematically document the startling lacunae in the nation's science and engineering work force and educational pipeline. Briefly stated, the United States faces an increasing shortage of engineers. In the past, white males have traditionally dominated all engineering and science fields. Not only do fewer white males enroll in engineering degree programs, but the significant gains in female enrollment during the early 1980s have stagnated and, in fact, the number of women in these fields is now declining. In essence, these trends reflect the waning interest of American students in engineering, technological, and scientific disciplines.

It would be incorrect to blame these trends on any one factor; they result from a combination of demographic and cultural factors. First, the traditional population entering these fields is primarily white males. As the Department of Labor's *Workforce 2000: Work and Workers for the 21st Century* documented, this population is declining and by the turn of the century will represent only 15 percent of new entrants to the work force. Second, other segments of the population such as women and minorities have been discouraged from entering these fields because of tradition, lack of information, and prejudice. Finally, many students are not receiving preparation at the elementary and secondary levels that would allow them to pursue such careers.

The 1990 National Science Foundation (NSF) report, *Women and Minorities in Science and Engineering* (WMSE), provides documentation and statistics similar to those found in the Task Force report, but in a more detailed format. Both reports echo the findings of *Workforce 2000*, published in 1987. Besides emphasizing that 85 percent of all new entrants to the labor force will be women, minorities, and immigrants, the authors of WMSE carefully examine the economy's needs for training and education in areas in which these groups are traditionally underrepresented. Taken together, these reports offer a cogent analysis and a blueprint for action that will change the face of America's scientific, engineering, and technical work force over the next decade.

Workforce 2000: Work and Workers for the 21st Century makes note of several important economic trends including the proliferation of advanced technologies. The technological areas of growth that are listed in the report include computer science, advanced telecommunications, advanced materials, biotechnologies, and superconductive materials. All these areas of employment require postsecondary education or training. Many require advanced degrees or continuing education. Other areas of concern in *Workforce 2000* include the retraining of the work force and the need for flexibility in the future on the part of the labor force and the employers.

DEMONSTRATION PROJECT

New Jersey Institute of Technology (NJIT) plans to explore how more women and minorities can be recruited into careers in engineering, science, and technology. One part of the Institute's effort will take shape in the form of a demonstration project entitled "Women in Engineering, Science, and Technology" (WEST). As the only state-supported technological institute in New Jersey, NJIT must play a leading role in meeting the state's and the larger national need for qualified professionals in these areas.

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NJIT is the largest engineering college in the state; it is coupled with undergraduate and graduate degree programs in architecture, industrial management, and the sciences. NJIT offers degree programs in many fields in which women are traditionally underrepresented.

The decision to form the WEST program was prompted by an earlier study by NJIT Office of Institutional Research and lengthy conversations with six administrators of special programs for women in engineering and science at other universities around the country. The first study indicates that only 10.8 percent of all community college students transferring to NJIT are women, although women represent 15 percent of all full-time undergraduates at NJIT. This same study also outlines the disparity between the number of male undergraduate transfer students, which totaled 411 entering in fall 1989, and the number of female undergraduate transfer students, which totaled only 54 in the entering class. One inference that can be drawn from these data is that a program concentrating on women from community colleges will increase the total number of women transferring to NJIT and other schools with strengths in science and technology.

Information gathered through phone conservations with administrators of women in science and engineering programs around the country indicates that a multifaceted approach is necessary to encourage women to consider careers in science and engineering and to remain in these curricula once elected. These approaches frequently include precollege summer programs, career days, alumna mentorship of accepted students, special seminars for women students, and the establishment of support groups. The effectiveness of such programs is clear. Although the national percentage of full-time undergraduate women enrolled in engineering programs is about 15.8 percent, universities with established programs, such as Purdue University, have a student body made up of 21.7 percent women.

NJIT's interest in encouraging the recruitment of more women to nontraditional professional areas is a natural extension of the leadership role it has assumed in this area in the past. Current NJIT programs for women include the Program for Women in Engineering and Construction, under the auspices of the Center for Transportation Studies and Research; the Females in Engineering: Methods, Motivation, Experience program (FEMME), geared to middle school students and sponsored by the Center for Precollege Programs; the Career Advancement Plan (CAP), sponsored by the Cooperative Education Division, offering women and minority students special seminars that complement their cooperative placements; an active student chapter of the Society for Women Engineers; the Women in Science and Engineering (WISE) program, a weekly seminar for 15 selected first-year women students; a Big Sister–Little Sister Program; and monthly meetings for returning women students over 25 years of age. The last four programs are offered through the Office of the Dean of Student Services.

Through its commitment to public service, NJIT has already begun meeting some of the challenges delineated in the NSF and Department of Labor reports. NJIT has a Center for Precollege Programs and Distance Learning and a Joint Mathematics and Science Articulation Program for community college students sponsored by the Educational Opportunity Program (EOP). The EOP's mission is to recruit minorities and increase not only their access to higher education but also their retention rates. NJIT's EOP office is one of the largest in New Jersey with over 500 students.

Although the range of activities originating from the WEST program will be extensive, the initial stages will focus on recruiting top minority community college students. The program will address this area in particular for four reasons. First, NJIT has preexisting articulation agreements with all the community colleges in New Jersey that will ensure a positive working relationship with their staffs. There are 68,000 women enrolled in New Jersey's community colleges. Second, community college populations frequently include minority, economically disadvantaged, and returning or mature students. Third, both the Center for Precollege Programs and Distance Learning and the EOP have established programs in conjunction with community colleges, thus facilitating the development of special activities and outreach for women. Fourth, national attention has been drawn to the need for more students with 2-year degrees to continue their educations at 4-year colleges. By developing a successful program for increasing the transfer population, NJIT will provide a model for colleges and universities around the country.

PROJECT DESIGN

The primary goal of the newly established WEST program will be increased recruitment of women to engineering, science, and mathematics-based career paths from New Jersey's community colleges through a preengineering course using distance learning and multimedia technology, a summer EOP program, and intensive recruitment and support strategies.

The objectives are to increase by 10 percent each year the number of community college women from selected colleges transferring to 4-year colleges and universities to pursue majors in engineering, science, and mathematics; to encourage women with undeclared majors at community colleges to select preengineering and science curricula; to help the community colleges recruit more entering women students to the preengineering and science curricula; to evaluate the model after its first year for the purpose of improvement and dissemination to other 4-year colleges during its second year; and to expand the scope of activities of the WEST program to other community colleges after its first year of operation. If successful, the WEST activities will provide other colleges and universities around the nation the opportunity to implement similar plans.

ANTICIPATED RESULTS

These objectives will be accomplished through four areas of activity: the development of recruitment and support networks; the establishment of a specific preengineering course aimed toward women at community colleges; the development of special courses for women in the summer EOP program for community college students; and the dissemination of information about these activities to other 4-year colleges.

Support and outreach networks will include two seminars per semester for women students on at least four community college campuses. These seminars will introduce them to the administrator of the WEST program; engineering, science, and mathematics majors; and representatives of other programs established for women at NJIT. The seminars will also discuss the WEST program's preengineering multimedia telecourse and the EOP summer program for students who have completed their first year of study.

Another important part of the outreach aspect of WEST will include the invitation of community college students to career days on the NJIT campus, one to be held in the fall, the other to be held in February. During these visits, students will be introduced to the admission and financial aid staff.

NJIT alumnae will be used as role models and mentors in various phases of the support and outreach activities. They will be asked to speak at career days and to mentor women who have elected a math, science, or engineering curriculum.

The WEST program will also produce posters and brochures to encourage women to consider mathematics, science, and engineering careers. These materials will be distributed to community college recruitment offices. Special flyers will be developed for recruitment to the long-distance learning and EOP programs.

The preengineering course will be developed by an NJIT faculty member and delivered to community colleges as a live, interactive telecourse through available systems. Distance learning has developed rapidly at NJIT because it serves large numbers of geographically dispersed students effectively and efficiently. Access is improved by allowing students to work on course materials at flexible time periods instead of at one fixed time, while emphasizing the importance of engaging students in ways that involve them actively in learning.

A telecourse is an integrated learning system that uses television and various print materials. This system is specifically designed to involve a variety of learning strategies to forge a complete education unit available to the student at a site remote from the university. It is not a correspondence course with pictures; nor is it a televised lecture with supplementary readings. It is an examination and presentation of a body of knowledge and information through the use of sight, sound, color, movement, and print, in a manner designed to stimulate, clarify, and quantify. A telecourse is designed to take maximum advantage of the strengths of each component to lead the student through a success-oriented experience.

The telecourse can be delivered by satellite transmission alone or in combination with Instructional Television Fixed Service. The actual delivery system will depend on location and equipment at receiving sites. Each receiving site is required to provide a facilitator who handles record keeping, proctors exams, etc. The NJIT faculty member serves as mentor, working with the facilitator and communicating with the students by live TV when possible, and by other means, such as telephone, fax, electronic conferencing, etc.

This one semester, two-credit elective course will be provided to students at four selected community colleges to which NJIT has already provided similar services. The course will focus on guided engineering design and will develop students' decision-making skills and introduce them to basic principles. Effectiveness will be enhanced by WEST facilitation of collaborative or group learning in a peer support and exchange environment. Before the course, students will be surveyed to determine their attitudes towards careers in engineering. After each semester, student evaluations will be taken to determine whether student interest in the engineering profession has increased through the course. Students will be provided support services to encourage them to take other required preengineering courses and to facilitate their transfer to colleges that offer the bachelor's degree in engineering. Their academic progress will be followed throughout the 2 years of this project to determine the effectiveness of the activity. The goal is to enroll at least 10 women on four different campuses in the course each year. After evaluation, the course may be modified.

Another activity of the WEST office will be the recruitment of women to the EOP-sponsored Joint Mathematics and Science Articulation program that was established by the NJIT EOP office 2 years ago. This program was established with the purpose of better preparing students from community college Educational Opportunity Fund (EOF) programs for senior engineering colleges, including NJIT. The courses in the program have been designed to supplement the students' academic background rather than replace any of the home school requirements. The program recruits African-American, Puerto Rican, and female students. It draws primarily from those institutions that have articulation agreements with NJIT and preengineering programs. The largest number of students are from Essex Community College. In the past, approximately 25 percent of the students involved in this program have been female.

The WEST program would initiate two changes in this program. First, it would actively recruit women to the EOP summer program to increase the percentage of women from 25 to 40 percent. This process would include working with the NJIT EOP staff as well as the community college EOP staffs. Secondly, it would work with the mathematics summer program instructor to raise awareness about women and mathematics anxiety. After their participation in the summer program, the students would be followed until the end of the demonstration project. Their attitudes toward mathematics would be measured before and after the program, and their progress in their academic careers would be followed. Progress for women in mathematics classes between the years covered under this demonstration and previous years would be measured to determine if the special support structures have contributed to better grades and commitment on the part of the students.

