TRANSPORTATION RESEARCH

RECORD

No. 1262

Planning and Administration

Planning, Management, and Economic Analysis 1990

A peer-reviewed publication of the Transportation Research Board

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1990

Transportation Research Record 1262
Price: $28.00

Subscriber Category: IA planning and administration

Modes
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3 rail transportation

Subject Areas
11 administration
12 planning
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Printed in the United States of America

Library of Congress Cataloging-in-Publication Data
National Research Council. Transportation Research Board.

Planning, management, and economic analysis 1990.
p. cm. — (Transportation research record, ISSN 0361-1981 ; no. 1262)
ISBN 0-309-05014-6
1. Transportation—United States—Planning—Congresses.
2. Land use—United States—Planning—Congresses. 3. Space in economics—
Congresses. I. Series: Transportation research record ; 1262.
TE7.H5 no. 1262
[HE206.2]
388 s—dc20 90-6643
[388′.068] CIP

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Foreword

This Record examines a wide variety of economics and planning topics. Most of the economic analysis papers are concerned with the costs and benefits of highway systems. A second group of papers focuses on issues of land use planning and urban activity centers. A third group deals with issues of planning, programming, and project selection and scheduling. A final group of papers discusses citizen involvement and capital management.

In one of the papers dealing with economic issues, Fwa et al. recommend the establishment of a permanent cost allocation data base to enable a periodic update analysis. Bennett and Dunn found that motor vehicle depreciation costs were due primarily to time, not vehicle use. Garrison and Souleyrette offer a novel way of thinking about transportation and production relations. Ryan found that accident costs are generally higher than delay costs at railroad-highway grade crossings. Nassar and Najafi propose a "quick-approach" for estimating law enforcement costs on urban roads. Gibby et al. found that the average annual maintenance cost per heavy truck per day amounts to $7.60 per mile per year, whereas the corresponding cost per passenger car is 8 cents per day. Weisbrod and Beckwith developed a comprehensive method for evaluating the potential economic development benefits associated with proposed major regional highway projects, and subjected such projects to a cost-benefit analysis. Turner et al. report on their development of a state-of-the-art highway utilities policy manual. Bein evaluated the current version of the Highway Design and Maintenance Standards Model, HDM-III, for applicability to Canadian heavy-vehicle operating conditions.

Among the papers that deal with the interrelationships between transportation and land development, Herendeen and Moreno suggest a modification of the circulation/distribution system analysis procedures in order to provide cost-effectiveness procedures to measure trip-making patterns. Replogle discusses the application of land use and transportation modeling techniques to support several planning methodologies. Oppenheim posits a dual equilibrium model in which zonal retail price and travel times are in equilibrium.

In the area of programming, project selection, and scheduling, Fernando et al. use the RAMS District Optimization Program to maximize network benefits in the selection of projects at the district level. Van De Steeg and Ohrn report on a process aimed at reducing the exchange of project programming and scheduling paperwork between state and federal offices. Thurgood et al. found that in the post-Interstate construction environment, there is a greater probability of cost overruns. McPherson et al. describe how the Preconstruction Engineering Management System (PCEMS) is being used to assist the North Carolina Transportation Department engineering staff in the scheduling phase of project development. Jiang and Sinha advocate an approach to a combined ranking and optimization technique that would integrate different priority ranking techniques for highway and bridge project selection techniques. The application of micro- and minicomputers to project management is evaluated by Hazarvartian et al., who present a conceptual model.

Rao and Larson look at highway capital program management and show how various external factors and self-imposed internal conditions affect the programming process. Alvarez et al. demonstrate how a proactive and interactive citizen involvement process was successful in resolving conflicts in a major new highway construction project in Delaware.

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Update Analysis of Highway Cost Allocation

T. F. Fwa, K. C. Sinha, and S. K. Saha

Many states have recently performed cost allocation studies to provide a logical basis for formulating equitable tax structures and registration fee schedules. Many states have also recognized the dynamic nature of the problem, and the need to conduct an update analysis periodically. A full-scale update analysis is often costly and time consuming and little effort has been made to address this problem. Using the 1988 Indiana update analysis of highway cost allocation as an illustration, the key elements in an update analysis are identified here and a recommendation is made that the establishment of a permanent cost allocation data base would enable an update analysis to be conducted periodically in an efficient manner within a time frame acceptable to most highway agencies. The important steps in the Indiana update study are described and examined in detail. Study results and findings are also discussed.