EVALUATION AND DISSEMINATION

The fourth area of activity for the WEST program would be evaluation of the activities and dissemination to other colleges. Each area of activity will be evaluated separately and changes made accordingly both in recruitment strategies and in curricular design. Because the one-semester long-distance learning class will run only twice, changes can be made in recruitment and presentation for the second session after evaluation of the first. The summer EOP program will be run twice. Follow-up on individual women students and their evaluation of the mathematics course and support networks will determine changes to be made for the second course.

In the fall of 1992, evaluation will begin of the first year's efforts. Students recruitment, retention, and progress will be areas of study in the evaluation process. By the late fall, a report will be prepared and disseminated to 4-year colleges in the New Jersey and New York area interested in recruiting more women from community colleges to their science, mathematics, and engineering departments. The WEST office will sponsor a meeting for the purpose of discussing pilot results and sharing the report with interested colleges and universities in the geographical area.

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Transportation Engineering and Planning Program for Postgraduate Studies in a Small Developing Country

S. C. WIRASINGHE AND L. L. RATNAYAKE

The proper planning, design, and operation of the transportation system is essential for the development of a country. However, the level of adequacy of the local professional human resources that are available in developing countries is poor. A single postgraduate program that trains the transportation engineering and planning (TE&P) professionals that are needed is appropriate for a small developing country with limited resources. The program can also be disseminated through distance education services. A program that can offer M.Sc. degrees in TE&P as well as M.Phil. (course work and research) degrees is proposed. The target pool of students, the basic principles for curriculum development, and the staff requirements for offering such a program are discussed. It is suggested that three full-time local staff that are trained abroad under scholarship programs as well as part-time staff be used. The courses should be open not only to engineering graduates but others who are suitably qualified. Typical course outlines for the proposed courses are given.

Transportation engineering and planning (TE&P) courses are rare in developing countries despite the obvious importance of transportation in the socioeconomic fabric of a country and for development. However, highway and traffic engineering courses are usually offered as a part of civil engineering bachelor's degree courses. Although an additional undergraduate course in TE&P would be of use to all civil engineers, it is also appropriate to teach the discipline as a postgraduate program, given it's broad scope.

An ITE technical committee surveyed transportation education needs in developing countries (*1*) and concluded that the level of adequacy of local professional human resources was poor. The following were suggested as possible remedies:

1. Professional training programs (3 to 6 months);
2. Foreign scholarships for M.S. and Ph.D. programs;
3. Undergraduate programs in civil engineering, planning, and architecture; and
4. Correspondence courses.

The committee also concluded that "very few universities in the United States (and presumably in other countries) have adequate resources to offer such a specialized program" (i.e., TE&P in developing countries) and that "serious efforts should be made to offer (such) programs in the developing countries themselves." The committee also felt that "lack of foreign exchange would not allow these countries to send any appreciable number of professionals abroad."

Most developing countries do have undergraduate civil engineering programs. Professional training programs are appropriate short-term solutions to retrain existing human resources. The long-term solution to the lack of specialized professionals in developing countries is for postgraduate programs to be offered in those countries. Whenever possible, the postgraduate programs should be staffed by people from the same country that understand indigenous problems and can suggest indigenous solutions. Initially, the academic staff for the postgraduate programs can be trained in developed countries.

Small developing countries (SDCs) (e.g., Sri Lanka, Guatemala, Ghana, Rumania) have limited resources for training the professionals needed for development in areas such as transportation, water supply, agriculture, and public health. Consequently, it would be wasteful to offer more than one postgraduate program in any one of these areas. On the other hand, that program should be designed to provide expertise in all aspects of the discipline. Once developed, the program can also be disseminated through distance education services. In some cases, one program could cater to a group of several countries in one region, for example Sri Lanka, Nepal, Bhutan, and the Maldives. In appropriate cases, such regional cooperation could result in economies of scale, reduction of staffing problems, and also easier access to funding from international agencies.

In the following, a model package for a postgraduate program in TE&P is proposed for SDCs. It was developed by Canadian and Sri Lankan academics with a background in TE&P problems facing SDCs. It has benefited greatly by the suggestions and criticisms offered by a panel of Sri Lankan experts with a strong and varied background in TE&P in SDCs. Sri Lanka, a typical SDC, was chosen for reviewing and testing various drafts of the proposal.

TE&P

The discipline of TE&P covers all aspects of the planning, design, and operation of transportation systems. For example, the feasibility analysis for a rural highway, the specification of its horizontal and vertical alignment and thickness of its pavement layers, and the ongoing maintenance of the highway could be considered to be the planning, design, and operations components, respectively, of a highway project.

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In addition to the highways, transportation professionals along with professionals with expertise in commerce and economics are responsible in various degrees for railways, light-rail and metro systems, bus systems, ports, urban transportation, freight transportation, water transportation (e.g., canals), and air transportation.

The design, manufacture, operation, and maintenance of the vehicles and power systems used for transportation are the responsibility of other professionals such as mechanical engineers. Further, the technologies associated with controlling the free movement of vehicles (e.g., the electronics of the controllers used for traffic signals) are in other domains.

The design of transportation infrastructure facilities (e.g., highways, railways, and canals) and the operation of the highway system (traffic engineering) have traditionally been and will continue to be the domain of civil engineers. The remaining areas have been staffed with engineers and others with varied backgrounds but with little formal training in transportation.

TARGET POOL OF STUDENTS

In many instances, transportation agencies are staffed by civil servants with varied backgrounds who have no understanding of the basic principles underlying the transportation discipline. This will change in the long run if new recruits have a formal training in TE&P and middle-level officials are given retraining.

TE&P has little in common with traditional civil engineering subjects such as the theory of structures and hydraulics. Consequently, the background of students who can be admitted to a postgraduate course should not be restricted to civil engineering. However, an adequate background in mathematics equivalent to first-year university mathematics is essential.

Prospective students should have one of the qualifications listed in Table 1 for consideration for admission to a graduate program in TE&P. The students with a first degree in nonengineering subjects are unlikely to be considered for registration as professional or chartered engineers after they complete a postgraduate course in TE&P. However, they will likely be eligible for membership in societies of transport professionals.

CURRICULUM FRAMEWORK AND DEGREES

The following are the basic principles underlying the development of the curriculum given in the next section.

1. Transportation systems should be planned, designed, and operated by formally trained professionals.

TABLE 1 REQUIRED QUALIFICATIONS

	Degree	¯ Class/GPA (4.0)
1.	*Engineering	Second/3.0
2.	Transportation	Second/3.0
3.	#Economics	Second/3.0
4.	#Geography	Second/3.0
5.	#Mathematics	Second/3.0
6.	#Physics	Second/3.0
7.	#Computer Science	Second/3.0
8.	**General Degree with two or more of the above subjects	Upper Second/3.5
9.	+Other Special Degree with minor in mathematics	First/3.75

Notes:

* A degree in any branch of Engineering

\# Special or Honours degree of 4 years duration

** An Upper Second Class (G.P.A. 3.5) is required because these are usually 3 year programmes

\+ Students with Special Degrees in subjects such as Sociology and Psychology may be considered if the mathematics background is sufficient

¯ Experience in the Transport Sector may be considered to be equivalent to the G.P.A. or Class given above. The actual equivalence should be determined on a case by case basis.

2. Given the limited resources in SDCs, a single postgraduate program should be designed to cover the requirements of the TE&P sector. However, economists and M.B.A.s with expertise in transportation can be trained within existing general economics and business programs.

3. Although specialization in some aspects of transportation is desirable, a general understanding of the basic principles underlying the three major areas of planning, design, and operations is required for all professionals.

4. The course should be practically oriented so that the graduates will need little or no further training by particular agencies. However, it is noted that "nothing is more practical than a good theory."

5. Master's level qualifications are adequate for most professionals. However, the course should be designed to accommodate students proceeding subsequently to a Ph.D. program.

6. The course should be designed to accommodate both parttime and full-time students. It should be presented in class and also through distance education services.

7. The limited staff available in a small developing country for teaching a postgraduate course is a consideration in curriculum development.

CURRICULUM FRAMEWORK AND DEGREES

The framework of the curriculum is given in Table 2. The four main divisions of the curriculum are general (G), planning (P), engineering (E), and functional design and operations (F). Each of the courses is equivalent to 3 hours of lectures per week during a 13-week semester.

The individual courses listed in Table 2 were selected independently of the ITE proposals (*1*). However, a subsequent comparison revealed that 7 of the 18 topics suggested by the ITE committee are listed as courses in Table 2 and that 7 other topics are covered in four of the courses. The four topics suggested by the ITE committee and not covered here were all given low priorities (ranging from 5 to 7 on a scale of 1 to 10) by the committee. They would be more appropriately housed in a business administration program. On the other hand, Table 2 includes several courses under the general category (G2, 3, and 5) that were not proposed by the ITE committee.

Both the M.Sc. degree courses have been designed to provide a solid background in all aspects of transportation as well as specialization in certain areas. The four introductory courses in transportation economics, planning, designs, and operations, respectively, are mandatory for all students. Thus, engineers will appreciate economic and planning problems and vice versa.

Either program can be completed in three semesters by a full-time student.

M.Sc. In Transportation Engineering (T.E.)

This program should normally be available only to students with a first degree in an engineering discipline.

The M.Sc. (T.E.) degree will be awarded upon the successful completion of the following 10 courses and a final oral examination. This course is designed for those planning careers in highway and traffic engineering as well as for engineers dealing with airports, railways, and urban rail and bus systems design.

No. of Courses	*Group or Course*
2	E1, F1
Choice of 3	E, F
2	G1, G2
1	P1
Choice of 2	Optional

M.Sc. in Transportation Planning (T.P.)

This program should be available to all groups listed in Table 1. The M.Sc. (T.P.) degree will be awarded upon successful completion of the following 10 courses and a final oral examination. This course is designed for those planning careers in transportation planning, transportation systems analysis, and urban and rural development

No. of Courses	*Group or Course*
2	P1, F1
Choice of 3	P, F
2	G1, G2
1	E1
Choice of 2	Optional

TABLE 2 TRAFFIC ENGINEERING AND PLANNING COURSES

General (G)	Planning (P)	Engineering (E)	Functional Design and Operations (F)
1. [a]Introduction to Transport Economics	1. [a]Introduction to Transport Planning	1. [a]Introduction to Transport Facilities Design	1. [a]Introduction to Transport Operations
2. [a]Probability and Statistics for TE&P	2. Urban Transport Planning	2. Geometric Design of Highways and Railways	2. Traffic Engineering
3. Operations Research for TE&P	3. Freight Transportation	3. Pavement Design of Highways	3. Public Transport Operations
4. [b]Urban and Regional Planning			
5. [b]Computer Literacy			

NOTE: Duration of each course: 3 hr/week for 13 weeks or equivalent.
[a]Mandatory courses for all M.Sc and M.Phil. students.
[b]These courses are usually offered in other university departments. Course outlines are not provided in this paper.

M.Phil. Degree

The M.Phil. degree can be awarded upon the completion of (a) a thesis subsequent to 1 year of research and (b) the coursework requirements. It is recommended that the course G3 be mandatory for all M.Phil. students. This degree is appropriate for those planning careers in research agencies or planning to enter a Ph.D. program.

Staffing and Staff Training

Ideally, a full-time staff of three lectures should be available for teaching the courses given in the previous section. They should be specialists in Transportation Planning, Transportation Engineering, and Transportation Facilities Design and Operations, respectively. Then, each lecturer is required to teach three courses per academic year (two in one term, one in the other term in semester systems; one in each of three quarters in quarter systems). In addition, the support of other university departments is required to teach Section G courses.

If the M.Phil. degree is to be offered, at least two of the staff members should have Ph.D. degrees. Otherwise, one staff member with a Ph.D. degree and two experienced lecturers with master's degrees are sufficient. Ideally, all three should have the Ph.D. qualification.

It is recommended that the three lecturers should not only have varied specializations, but that they should be trained in various regions and countries of the world (e.g., Asia, Australia, continental Europe, North America, United Kingdom) whenever possible, rather than in one university or even one region. In recruiting staff for training abroad, it is essential to interview and handpick not only the brightest but those who are highly motivated to return.

If a minimum of two faculty members are available, the proposed program could be implemented with the use of visiting lecturers picked from the pool of practitioners that is normally available in any country. The visiting lecturers should have a significant amount of professional experience and preferably a master's degree. In fact, the use of visiting lecturers should be encouraged for specific lectures, even if full-time staff are available, to take advantage of their considerable experience and to strengthen the program by maintaining links to the practitioners.

PROPOSED POSTGRADUATE PROGRAM—UNIVERSITY OF MORATUWA, SRI LANKA

The University of Moratuwa proposes to conduct only one M.Sc. course in transportation. The course will be conducted by the Department of Civil Engineering with supporting staff from the Departments of Mathematics and Town and Country Planning in the university. There will be about four visiting staff. The course will be open to engineers, planners, economists, geographers, mathematicians, computer scientists, and others with suitable background preparation.

The M.Sc. degree will be awarded upon the successful completion of the following 10 courses and the successful completion of a dissertation and oral examination. This degree is equivalent to the M.Phil. degree proposed earlier.

- Term 1 (Weeks 1 to 13)

  1. Introduction to Transport Economics.
  2. Transport Planning (General).
  3. Probability and Statistics.
  4. Computer Literacy.

  Written Examinations (Weeks 14 to 16).

- Term 2 (Weeks 17 to 30)

  5. Introduction to Transport Operations.
  6. Introduction to Transport Facilities Design.
  7. Traffic Engineering and Public Transport Operations.

  Written Examinations (Weeks 31 to 33).

- Term 3 (Weeks 34 to 46)

  8. Highway Planning and Design, and Urban Transport Planning.
  9. Pavement Design and Maintenance and Urban and Regional Planning
  10. Operations Research and Freight Transportation

  Written Examinations (Weeks 47 and 48).

Because local employers are usually not willing to release their staff on a full-time basis for a significant period, all M.Sc. courses in the Faculty of Engineering at the University of Moratuwa are conducted on a part-time basis. The lectures, practicals, project work, etc., are conducted on Fridays and Saturdays from 8:00 a.m. to 4:00 p.m. Hence, it takes 2 years to complete all 10 courses. In general, it takes about 1 to 2 years to complete the research project. The time table and the implementation program are given above.

The University of Moratuwa by-laws allow a student to opt for postgraduate diploma after the successful completion of the 10 courses. This diploma is equivalent to the M.Sc. degrees proposed earlier.

At the University of Moratuwa, M.Phil. degrees are awarded by research only. A student should perform at least 2 years of full-time research or equivalently more than 3 years on a part-time basis to be eligible for an M.Phil. degree. The student will be required to present one or more seminars on his research work and submit a thesis for an oral examination with external examiners. Only persons with a very good undergraduate degree (1st Class or 2nd Class, upper division) are allowed to register for an M.Phil. degree. Because only a very few transport-related courses are taught in undergraduate programs, students in general will not be encouraged to undertake M.Phil. degrees in transportation.

When the proposed M.Sc. course in transportation commences in 1991 there will be three staff members with postgraduate qualifications in traffic engineering (M.Sc.), transport planning (Ph.D.), and public transport operations (Ph.D.).

The Mathematics Department is expected to conduct two courses (probability and statistics and operations research) and the Town and Country Planning Department to conduct the urban and regional planning course. Visiting lecturers are expected to give four courses: Introduction to Transport Economics, Freight Transportation, Highway Planning and Design, and Pavement Design and Maintenance.

TYPICAL COURSE OUTLINES

The following outlines for the courses in Table 2 (with the exception of G2 to G5) are meant only to be used as guides in developing specific courses appropriate for specific countries. Detailed curricula and 74 references are given by Wirasinghe and Ratnayake (*4*). Though the outlines were developed with the intent of being generally applicable, all the authors and the experts who commented on drafts were either Sri Lankans or Canadians, and their biases are likely to have been a factor. However, the outlines given here will provide a good starting point and also considerably reduce the workload involved with curriculum development.

The course numbers in the following section refer to Table 2.

G.1. Introduction to Transport Economics

1. Introduction to Basic Microeconomic Theory.
2. Economic Significance of Improved Transportation.
    a) Transportation and Availability of Goods.
    b) Price Stabilization and Equalization.
    c) Relation of Transportation to Land Values.
    d) Transportation and Prices.
    e) Territorial Division of Labor.
    f) Transportation and Large-Scale Production.
    g) Transportation and Competition.
    h) Transportation and Urbanization.
    i) Low Freight Rates in the Public Interest.
    j) Transportation and Economic Development.
3. Demand for Transport.
    a) Factors that Influence Demand.
    b) Need for Transport.
    c) Valuation of Travel Time Savings.
    d) Demand Elasticities.
4. Direct Cost of Transport.
    a) Supply of Transport.
    b) Fixed and Variable Costs.
    c) Specific, Joint, and Common Costs.
    d) Problems of Common Cost Allocation.
    e) Transport User Costs.
    f) Resource Costs.
5. Economics of Transport Pricing.
    a) Economic Structure of Transport.
    b) Theory of Pricing and Price Elasticity.
    c) Theory of Pricing of Transport.
    d) General Level of Rates.
    e) Rate Making in Practice.
    f) Peak-Load Pricing.
6. Industry Study.
    a) Economics of Urban Transport (Including Environmental and Health Care Costs).
    b) Economics of Air Transportation.
    c) Economics of Highway Trucking.
    d) Economics of Railroad Transportation.
    e) Economics of Shipping.
    f) Economics of Pipeline Transportation.
7. Development and Transportation.
    a) Transport Patterns.
    b) Transport Means.
    c) Transport Policies.
    d) Conclusions and Policy Implication.

P.1. Introduction to Transport Planning

1. Transportation Planning Within the Context of National Planning.
    a) Energy Costs of Transport Modes.
2. Role of Transportation in Economic Development.
3. Relationship Between the Transport System and the Environment.
4. Concepts of Mobility, Accessibility, Congestion, and Free Movement of People and Freight.
5. Transport Modes and Networks.
    a) Roles of Traditional Modes (e.g., carts and bicycles).
6. Urban Transport Planning.
    a) Trip Generation, Distribution, Modal Split, and Assignment.
    b) Alternate Approaches and Community Involvement.
    c) Standard Computer Packages.
7. Freight Transportation Issues.
8. Rural Transportation Problems.
    a) Mobility of the Rural Poor.
    b) Network Connectivity.
    c) Traditional Transport Modes.
9. Intercity Transportation.
    a) Properties of Transport Modes.
    b) Demand Estimation and Forecasting.
    c) Assessment of Supply.
10. Feasibility Studies for Highways and Other Transport Systems.

P.2. Urban Transport Planning

1. Introduction to Urban Transport Planning.
    a) History of Urban Transport Planning.
    b) Areas of Urban Transport Planning.
    c) Elements of Urban Transportation Planning.
2. Assessment of Need and Impact Studies.
    a) Assessment and Ranking of Transportation Projects.
    b) Selection of Appropriate Solutions.
    c) Impact Evaluation.
3. Demand and Supply Analysis of Urban Transportation.
    a) Demand Theories.
    b) Supply Analysis.
    c) Introduction to Methods of Demand Analysis and Forecasting.
4. Data Collection.
    a) Methods of Data Collection.
    b) Process of Data Collection.
5. Process of Urban Transport Planning and Some Case Studies.
    a) Problem Definition (Examination of Some Classical Problems).
    b) Solution Generation.
    c) Solution Formulation.
    d) Evaluation of Alternatives, Choice, and Policymaking.
    e) Citizen Participation.
    f) Implementation.

P.3. Freight Transportation

1. Introduction to Freight Transportation.
   a) Description of Current Status by Mode for Urban, Intercity, and Rural Transport.
   b) Role in the Economy and Relationship to GNP.
   c) Containerization.
2. Urban Freight Transportation.
   a) Operating Costs, Facility Costs, and the Warehouse Location Problem.
   b) Traffic Effects of Urban Freight Vehicles.
   c) Loading and Unloading Facilities.
3. Intercity Freight Transportation.
   a) Economics of Freight Transport.
   b) Prediction of Flows.
   c) Freight Transport by Highways.
   d) Freight Transport by Railways and Unit-Trains, and Problems of Access.
   e) Water Transport.
   f) Pipelines.
4. Rural Freight Transportation.
   a) Joint Passenger-Freight Transport.
   b) Transport of Produce to Markets and Processing Centers.
   c) Animals and Portage.
5. Other Issues.
   a) Air Cargo.
   b) Ocean Freight.

E.1. Introduction to Transport Facilities Design

1. Design of Urban Streets, Sidewalks, and Bicycle Lanes.
   a) Networks.
   b) Typical Cross Sections.
   c) Pedestrian Crossings (At-, Above-, and Subgrade).
2. Highway Design.
   a) Horizontal and Vertical Curvature.
   b) Superelevation and Sight Distance.
   c) Signing.
   d) Standards.
3. Pavement Design.
   a) Urban Streets.
   b) Highways.
   c) Types of Pavements and Shoulders.
   d) Standard Design Procedures.
4. Airports.
   a) Airport Locations.
   b) Runway Orientation and Design.
   c) Runway Pavements.
   d) Taxiways and Aprons.
   e) Design of Marking and Lighting Systems.
5. Introduction to Railway Design.
6. Introduction to the Layout of Ports.