In the United States, highway cost allocation analysis has now become an integral part of a process of pricing and financing highway services in many states. Typically, the analysis is conducted to provide the following information: the cost responsibilities of various vehicle classes; the revenue contributions made by different vehicle classes; and the revenue-cost ratio of each vehicle class. The analysis results are useful for determining if different groups of highway users are paying their fair shares of cost responsibilities. They can also be used directly as the basis for formulating highway user-tax schedules. A number of recent publications illustrate these applications (*1–5*).

An important feature of highway cost allocation analysis is that results vary with changes in the following factors: expenditure pattern of the highway agency concerned; travel pattern of highway users; and composition of traffic streams in terms of vehicle type. These factors generally do not remain constant from year to year. They could differ significantly over a few years because of shifts in highway program emphases, changes in the age structure of highway facilities, and new developments in the socioeconomic environment. It is therefore important to conduct update analysis of highway cost allocation periodically to provide a valid basis for assessing the reasonableness and equity of highway user-tax structures.

An update analysis of highway cost allocation has recently been performed in Indiana. The salient features of the update analysis are described in this paper and the results of the study are presented. The important elements in an update analysis are highlighted, and the need to establish an efficient data base structure to enable update analysis to be completed within a reasonable time is stressed. A periodic update analysis of highway cost allocation can thereby be fiscally and practically feasible.

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BACKGROUND

The previous Indiana Highway Cost Study (*6*) was mandated in April 1983 and completed in two years. Its main objective was to determine if the tax payment of each user group matched its share of cost responsibility for highway expenditures. The study's major findings formed important input for the highway user-tax revisions enacted by the Indiana General Assembly in 1985.

The 1988 update analysis of highway cost allocation for Indiana was initiated in August and completed in less than six months. The main purpose of the analysis was to derive a new set of cost responsibilities and revenue-cost ratios for various vehicle classes based upon 1988 traffic composition and travel pattern data, and 1988 levels of expenditure and revenue. It also highlighted the data requirements and considerations important in an update analysis of highway cost allocation.

Figure 1, a flow diagram, shows the major steps in the cost allocation analysis. Three basic phases are identified in the flow diagram: defining of framework of analysis, collection and processing of data, and performing revenue contribution and cost responsibility analysis.

FRAMEWORK OF ANALYSIS

The overall framework of analysis in the update study was similar to that of the 1983 study. The same highway classification was adopted: Interstate urban, Interstate rural, State Route primary, State Route secondary, county road, and city street.

The classification of all vehicles in four categories—passenger car, bus, single-unit truck, and combination truck—also remained the same. However, some refinements in the subdivision of these categories were made in the update analysis to allow for more precise identification of certain vehicle types. These vehicle types were found to be of concern to several interest groups after the 1983 study results were published. Table 1 lists the 11 vehicle classes considered under the four main categories. These vehicle classes were further