E.2. Geometric Design of Highways and Railways

1. Introduction.
   a) Overview of Planning Process.
   b) Location of Links and Route Layout.
   c) The Highway as a Multiple User Facility (Automobiles, Trucks, Bicycles, and Pedestrians).
2. Design Control Criteria.
   a) Data Gathering.
   b) Traffic Volumes.
3. Capacity.
   a) Width of Roadway and Sidewalks.
   b) Highway Intersection Capacity.
   c) Railroad and Transit Guideway Tracks.
4. Horizontal Alignment of Highways and Railways.
   a) Circular Curves.
   b) Superelevation.
   c) Spiral and Transition Curves.
5. Vertical Alignment of Highways and Railways.
   a) Vertical Curves (Crest and Sag).
   b) Passing Sight Distance.
   c) Stopping Sight Distance.
6. Cross-Sectional Elements of Highways.
   a) Right of Way.
   b) Parking Lanes, Bicycle Lanes, Shoulders, and Sidewalks.
   c) Pavement Crown and Slope.
   d) Guardrails.
   e) Curbs, Gutters, and Drainage Ditches.
7. Intersections.
   a) Channelized Intersections.
   b) Rotary Intersections.
   c) Grade-Separated Intersections.
   d) Railway Crossings.
8. Drainage.
   a) Surface Run-Off.
   b) Rain Fail Intensity and Coefficient of Run-Off.
   c) Culverts and Drainage Channels.

E.3. Pavement Design of Highways

1. Pavement types, Wheel Loads, and Design Factors.
2. Stresses in Flexible Pavements.
3. Vehicle and Traffic Consideration.
4. Climate and Environment.
   a) Effect of Water in Pavement.
5. Material Characterization.
6. Subgrade.
7. Bases.
8. Bituminous Surfaces.
   a) Surface Types and Thickness Requirements.
9. Design of Flexible Airport Pavements.
   a) CBR, FAA, and Asphalt Institute Methods.
10. Design of Flexible Highway Pavements.
11. Pavement Evaluation.
    a) Present Serviceability Index and Skid Resistance.
12. Highway Rehabilitation.
13. Equipment Used in Highway Construction.

F.1. Introduction to Transport Operations

1. Highway Traffic.
   a) Reasons for Congestion.
   b) Wardrop's Principles of Highway Traffic Assignment.

c) Methods of Traffic Control
d) Mobility, Accessibility, Congestion, and Environmental Impact.
2. Traffic Management in Small Towns
3. Basic Principles of Traffic Signalization.
4. Operations of Urban Bus Systems.
a) Types of Service.
b) Routing and Transfers.
c) Scheduling.
d) Location of Stops.
5. Urban Rail Services.
a) Trams.
b) Light-Rail Transit.
c) Metro Rails.
d) Feeder Bus Systems.
6. Safety Management and Accident Analysis.
a) Collection of Accident Data.
b) Sorting and Analysis of Data.
c) Identification of Blackspots.
d) Identification and Selection of Countermeasures.
e) Implementation and Monitoring.
f) Safety Management.
7. Management of Pedestrian Travel.
a) Significance of Pedestrian Travel and the Need for Pedestrian Studies.
b) Need for Information and Methods of Information Acquisition.
c) Pedestrian Corridor Analysis.
d) Methods of Forecasting Pedestrian Demand.
e) Pedestrian Safety Needs.
f) Incorporation of Pedestrian Plans into Overall Transportation Plans.

F.2. Traffic Engineering

1. Traffic Flow Theory.
a) Speed, Density, and Flow Relationships at Micro and Macro Levels.
b) Measurements and Probability Distributions.
c) Analysis of Traffic Shock Waves and Delay Calculations.
2. Traffic Surveys and Analysis.
a) Traffic Surveys, Survey Methods, Sampling, Home Interviews, and Questionnaire Survey procedures.
3. Traffic Control Systems.
a) Major/Minor Priority Intersection Design Methods and Capacity Determination.
b) Capacity of Intersection with Roundabouts (Conventional, Small, and Mini), Design, and Warrants for Roundabouts.
c) Capacity and Warrants for Undersaturated Intersections, with Signals, Phasing, Cycle Time, Green-Red Split, and Vehicle-Actuated Signals.
d) Coordinated Signal Systems, Area Traffic Control.
e) Signalization at Saturated Intersections.
4. Parking.
a) Parking Surveys, Characteristics, Generation, Parking Methods, Location, and Standards.
5. Traffic Management.
a) One-Way Streets, Turning Traffic, Clearways, Tidal Flow, Pedestrian Management, Segregation Methods, and Public Transport Priority Methods.
6. The Road User, the Vehicle, and the Road.
a) Physiological Factors Influencing Behavior of Road User.
b) Visibility, Lighting, and Braking Characteristics of Vehicles.
7. Street Lighting, Signs and Markings.

F.3. Public Transport Operations

1. Introduction.
2. Transit Technology.
3. Dispatching Policy.
a) Capacity, Round-Trip Time.
b) Headway.
c) Fleet Size.
4. Scheduling.
a) Schedule Writing.
b) Vehicle Assignment.
c) Run Cutting.
d) Crew Assignment.
5. Stop Spacing and Location.
a) Stop Categories.
b) Spacing and Locations.
c) Pedestrian Access and Other Considerations.
6. Terminals.
a) Terminal Types.
b) Sizing Terminal Facilities.
c) Parking.
d) Access Roads.
7. Service Monitoring and Control.
a) Service Data Required and Surveys.
b) Performance Indicators.
c) Reliability.
d) Route Control Strategies.
8. Routes and Networks.
9. Fare System and Collection.
10. Transit Policies.

CONCLUDING REMARKS AND SUMMARY

In order to break out from the vicious cycle of underdevelopment, the developing countries essentially have to be helped to be self-sufficient. In some cases, poorly designed foreign aid packages can make a country lose its internal strengths and become even more dependent.

The appropriate and cost-effective way to train the necessary human resources required in TE&P is to encourage developing countries to set up their own postgraduate programs by training the academic staff and equipping laboratories. In the case of SDCs, a single program may be sufficient. Although specialization in some aspects of transportation is desirable, a general understanding of the basic principles underlying the three major areas of planning, design and operations is required of all professionals. A postgraduate master's level program can be offered with three full-time staff or with a minimum of two supported by visiting lecturers. The target pool of students should not be restricted to those with a bachelor's degree in engineering.

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Training Needs for Civil Engineers: A University Perspective

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The new technologies and new problems of the past 25 years have caused changes in engineering practice. Changes in engineering education have not kept pace with the changes in practice, which has created a demand for more training of professionals. Skills where the demand appears to be greatest are in the areas of written communication, project management, and computer-aided practice. At the present time, the profession does not have an organized framework to ensure that high-quality training is available. Therefore, the profession needs to adopt some standards and develop guidelines for training to ensure that the needs of the profession are met. One path to improved training would be to make better use of the new technology of instructional television. The profession should also ensure that training involves education, not just skill enhancement.

In order to properly address the training needs for engineers, it is important to define and distinguish between the terms education and training. Education, as used herein, is the process of imparting knowledge, where knowledge is the sum of what has been perceived, discovered, or inferred (*1*). The word "education" will be used herein most often when referring to formal instruction in an institution of higher education.

Training herein means the specialized instruction that includes problem solving for the purpose of making the participants proficient at a specific skill. Use of the word "training" usually infers that the instruction deals with a limited aspect of a broad topic. For example, training on the use of a computer package would instruct the audience on the way to get data into the computer and where to find results on the computer output; it would not include a thorough discussion of the concepts and underlying assumptions behind the computer program.

When discussing training needs for engineers, there are several important questions that need to be addressed. Why has the need for training increased in recent decades? Is current civil engineering (CE) education relevant to the needs of engineering practice? What skills of recent engineering graduates are the most deficient? What proportion of training sessions sponsored by industry should be education oriented rather than just skill enhancement? How can advances in technology improve training effectiveness and efficiency?

EFFECT OF CHANGES IN EDUCATION AND PRACTICE ON TRAINING DEMAND

CE practice has changed considerably in the last 25 years. Problems must now be addressed that the engineers of the previous generation did not have to contend with. Although hazardous wastes existed, the problems associated with them were not understood, so abating them was not a standard part of practice. The hydrologic effects of urbanization were just beginning to be recognized, but stormwater management was not a primary design responsibility of the engineer as it is today. We now have many safety and public health regulations that significantly affect engineering practice. New technologies have created new demands. Computer-aided design is one example. Hydrologic modeling capabilities have improved, greatly influencing engineering practice. Projects such as shopping malls are much bigger now than they were 25 years ago. These changes to engineering practice have made it necessary for the practicing engineer to have greater knowledge and improved skills.

How has engineering education changed to fill this need? The academic course load has not increased in the last 25 years; in fact, the number of credit hours required for graduation may have decreased. Program specialization is one of the major changes to the CE curriculum. In the 1950s and 1960s, all CE students had the same course requirements for graduation; for example, the author had only one technical elective. The CE students of 1990 have a senior year that is almost all electives, and they must elect a technical specialty within CE, e.g., structures, transportation, or hydrology; when the author was an undergraduate, it was not possible to select a major within CE.

The increase in specialization that characterizes current CE curricula has not kept pace with the increase in knowledge and skill needs associated with the changes in engineering practice. Engineering education has improved, but it has not been able to keep pace with demands. The inability of education to keep pace with the increasing need means that, until changes are made to CE education, the demand for postbaccalaureate training will increase significantly.

IS CE EDUCATION RELEVANT?

Over the past 25 years, criticism of CE education has increased. CE practitioners argue that CE education is becoming too research oriented, while losing the desired orientation towards practice. They point towards a research-oriented faculty and a system that rewards research, not the teaching of engineering design. There is some validity to the practitioner's concern.

In response to this criticism, the faculty argue that a primary goal of CE education is the development of problem-solving skills. The problems 25 years into the future will be different

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from the current problems and the classes of the 1990s will need to be able to solve the future problems, not just design for the conditions of the 1990s.

Faculty also argue that society has a larger goal beyond the development of design practitioners. Specifically, they cite research funds provided by institutions such as the National Science Foundation, which are unmatched by the design community. They argue that research is necessary to keep pace with the ever-changing problems and for the United States to maintain economic competitiveness in the global economy of the 21st century.

Just as the practitioner's express some valid concerns, the educators also make valid points.

What does this debate imply for the demand for training? Unless the drastically uneven balance of payments can be changed, it appears that CE education will continue to be research oriented, at least into the early part of the 21st century. Thus, the demand for practice-oriented training is going to increase. Instead of the CE industry putting their resources into the educational system, they will support a training industry. This has several advantages. First, the training will be ready on demand to meet immediate needs. Second, the training can be oriented towards a specific need. Third, it will be less costly. The small firm will be capable of actively participating in the training activities; a large resource base will not be necessary to stay abreast of current practice requirements. In general, the CE practitioners will have greater control over their profession. The educational institutions will provide a pool of educated employees, with industry responsible for meeting the direct training needs for practice.

SKILLS REQUIRING INCREASED EMPHASIS

Water resource educators and practitioners were questioned about skills that need greater emphasis in higher education (*2*). An open-ended question produced four clear needs. Specifically, the respondents listed communication skills, computers and modeling, statistics, and management as the areas requiring increased emphasis (see Table 1). Educators responded to these skill needs with different proportions than practitioners, but these skills were the dominant ones mentioned. Practitioners emphasized communication management and skills whereas educators put greater emphasis on using computers and modeling. Practitioners identified project management, project planning, leadership and motivation, and ethics as the management skills needing greater emphasis.

Recent pressure from the Accreditation Board for Engineering and Technology (ABET) for CE programs to include a capstone course may cause improvements in the abilities of graduates in project management and project planning. Many programs are incorporating ethics into CE curricula, which should help meet this need identified by water resource practitioners.

COMMUNICATION SKILLS

What is the greatest deficiency of engineering graduates? A strong argument can be made for communication skills. A study by Kimel and Monsees (*3*) indicated that CE practitioners believed that it was the most important expertise in CE practice, but it was, by far, their most deficient skill. As Table 2 indicates, approximately 60 percent of the respondents rated communication skills as being important but 65 percent indicated that recent CE graduates had inferior communication skills.

Davis (*4,5*) conducted a study to determine how much time prominent engineers spend either writing or working with materials that others have written, how important it is in their positions, and how important the ability to write effectively might be to someone who was being considered for advancement. The results of a questionnaire that was completed by 245 prominent engineers indicated that they spent an average of 24 percent of their time writing and 31 percent of their time working directly with material that others have written. Furthermore, the respondents believe that the writing they do is important, often critical, to their positions and that young engineers are often deficient in their ability to communicate on paper.

The ASCE study (*2*) agreed with the findings of Kimel and Monsees (*3*). As indicated in Table 3, report writing and oral communication received some of the poorer ratings on the educational preparedness of recent B.S. graduates. Table 4 presents the writing skills required in engineering practice.

TABLE 1 INCREASED EMPHASIS REQUIRED

Response	Percent of Respondents (%) Educators	Practitioners
Communication skills	18	27
Computers and modeling	27	11
Statistics	16	5
Management	7	13
Hydrogeology and ground water	4	9
Water resources courses	29	16
Other science courses	15	11
Other nonscience courses	20	25
Techniques and design	35	15

Note: Responses below the broken line are combinations of responses into broad categories.

TABLE 2 CAPABILITIES OF RECENT CE GRADUATES (3)

Importance to Civil Engineer Practice			Area of Competence	Capability of Recent C.E. Graduates (1-5 years)		
Most Imp.	Impor-tant	Less Imp.		Super-ior	Ade-quate	Infer-ior
137	86	9	Writing and speaking	7	69	142
106	127	9	Structural analysis and design	25	160	28
72	156	13	Soil mechanics and foundation	9	157	46
62	125	47	Water and waste-water treatment	13	144	27
55	131	38	Fluid mechanics, hydraulics, hydrology	10	136	42
53	153	32	Computer and numerical methods	42	139	30
50	132	49	Economics, finance	4	96	106
47	147	54	Construction methods and equipment	9	107	95
46	105	70	Law, labor, management	4	81	120
20	148	67	Surveying and measurement	4	139	65
19	110	92	Transportation, highways, traffic	5	161	30
14	124	51	Materials	6	153	35
13	85	132	Social sciences and humanities	12	137	53

TABLE 3 EVALUATION OF EDUCATION PREPAREDNESS OF RECENT BACHELOR DEGREE GRADUATES BY DISCIPLINE

	Mean Response[a]		Percent Inadequate	
Discipline	Educator	Practitioner	Educator	Practitioner
(a) Engineering and Science				
Structures	1.13	1.43	1.6	7.2
Soil mechanics	1.19	1.62	9.8	3.8
Physics	1.22	1.29	2.4	2.6
Mathematics	1.26	1.20	1.0	4.2
Surveying	1.32	1.75	19.1	6.2
Chemistry	1.40	1.40	5.0	5.2
Computer Science	1.43	1.43	5.7	5.7
Thermodynamics	1.47	1.57	14.3	9.7
Electrical circuits	1.52	1.64	17.5	10.9
Engineering drawing	1.56	1.85	26.7	12.5
Statistics	1.88	1.76	14.4	23.2
Biology	2.07	1.62	27.0	40.1
Mean	1.45	1.55	-	-
(b) Water				
Fluid mechanics	1.14	1.64	5.1	2.6
Hydrology	1.32	1.59	13.8	4.7
Environmental	1.33	1.64	10.8	4.2
Water resources	1.40	1.59	6.9	4.8
Mean	1.30	1.62	-	-
(c) General				
Economics/finance	1.65	2.14	33.5	9.5
Social	1.93	2.00	26.4	25.0
Report writing	2.05	2.48	42.4	27.5
Oral communication	2.11	2.44	43.8	30.0
Contracts/legal	2.21	2.27	47.2	38.9
Mean	1.99	2.27	-	-

[a]Scale: 1 = Sufficient, 2 = Marginal, and 3 = Inadequate

TABLE 4 EMPHASIS NEEDED IN TECHNICAL WRITING SKILLS

Skill	Average Response[a] Educators	Practitioners
Clarity of thought	1.1	1.1
Report organization	1.6	1.7
Grammar and syntax	1.9	2.0
Sentence structure	1.9	2.0
Vocabulary and spelling	2.0	2.1
Rewriting of drafts	2.2	2.5
Use of visual aids	2.3	2.5
Writing for nontechnical audiences	2.4	2.2
Letters and memos	2.6	2.4

[a]Based upon scale of 1 (essential) to 5 (unimportant).

What messages do the findings of Kimel and Monsees, the ASCE committee, and Davis convey?

First, there wasn't much improvement in the decade between the studies by Davis (*4,5*) and Kimel and Monsees (*3*) and that by the ASCE (*2*). Engineering schools may not have the resources to improve the situation. Given high enrollments in engineering programs and the even greater national need to increase the number of engineering graduates, it is unlikely that the situation will improve during this decade. Improving writing skills is labor-intensive and requires skills that engineering faculty often lack, especially when English is often not the native language of many of the faculty. Also, there is a hesitancy to bring English faculty into the engineering curriculum to meet this need.

Second, the capability for computer-aided grading of written reports needs to be developed. This procedure would reduce the resource requirements by reducing the need for engineering faculty to correct spelling, grammar, and syntax. Instead, they could concentrate on helping students improve their ability to organize a report and express technical ideas in a clear way.

Third, the viewpoint of students on the issue of writing must be changed. In a survey of students, McCuen and Berman (*6*) found that 43 percent indicated that most students would object to a technical writing course requirement. Many respondants indicated an objection because of the heavy load of required courses in their program. Contrary to the results of the questionnaires distributed to educators and practitioners, most students believe that basic grammar, syntax, and sentence structure was not a major problem. Most students may believe that technical writing training should concentrate on library searches and the process of putting together the final document. Thus, it would be difficult for a technical writing program to be effective until the students are made aware of their deficiency in basic writing skills.

Fourth, industry must gear up for training in technical communication. Industry cannot rely on higher education to fulfill this need. Communication needs and formats differ considerably from company to company and from locality to locality. Thus, training needs will be company-specific and they need to develop training programs that meet these specific needs.

EDUCATIONAL PHILOSOPHY AND TRAINING NEEDS

Two questions in the ASCE survey addressed the issue of the philosophy of water resources education. Specifically, the questions sought the level of emphasis that should be placed on (a) facts and principles; (b) critical thinking, analysis, and problem solving; and (c) ethical, social, and moral values. Table 5 presents a comparison of the current emphasis and the perception of what would represent proper emphasis by both educators and practitioners. Both educators and practitioners believe that the current educational process does not place proper emphasis on the three categories. Both of the groups believe that more emphasis should be placed on Categories 2 and 3 than is currently done, with facts and principles receiving less emphasis than it currently receives.

How would a shift in emphasis affect the need for training of graduates? If problem solving is interpreted as the solution of practice-oriented problems, then the shift of an educational philosophy towards Category 2 would reduce the need for postdegree training. The decision, of course, is to identify facts and principles that can be sacrificed to provide greater emphasis on problem solving.

PROFESSIONAL CONTROL OF TRAINING

It appears that training needs will increase dramatically in the next decade. As the diversity in problems increases and as the societal importance of these problems exhibits a corresponding increase, the demand for training will also increase. But the profession has a problem. Although there is some quality control in the academic community, there is an almost complete lack of quality control in training. There are some good short courses, but many are ineffective. In order for training to better serve the profession, it is important for the profession to take the steps that are necessary to ensure that training is more effective than it currently is. This is not necessarily a call for a bureaucracy within the training commu-

TABLE 5 CURRENT AND PROPER EMPHASIS IN UNDERGRADUATE EDUCATION

	PERCENT OF CURRICULA			
	Current Emphasis		Proper Emphasis	
Area	Educators	Practitioners	Educators	Practitioners
Facts and principles	54	63	46	47
Critical thinking, analysis, and problem solving	37	28	42	37
Ethical, social, and moral values	9	9	13	15

nity, but for the adoption of some standards and guidelines to ensure that the needs of the profession are met.

This call for improved quality control in training must take into account the variation in regional problems. Irrigation is important in some areas, but not in others. Snowmelt flooding is important in some areas, but not in others. Wetland preservation is important in some areas, but not in others. Design methods also exhibit regional variations. Some areas use Soil Conservation Service hydrologic methods; other regions use the rational method, whereas others use locally calibrated models. This diversity creates regional training needs and thus the need for regional quality control of training.

Although there are regional needs, there are some national solutions. There exists a national instructional television (ITV) system that is currently underused for training. Training programs could be presented on the ITV system so that the best training is available nationally. The ITV solution has the added advantage that greater quality control would be possible. It would be easier to develop more uniform criteria for relating continuing education units (CEU) to the content and level of effort required if the training process were handled through a national organization like the ITV system. The ITV system can meet both national and local needs, so it would be possible to include training for localized problems and local design methods.

If it becomes more common to use CEUs as a criterion for professional registration, then the demand for training will increase and the need for improved quality control will be much greater. It will no longer be proper for a company to send one employee to a short course, with the others left to learn by on-the-job training by the employee who attended.

ETHICAL CONCERNS IN TRAINING

The author is frequently asked to offer short courses on computer packages such as the SCS TR–20 flood hydrograph program and the HEC–2 water surface profile program. Employers requesting the training want instruction for their employees on the proper format for the input. When employers are asked whether or not the employees understand the hydrology or hydraulics that forms the basis of the computer package, they exhibit a lack of concern for instruction on the knowledge base of the program. This raises an ethical question: Is it proper for software training to be devoid of the conceptual basis of the method? The user's manuals for the software rarely provide educational material on the underlying methods, so if it is not presented as part of the training, then the employees will be left to apply the method without an adequate understanding of what they are using.