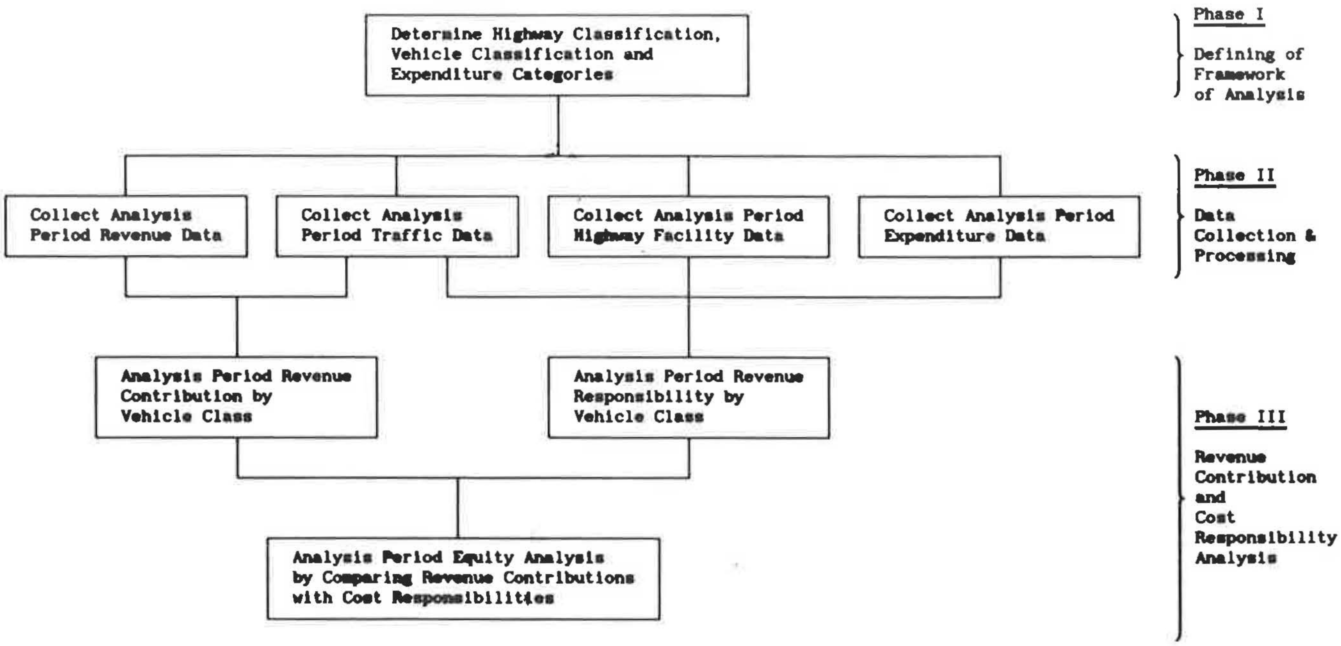

FIGURE 1 Flow chart for Indiana Highway Cost Allocation Analysis.

subdivided into vehicle groups on the basis of their operating vehicle weights. Table 2 shows the vehicle weight group classification adopted in the update analysis.

Expenditure categories were defined by six expenditure areas with several expenditure items under each as shown in Table 3. The dollar amounts of individual expenditure items were the costs used in the cost allocation analysis. These expenditure amounts were computed separately for each of the six highway classes. Such a detailed computation of highway expenditures was necessary because the relative shares of cost responsibility among vehicle classes varied from expenditure item to expenditure item and from highway class to highway class.

DATA COLLECTION AND PROCESSING

Four basic forms of data have been identified in Figure 1. The major requirements of each are discussed below.

Attributed Revenue

Table 4 shows the 1988 revenues contributed by Indiana highway users. Note that the main revenue sources were motor fuel taxes and vehicle registration fees. These two forms of tax (items 1, 2, 3, 4, 5, 8a, and 8b in Table 4) accounted for more than 90 percent of the total highway user revenue con-

TABLE 1 VEHICLE CLASSIFICATION

Main Category	Vehicle Class	Description
1. Passenger Car	1	Small Passenger Car
	2	Larger Passenger Car, Pickup and Van
2. Bus	4	Bus
3. Single Unit Truck	3	2-Axle Single Unit Truck
	5	3-Axle Single Unit Truck
	6	4-Axle Single Unit Truck
4. Combination Truck	7	3- or 4-Axle Combination Truck
	8	5-Axle Single Trailer Combination Truck
	9	5-Axle Multiple Trailer Combination Truck
	10	6-Axle Single Trailer Combination Truck
	11	6-Axle Multiple Trailer Combination Truck, or any Combination Truck with 7 or more Axles