Training is frequently used to instruct nonengineers in the use of computer tools for engineering design. Frequently, the largest portion of those in the short courses that the author teaches does not have an engineering baccalaureate degree; degrees in environmental science, geology, and zoology predominate, with little exposure to engineering hydrology and almost no education in hydraulics. Yet those with nonengineering degrees are performing functions that have, in the past, been performed by individuals having engineering degrees.

CONCLUSIONS

Societal problems that require technical input during the solution have increased both in number and in complexity. Given that higher education does not have the resources or support to expand to fill this need, the profession will have to expand its capacity for training. In the past, there has been little quality control of training programs and no professionally sponsored organization responsible for oversight of training. This must change if the training needs of the profession are to be met.

The following are some specific conclusions based on the discussion herein:

1. There is a critical need for oversight responsibility of training, including the development of criteria to assess training quality and guidelines for the development of training programs.
2. Formal educational programs are not expanding to meet the need for training, thus the practitioners will have to act to meet the demand.
3. Specialization in educational programs has not kept pace with the increase in the complexity of engineering problems, which will increase the demand for training.
4. Engineering education has become more research oriented and less practice oriented, which is increasing the demand for training.
5. There is a need to make greater use of new technology, such as ITV, to improve both the availability and quality of training.
6. Training in communication skills appears to be the greatest need, followed by project management, computers and modeling, and statistics.
7. Training should include knowledge development, not just skill enhancement.

It is worthwhile mentioning some of the recommendation made in the ASCE (*6*) report:

1. A forum should be developed to provide a systematic means of collecting and organizing the ideas of practitioners and transmitting these ideas to the academic community.
2. Practitioners should be involved in practice-oriented instruction at both undergraduate and graduate levels by developing case study material, serving as consultants to students, and providing resource material.
3. Formal education beyond the bachelor degree should be required for initial professional engineering registration.
4. Continuing education or professional society activity should be required for renewal of professional registration.
5. Necessary adjustments should be made so that those in practice can be more involved in continuing their education and training.
6. Those in practice should be assigned lighter work loads while they are actively and successfully pursuing advanced degrees or continuing education programs.
7. Universities should be attentive to the needs and desires of part-time students in planning and scheduling graduate courses and other forms of continuing education.

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Toward a Balanced Transportation Research Program

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National interest in transportation research is increasing. The advancement of U.S. transportation technology and expertise is one of the six major themes of the U.S. Department of Transportation policy plan published in February 1990. Research is cited as a strategy for maintaining a competitive economy and for meeting social goals. This belief is becoming widespread at the state level also, as transportation problems such as traffic congestion become more critical. However, there are challenges in developing transportation research programs to meet these needs. First, transportation is a broad field with many constituencies; there is disagreement over what type of research is most urgent. Second, consensus on the value and purpose of research is often lacking, particularly regarding the differences over basic versus applied research. These two challenges to developing transportation research programs are serious, at times causing disunity among parties who should have common interests. In Minnesota, the University of Minnesota Center for Transportation Studies has worked to develop a balanced transportation research program through a strategic planning process that is highly participatory. In this paper, the processes used are described, results are evaluated, and plans for the future are presented. Conclusions from the Minnesota experience that could be applied in the development of a national transportation research program are also presented.

There is a renewed national interest in transportation research. The national transportation policy issued by the U.S. Department of Transportation (DOT) Secretary Samuel Skinner in February 1990 has as one of its six major policy agenda themes "the advancement of U.S. transportation technology and expertise for the 21st century" (*1*). The U.S. DOT feels that the United States must strengthen its focus on technology and innovation to improve its transportation systems and to maintain technological leadership in the world. Research on several issues is proposed, such as human factors, information technology, financing techniques, environmental protection, high-speed and magnetic levitation rail systems, intelligent vehicle and highway systems, and design safety. Emphasis is also placed on disseminating information and research results and improving transportation education. DOT plans to expand its efforts to ensure that the U.S. transportation community is aware of and has access to emerging technological advances.

This new policy direction was fueled by several previous studies. TRB has long called for increased research, citing a decline in federal research funding for all transportation modes from more than $1 billion in 1980 to an estimated $750 million in 1987 (adjusted for inflation) (*2*). This decline happened during a period when federal research funding for defense and public health was increasing. Compared with private industry research, transportation research funding also looks weak. High-technology businesses spend 7 percent of sales on research; other firms with research budgets of $1 million or more spend 3.5 percent of sales. In comparison, federally funded research for transportation accounts for less than 1 percent of total expenses.

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At the national level, there is also increased awareness of transportation research underway in Europe and Japan, particularly in the area of intelligent vehicle and highway systems. By failing to keep pace with these research advances, the United States loses an opportunity to develop private-sector leadership in a high-technology field and also falls behind in the implementation of transportation innovations. The research efforts in Europe and Japan are impressive, involving large collaborative efforts among academia, government, and the private sector (*3*).

This renewal of interest in research is also taking place at the state level. AASHTO has sponsored several studies by its Standing Committee on Research that outline future research directions for state DOTs. A report published in January 1990 presents the results of a detailed questionnaire completed by state transportation agencies, indicating a strong desire for increases in transportation research (*4*).

CHALLENGES TO DEVELOPING TRANSPORTATION RESEARCH PROGRAMS

Although there seems to be consensus that increased transportation research is needed, agreement regarding the type and purpose of the research is lacking.

Engineering Versus Planning and Policy Research

There is often debate between those who believe more policy-oriented research is needed versus those who desire more technological research. Transportation is a complex field, with many constituencies. As transportation problems grow, so do these constituencies. The problem of urban traffic congestion, for example, has increased the number of citizen groups, planners, and elected officials involved in the transportation debate. These groups believe that engineering solutions alone cannot solve the growing problems. They call for new methods of designing transportation systems that are integrated with land use and environmental planning and that also support social and economic goals. They would like increased policy and planning research to investigate new solutions.

On the other hand, engineering professionals point to the critical stage our infrastructure has reached, with investments in bridges, pavements, and other public works in danger of being lost. They call for increased research in materials, engineering design practices, traffic management, and so on. They see tremendous opportunities in applying technological advances to transportation problems.

This debate is not simple. There are certainly those in the engineering community who want policy research and those in the planning community who value infrastructure research. But in times of scarce resources, if often appears that sides are drawn. One discipline has difficulty understanding the value of another discipline's arguments.

In Minnesota, the largest transportation research efforts have been conducted or funded by the Minnesota DOT (Mn/DOT). These efforts have traditionally focused on what is called the "hard" side of research—materials, pavement, structures, etc. There is growing interest, however, by the state legislature and communities for "soft" research—on alternative transportation systems for congested urban areas and the relationship of transportation to the rural economy. The challenges lie in deciding how to allocate research funds to these various interests.

Basic Versus Applied Research

Another issue that is often debated when choosing research to fund concerns basic research versus applied research. Basic research deals more with discovery and theory, whereas applied research develops new methods (often based on the results of basic research) to address specific problems. Which has more value? How should funding be used for each? What should be the sources of funding for each?

Charles Fairhurst, former head of the Civil and Mineral Engineering Department at the University of Minnesota, has pointed out that university departments of civil engineering today emphasize one of two approaches in their teaching and research (*5*):

1. A modern approach, emphasizing laboratory experiments and mathematical analysis, and the development of computer and analytical or numerical approaches suitable for future applications (a basic research approach).
2. The traditional empirical approach, emphasizing case histories and collection of field data, heavily oriented towards design and consulting problems (an applied research approach).

Fairhurst states that ideally both approaches should be pursued, as they are in other fields. For example, basic research in a university electrical engineering department is complemented by applied research in private sector R&D laboratories; basic research in a medical school is closely tied with applied research in a university hospital; and basic research in agriculture is tested through applied extension programs.

However, university civil engineering departments have few opportunities to work with an applied research organization. If they choose the modern research approach, their theoretical work is restricted by the lack of adequate physical verification. If they choose the empirical approach, the lack of fundamental basis for their designs limits the applications. They cannot do both approaches themselves because of limited resources.

Civil engineering faculty are most likely to be judged within their university (in promotion and tenure review, for example) on the basis of their performance in basic research—the primary emphasis of their colleagues in other university disciplines. Officials and practitioners in public agencies, because of limited applied research groups to consult, are more likely to press faculty for quick answers to urgent problems. If the faculty member tries to do both basic and applied research, usually neither group is satisfied.

The situation described earlier for civil engineering also applies to the other disciplines that conduct transportation research—economics, public policy, urban planning, etc. Most transportation research results are applied in the public sector. Few private sector research laboratories are involved, and rarely are special organizations, such as agricultural experimental stations, established to test basic research results before they are implemented.

The result of this situation is a lack of understanding by both academicians and practitioners about the needs and purposes for transportation research. Public sector practitioners are often desperate for help from the university to develop and apply new techniques that solve immediate problems. They may not appreciate the value of the theoretical work the academicians would like funded. The academicians at times think the practitioners are short-sighted in defining their research needs. They have little interest in pursuing the agency's applied projects, because they will not enhance their academic careers.

In Minnesota, these issues arise during transportation research discussions between Mn/DOT and the University of Minnesota. They also arise in other state efforts. In the past year, a study by the Stanford Research Institute (SRI) proposed the creation of a new urban university in the Twin Cities that would be more closely tied to the community through applied research and teaching. Some people hailed this proposal, saying that a new institution could provide services that the University of Minnesota does not. This produced counterarguments, particularly related to the role the University plays (*6*). Some felt the SRI suggestion implied that the basic scholarship in research universities is less relevant to the community.

The fear often present in these debates, as in transportation research debates, is that resources targeted for one (basic or applied research) will be used for the other.

Risks of Conflict

The debates described earlier can present serious challenges to developing transportation research programs. A certain amount of conflict can be healthy, sharpening the issues and leading towards a constructive consensus. However, conflicts that turn destructive can lead to a situation where neither side wins.

At both the federal and state level, funding decisions encounter growing pressure and competition, as there are many other serious problems to address besides transportation: education, health, economic development, the environment, etc. There is also the growing national deficit, which has caused some decision makers to look at traditional transportation funding—the gas tax—as a deficit reduction method. Even though interest in transportation research is increasing, it faces serious competition in attracting needed funding.

Most of the transportation research funding will result from decisions by elected officials who are sensitive to disagreements among constituencies. If transportation groups are in conflict over the types of research needed, they risk being ignored in the competition for funding. The elected officials instead may turn to funding requests by interest groups that are united and well coordinated, which are much easier for them to deal with. If a balance can be developed and communicated to decision makers that is satisfactory to all transportation interests—between engineering and policy research and between basic and applied research—efforts to increase state and federal research funds stand a much better chance for success.

CURRENT APPROACHES

AASHTO Survey

The AASHTO report providing the results of research questionnaires (*4*) reveals how one key constituency views the future needs for transportation research. State DOTs are clearly in favor of engineering and applied research.

In terms of engineering versus policy research, AASHTO members are strongly biased towards engineering. The subject areas preferred were infrastructure, highway safety, new materials, highway congestion, and computer technology. Support for policy research such as long-range strategic research, economic analysis, and regulatory issues was low. When asked how they would use increased funding for research, they said they would increase state research funds by 50 percent, FHWA demonstrations by 26 percent, Strategic Highway Research Program (SHRP) by 17 percent, and National Cooperative Highway Research Program (NCHRP) by 13 percent.

AASHTO favored applied research over basic research by a wide margin. "Applied research on state and regional problems" received the highest rating, and implementation, technology transfer, and contract research were also highly rated. Fundamental research was rated number 15 out of 17 items, while university support ranked number 12. No increase in funding for university research was desired, whereas increases of 20 to 60 percent were desired for the five top-rated research activities.

SHRP, NCHRP, and UTCP Research Programs

Two of the traditional programs that AASHTO wishes to be increased—SHRP and NCHRP—are primarily applied research programs that focus largely on engineering problems. SHRP is "a time-specific, concentrated, short-term, and results-oriented research effort" (*7*). It focuses on engineering research, with heavy emphasis on pavement, structures, and highway maintenance research. NCHRP is "a unique, applied research program designed to respond to the needs of state highway and transportation departments" (*8*). The problems are "specifically defined and limited in scope." Although these problems include policy, planning, and administrative issues, the majority of the research is directed towards engineering problems.

The processes used for soliciting and selecting SHRP and NCHRP projects somewhat naturally encourage applied research. Problem statements are defined primarily by users. Research plans must follow prescribed methodologies, and proposals are selected using a ballot process conducted by user panels.

Both SHRP and NCHRP emphasize solving a problem, not discovering a theory or new technology that might ultimately be applied to several problems. Academic proposers, unless they have been actively involved on NCHRP panels and in TRB, are omitted from two of the critical research steps that they take most pride in: defining the problem and developing the methodology, In contrast, the National Science Foundation (NSF) is much more supportive of basic research, and does not constrain proposers in what problems they address nor in how they address them. The SHRP IDEA program was established to have some of these characteristics, accepting innovative proposals generated by researchers outside the request-for-proposal process. However, these proposals are still encouraged to address applied rather than basic research problems. One consequence of the applied nature of the SHRP and NCHRP programs is that consultants perform much of the research.

In the last 2 years, a third transportation research program has begun that specifically involves universities, the University Transportation Center Program (UTCP). This program was initiated by universities working with the congressional delegation, with little federal or state DOT involvement. This is reflected in the low ranking the AASHTO report (*4*) gave the UTCP program; it ranks last in priorities for research funding increases. This program is new and needs time to demonstrate its value. The new U.S. DOT administration has now actively begun to shape the UTCP to serve the goals of the U.S. DOT policy plan (*1*), and many of the initial uncertainties in the program are being resolved. The original intent of UTCP research—to bring new disciplines into transportation research, with less emphasis on engineering—has been confirmed, and offers promise for new approaches to transportation problems. However, there still appears to be some uncertainty between universities and DOT agencies on what research role the universities should play. DOTs may expect this research to follow the applied research model of NCHRP or SHRP. while universities may see it as an opportunity to do what they do best—basic research.

Effects of Current Approaches

The bias towards engineering and applied research exhibited in these surveys and programs does not mean that this research is not needed. There have been many innovations, for example, developed from NCHRP research, and SHRP projects exhibit great promise. The problem is that the desire to continue research programs along these lines causes concern to the new actors attracted to the growing transportation challenges. Nonengineering and academic researchers feel their innovations can play a larger role in addressing transportation problems. If programs are not available for their involvement, transportation users do not benefit from the new approaches that might result.

If organizations that fund basic research, such as NSF, had a stronger commitment to transportation, complementary programs could be established with NCHRP, SHRP, and other applied research efforts. However, the lack of commitment to transportation by NSF is most likely influenced by the consistent message from AASHTO and others that transportation organizations place their highest priority on applied research.

C. V. Wootan, director of the Texas Transportation Institute, made a plea for more balance at the 1990 TRB meeting (*9*), calling for increased fundamental and applied research. He explained the important role university research plays in the education of transportation professionals, as well as in developing innovations.

CENTER FOR TRANSPORTATION STUDIES APPROACH

The University of Minnesota faced these issues in 1987 when the Center for Transportation Studies was established. The governor allocated $2.7 million of oil overcharge funds to initiate the Center, and the legislature allocated an additional $2.0 million of oil overcharge funds in 1988 for Center programs. In addition, the Minnesota Department of Transportation (Mn/DOT) and the Regional Transit Board (RTB) contributed administrative and research support. The Center has used these funds to establish ongoing programs of transportation research, education, information, and outreach. The oil overcharge funds must be spent in approximately a 4-year time period. The challenge for the Center is to establish worthwhile programs so that it can attract future funding when these funds are depleted. Because much of the funding is spent on research, the Center placed a high priority on establishing a balanced research program that meets the needs of various transportation interests in Minnesota.

Strategic Planning Process

The Center used a strategic planning process to develop its programs, with strong participation from the various constituencies, or stakeholder groups, that could benefit from these programs. An initial committee, primarily consisting of transportation professionals, developed broad recommendations (*10*) that outlined the Center's program areas, which allowed initial programs to begin while a longer term planning process was put in place. This planning process began with the formation of the Center's advisory board. This board has been involved in setting directions for education and information programs as well as research programs. Special emphasis has been placed on developing the research program.

Planning retreats were held to identify key stakeholder groups for the Center. These groups were used to select advisory board members and also to develop the Center's mailing list. Invitations were sent to selected leaders in Minnesota, and approximately 60 people volunteered to serve on the board. Ten of these people were also selected by the chair to serve on an executive committee. These leaders represent many groups, with a balance of government leaders (including 10 state legislators), private sector leaders (shippers, carriers, and vendors), and academic leaders (deans of the university). The board was intentionally designed to have a diverse membership, to reflect the broad interests in transportation.

The full advisory board meets twice a year. The fall meeting discusses current issues and outlines long-term directions for the Center. The spring meeting hears a report on Center results and approves directions for the next year; it is scheduled in conjunction with the annual Center research conference. The executive committee meets an additional four times a year, to refine the advisory board directions into work programs and to select research priorities.

Communication and Participation

The Center has placed a high priority on communication and participation. Because its constituencies are so diverse and because there are, at times, disagreements such as those described previously, an attempt has been made to bring these groups together around their common interest of transportation. The Center's goal is to be a focal point for these groups, raising awareness of transportation issues and offering programs to address them.

The first way of doing this is to communicate to them frequently about the Center's activities. A monthly newsletter is currently sent to over 1,600 people, primarily Minnesotans. This four-page publication includes short items about transportation activities occurring at the university and a calendar of upcoming transportation events. Faculty on the mailing list are asked each month to contribute items that relate to transportation. This newsletter has been an excellent mechanism to help show the breadth of transportation activities occurring at the university. An annual report has also been produced by the Center that has been distributed widely (*11*).

The second way of becoming a transportation focal point is to give these groups various opportunities to become involved in center activities. In addition to the participation of advisory board members, there is wide participation by others in Center events. An initial success was the establishment of quarterly luncheons, where national experts are invited to speak on various transportation issues. These luncheons regularly draw a diverse crowd of over 100 people. In May of 1990, the Center held its first conference, focusing on transportation research. Over 300 people attended, providing an opportunity for people with diverse interests to interact. A focus of this conference was to allow practitioners to hear about the research being conducted by faculty members. In addition, the Center sponsors regular seminars and periodic forums that focus on specific issues, and is regularly sought as a cosponsor for other events.

A key goal of these communication and participation programs is to generate increased awareness about transportation, which ultimately is translated into input and guidance to Center programs.

Research Goals of the Center

The emphasis on communication and participation was used by the Center's 60-member advisory board and 11-member executive committee to help define the Center's research program. The executive committee created a mission statement for the Center, which focused on the importance of multidisciplinary approaches for addressing transportation problems. It also decided to use a request for proposal process to solicit research ideas from university faculty.

The Center used a participatory process with the advisory board to define the research emphases outlined in the request for proposals. The process consisted of the board's hearing experts speak about transportation issues, breaking into small groups to generate issues, discussing these issues in a large group setting, and completing rating sheets that ranked research priorities. This information was collected and analyzed by Center staff and then discussed by the executive committee. Following their direction, the information was incorporated into the request for proposal.

A key decision by the executive committee and Center staff was to cluster the various research issues generated by the advisory board into overarching titles. The end result was that proposals were requested from faculty for research in three broad emphasis areas (*12*):

- Strategic Directions for Transportation in the Upper Midwest. Proposals were requested for research that examines the relationship between the transportation system and the changing economic and social characteristics of the Upper Midwest.
- Improved Management of the Transportation System. Proposals were requested for research on how to improve the management of the transportation system, including decision-making processes and roles as well as technical management improvements.
- Innovations in Transportation Technology. Proposals were requested for research on transportation technology, including innovations that link vehicle technology to infrastructure design and management.

The request for proposals also listed three or four research questions under each of the three emphases.

Aspects of the Process

There are two important aspects of this process to note, given the challenges in developing a research program that have been discussed previously. First, a variety of nonengineering research topics are proposed in these emphasis areas. This was addressed explicitly by advisory board members in the large group discussion. Initially, a feeling was expressed that others could conduct the technical research (on pavements, bridges, etc.) and that the Center should focus on policy concerns. However, the discussion eventually turned to the importance of technological advances, located in the third emphasis area. The backgrounds of the participants were significant. The executive director of a pavement association spoke strongly on the need for research that developed strategic directions for transportation (first emphasis area), and the chair of a transit authority emphasized the importance of technological research (third emphasis area). These positions would be reversed for people with these backgrounds. The communication and participation broke down traditional barriers and led to a consensus for a balance of engineering and policy-related research.

Secondly, the clustering of the research ideas by the executive committee left quite a bit of freedom for the proposer. This approach contrasts with the bottom-up process used by NCHRP, where several specific problem statements are created, methodologies prescribed, and research projects selected by a ballot approach. The specific issues generated by the Center's advisory board were instead used as indications of broader concerns. The clustering helped identify these concerns by creating overarching titles. The researchers were then asked to propose projects that would address pieces (which they would choose) of these three research emphasis areas and present their own research plans for accomplishing this research. This freedom allowed proposers to choose basic or applied research approaches and design their own research plans, an approach appropriate for academic researchers.

The request for proposals was announced to all university faculty. A peer review team of seven people was established to judge proposals against the criteria listed in the request for proposals. The executive committee reviewed the peer review results and made the final decision on what projects to fund.

RESULTS OF THE CENTER'S PROCESS

First Cycle

The first use of the request for proposals was in April 1989, when it was announced to all University of Minnesota faculty. Before that, the Center had funded some projects in selected areas, primarily in traffic engineering. The request for proposals required all faculty members interested in Center funding to follow the same process.

In response to this request, the Center received 31 proposals. The peer review team rated these proposals against several criteria established by the Center's executive committee. The executive committee made the final decisions on which proposals to fund, evaluating the overall balance of the program as well as the peer review results. Mn/DOT also reviewed all the proposals and selected five for Mn/DOT funding. The projects chosen for funding in July 1989 are summarized below under the three research emphases areas, indicating the university department and project subject:

- Strategic Directions for Transportation in the Upper Midwest.
  - —Agricultural/Applied Economics: transportation/economy.
  - —Forest Resources: transportation/forest planning.
  - —Marketing/Logistics: just-in-time impacts.
  - —Public Affairs: linkages among rural communities.
- Improved Management of the Transportation System.
  - —Civil Engineering: ramp metering control.
  - —Civil Engineering: intersection control (Mn/DOT).
  - —Civil Engineering: network design (Mn/DOT).
  - —Economics: airport congestion pricing.
  - —Psychology: air traffic controller training.
- Innovations in Transportation Technology.
  - —Agricultural Engineering: water flow/pavement subgrade.
  - —Civil Engineering: pavement deformation (Mn/DOT).

—Civil Engineering: modeling pavement systems.
—Civil Engineering: corrosion of reinforced-steel bridges.
—Civil Engineering: geostatics for pavement (Mn/DOT).
—Civil Engineering: frost heave in pavements.
—Computer Science: pavement simulation software (Mn/DOT).
—Forest Products: prestressed timber bridges.

In evaluating this first cycle, the Center's executive committee felt positive about the variety of disciplines attracted to the process, confirming a wide level of interest in transportation at the university. The process also confirmed the technical strength at the university, particularly in the Civil and Mineral Engineering Department. But there was disappointment that some areas did not attract more projects, particularly in the strategic directions emphasis. There was also disappointment that projects for the most part came from individual disciplines, even though the criteria were designed to rate a proposal higher if it involved multiple disciplines. Changes were made for the second cycle.

Second Cycle

The second request for proposal was announced in January of 1990. This followed another meeting of the advisory board and several revisions to the process by the executive committee. These revisions were as follows:

- The three broad research emphases were refined to five more specific needs.
- A special emphasis was put on one area, transportation and the economy, with an appendix outlining a long-term study and its components.
- The criteria were reduced, from nine items to four, as suggested by the peer review group.
- Financial incentives were established for multidisciplinary teams. A project could receive $10,000 of additional funds for each additional discipline added.

This request for proposals received a response of 33 proposals. The Center again asked the peer review group to review all proposals based on executive committee criteria. In addition, both Mn/DOT and the Regional Transit Board (RTB) reviewed all proposals, as a result of their interest in funding some of the projects. The executive committee, Mn/DOT, and the RTB chose the following projects for funding beginning in July 1990. The projects were announced under a new categorization that better reflected the Center's research focus.

- Transportation and the Economy.
  —Agricultural/Applied Economics, Sociology: trade patterns.
  —Management Information Systems: telecommunications/transportation.
  —Marketing/Logistics: intermodal transportation.
  —Public Affairs, Agricultural Economics, Economics: local economies.
- Transportation Safety and Traffic Flow.
  —Civil Engineering, Computer Science: traffic simulation (Mn/DOT).
  —Civil Engineering, Computer Science: incident detection.
  —Civil Engineering: origin-destination model.
  —Computer Science, Civil Engineering: parallel processing.
  —Human Factors, Computer Science: elderly driving.
- The Transportation Infrastructure.
  —Agricultural Engineering: water/pavements (Mn/DOT).
  —Civil Engineering: pavement test facility design.
  —Civil Engineering: bridge ratings (Mn/DOT).
  —Civil Engineering: crushed tires/pavement (Mn/DOT).
- Transportation and the Environment.
  —Civil Engineering: LRT station design (RTB).
  —Landscape Architecture: bicycle transportation.
  —Mechanical Engineering: alternative fuels (RTB).
  —Mechanical Engineering: methanol in engines (RTB).

Evaluation

The process chosen by the Center to establish a transportation research program in Minnesota has both strengths and weaknesses, as described in the following paragraphs.

Strengths of the Process

- The use of the Center's advisory board has brought a variety of transportation interests together, resulting in a concise articulation of the major transportation challenges facing the state, which has given direction to the Center's research efforts.
- The process has identified a wealth of expertise in university faculty members who are interested in conducting transportation research. The Center and the university are clearly capable of bringing together multiple disciplines to address transportation challenges, which has been called for by both national and state decision makers.
- The Center's process has attracted the interest and financial resources of two major transportation agencies in the state, the Mn/DOT and the RTB. Mn/DOT had previously funded research at the university; it is enthused about the increased access to new disciplines and ideas that the Center's process has generated. The RTB has found that the Center can help it perform its legislative mandate to conduct transit research.
- The iterative nature of the process, with frequent evaluation and discussion by the Center's executive committee, has helped define the Center's strategic strengths. The changing of the category titles reflects increased awareness of what the Center can do best. For example, it does not have a major strength in logistics, as another center (for example, the Massachusetts Institute of Technology) might. Instead, the logistics experts are part of the team that is addressing the relationship of transportation to the economy.
- The research program has a balance of engineering and policy-related projects that appears to meet the needs of the Center's advisory board. The announcement of the first cycle of projects caused concern by some that the Center's program was too dominated by traditional infrastructure research. The second cycle was successful in attracting new disciplines, while still maintaining a strong technical program that receives substantial support from Mn/DOT.

• The focus on whether a project is addressing the research needs has reduced the debate on whether the project is too basic or too applied. It has not mattered in the selection process as long as the proposal is sound and addresses a priority emphasis.

Weaknesses of the Process

• The request for proposal process, even with the adjustments in the second cycle, is still not satisfactory. Some projects that were strongly desired (and stated so in the RFP) were not proposed, even though the Center was aware of qualified principal investigators. Although the incentives for multidisciplinary teams worked in some cases, the results of this too were disappointing.

• There may be the impression, given the advisory board's initial statement of research goals, that the university can address all those issues. It clearly cannot. The critical factor is whether the faculty is interested in addressing these topics, more so than whether it is capable. If a faculty member is found who has the skills to address an urgent issue and funding is made available, that does not mean that he or she will do it. It may not be consistent with his or her long-term research interests. This is not widely known outside academia, sometimes causing expectations that are not met.

• Even though the debate about basic and applied research has been reduced, it remains a challenge as these projects are conducted and the results are disseminated. The Center still needs to demonstrate to many practitioners the value of basic research. This was pointed out at the Center's conference, where the reactions to theoretical presentations by faculty were mixed. The Center needs to be a catalyst to show practitioners long-term benefits of basic research and to focus researchers on potential applications of their theoretical findings.

• The requests for proposals have encouraged matching funds from private industry, but it has only happened in a few cases—even though there is increasing interest by the private sector in the Center's programs. This process provided limited mechanisms for this partnership.

THE CENTER'S FUTURE PLANS

The Center's executive committee has decided not to use the request for proposal process to fund future projects. Its use has been essential in the Center's early stages, to help identify interested faculty and the Center's strengths. These tasks have been accomplished, and now the Center will take a more proactive role in defining projects for funding. It will be guided by the advisory board's original goals—balancing policy, management, and technological research—but it will use the more specific research emphases areas that were announced for the second cycle of funding:

• Transportation and the economy,
• Transportation safety and traffic flow
• Transportation infrastructure, and
• Transportation and the environment.

Core faculty members for each of these four research emphases areas will be designated, drawn from those who have been funded and those who have shown interest in addressing issues in these areas. The Center will bring these faculty teams together with advisory board members and other interested external parties. Discussions will focus on the critical transportation issues in these areas, with much interaction between faculty and external representatives. The issues defined will be used to develop short proposals by faculty teams, which will be evaluated and expanded by group members. A selective request for proposal may be issued to other faculty if a critical area of expertise is needed. Decisions on funding will still be made by the executive committee, influenced by the recommendations of the groups.

The proposals developed will also be used to pursue additional funding from outside sources. Mn/DOT and the RTB will continue to be heavily involved in the process. The federal government, foundations, the private sector, and others will also be contacted for potential participation. The Center will offer support services in developing research directions, developing proposals that follow these directions, and making contacts with funding organizations.

The Center plans to increase its technology transfer efforts and continue the strong communication and participation efforts that have been started. It will increase its involvement in conferences (for example, supporting the 1991 ASCE International Conference on Advanced Technologies in Transportation) and offer frequent forums for researchers and practitioners to interact. The executive committee believes this is a critical role for the Center, not only leading to the implementation of innovations, but also in generating future funding support. The Center will particularly continue to make a strong case for academic research, which brings innovations and educational benefits to transportation that are needed to complement the current applied research programs.

CONCLUSIONS

The Center for Transportation Studies at the University of Minnesota has learned a great deal in its efforts to establish a transportation research program. A goal of this program is to be balanced, which is a subjective judgment. The Center bases its success in achieving this goal on the feedback of the diverse transportation interests it has assembled on its advisory board and executive committee. It has been successful in balancing engineering and policy-related transportation research. It continues to face challenges in showing why increased basic research is needed to balance the applied research demanded by users.

A balanced transportation research program is needed at the national level also. Some conclusions from the Minnesota experience are offered that may be useful in the development of a national program:

1. All transportation interests must be involved in developing a transportation research program. State DOTs are critical, but they must be joined by other key stakeholder groups to broaden the research agenda. This will result in increased awareness and support for all types of transportation research.

2. Additional disciplines must be brought into the transportation research program. Civil engineering must be strengthened, but must also be complemented by skills from

the social sciences, other technical fields, and public policy disciplines to answer the research questions a broad constituency is raising.

3. There needs to be increased understanding by transportation decision makers of the role universities and basic research play in addressing transportation challenges. Transportation can learn from medicine, agriculture, and defense how to use basic research from academia to develop innovations.

4. Mechanisms need to be established, at both the national and state level, to ensure a balance of basic and applied research. At a national level, an NSF-like program could be established to complement NCHRP and SHRP programs. At the state level, state research programs could result in increased master's and Ph.D. students being hired by state DOTs to apply the concepts and technologies developed in universities.

5. Transportation agencies and other government organizations must become aware of and promote the economic development benefits of both basic and applied research in transportation. The positive spin-offs of the increased knowledge base—in new technologies, better educated students/employees, new expertise for consultants—will help keep the United States competitive. A "let's wait and buy what Europe and Japan develops" attitude is short sighted and ultimately harmful to the U.S. economy.

6. Increased collaboration among government, academia, and the private sector is needed in transportation research, particularly in the development of advanced technologies (*13*). The DRIVE program in Europe is producing collaboration that goes beyond national boundaries and that will soon produce results that surpass the United States in technological leadership in transportation. The government should be the key instigator in developing these relationships, with strong support from transportation centers. For these relationships to succeed, all parties must understand the different organizational incentives involved—political, academic, and profit—and find ways for all of them to be achieved.

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