TABLE 2 VEHICLE CLASS WEIGHT GROUP CLASSIFICATION

Vehicle Class	Weight Group	Weight in Pounds
1	1	All
2	1	All
3	1	<7500
3	2	7500-10,000
3	3	10,000-12,500
3	4	12,500-15,000
3	5	15,000-17,500
3	6	17,500-20,000
3	7	20,000-22,500
3	8	22,500-25,000
3	9	>25,000
4	1	All
5	1	<17,500
5	2	17,500-20,000
5	3	20,000-22,500
5	4	22,500-25,000
5	5	25,000-27,500
5	6	27,500-30,000
5	7	30,000-32,500
5	8	32,500-35,000
5	9	>35,000
6	1	All
6	2	<22,500
6	3	>22,500
7	1	<22,500
7	2	22,500-25,000
7	3	25,000-27,500
7	4	27,500-30,000
7	5	30,000-32,500
7	6	32,500-35,000
7	7	35,000-37,500
7	8	37,500-40,000
7	9	40,000-42,500
7	10	42,500-45,000
7	11	45,000-47,500
7	12	47,500-50,000
7	13	50,000 & Above
8	1	<22,500
8	2	22,500-25,000
8	3	25,000-27,500
8	4	27,500-30,000
8	5	30,000-32,500
8	6	32,500-35,000
8	7	35,000-37,500
8	8	37,500-40,000
8	9	40,000-42,500
8	10	42,500-45,000
8	11	45,000-47,500
8	12	47,500-50,000
8	13	50,000-52,500
8	14	52,500-55,000
8	15	55,000-57,500
8	16	57,500-60,000
8	17	60,000-62,500
8	18	62,500-65,000
8	19	65,000-67,500
8	20	67,500-70,000
8	21	70,000-72,500
8	22	72,500-75,000
8	23	75,000-77,500
8	24	77,500-80,000
8	25	80,000-82,500
8	26	82,500 & Above
9	1	<42,500
9	2	42,500-45,000
9	3	45,000-47,500
9	4	47,500-50,000
9	5	50,000-52,500
9	6	52,500-55,000
9	7	55,000-57,500
9	8	57,000-60,000
9	9	60,000-62,500
9	10	62,500-65,000
9	11	65,000-67,500
9	12	67,500-70,000
9	13	70,000 & Above
10	1	<40,000
10	2	40,000-60,000
10	3	>60,000
11	1	<40,000
11	2	40,000-60,000
11	3	>60,000

tribution. The diesel surtax was an add-on tax charged on all diesel fuel consumed in Indiana and collected from trucking companies. The motor carrier fuel use tax was collected from all commercial vehicles for the fuel not purchased in Indiana but consumed on Indiana roads. The International Registration Plan (IRP) was a reciprocity agreement on motor carrier registration fees. This fee was collected from interstate carriers of those states with which Indiana had a reciprocity agreement.

The revenue data records did not contain sufficient detail to give the individual revenue amount contributed by each of the vehicle weight groups listed in Table 2. It was therefore necessary to back-derive such information from the available aggregated revenue data. The methods of back-deriving vehicle weight group revenue contributions for fuel taxes and vehicle registration fees are described below.

The amount of fuel taxes paid by a vehicle depends on its total fuel consumption in the analysis period. Fuel consumption in turn is related to the total vehicle miles of travel and fuel efficiency. The total 1988 VMT (vehicle miles of travel) of each vehicle–weight group was first derived from traffic data. Fuel consumption in number of gallons consumed was computed next by dividing these VMT values by appropriate fuel efficiency factors. The number of gallons of fuel consumed was then multiplied by corresponding tax rates to give the desired tax revenue contribution for each vehicle weight group.

Truck registration fees in Indiana are collected on the basis of vehicle registration weight classification which is different from the vehicle operating weight classification defined in Table 2. Transformation between the two types of classification is not a straightforward process because a simple one-

TABLE 3 EXPENDITURE ITEMS BY EXPENDITURE AREA

Expenditure Area	Expenditure Item
Highway Construction	Pavement Right-of-Way Grading and Earthwork Drainage and Erosion Control Shoulder Miscellaneous Items
Structure Construction and Replacement	Bridge Superstructure Bridge Substructure Sign Structure Excavation and Backfill Miscellaneous Items
Structure Rehabilitation	Bridge Superstructure Bridge Substructure Sign Structure Excavation and Backfill Miscellaneous Items
Highway Rehabilitation	Pavement and Shoulder Right-of-Way Grading and Earthwork Drainage and Erosion Control Miscellaneous Items
Routine Maintenance	Pavement and Shoulder Drainage and Erosion Control Bridge Miscellaneous Items
Other Costs	Enforcement (policing) Weight Inspection Special Railroad Crossings Miscellaneous Items

to-one relationship between the gross operating weights and registered weights of a vehicle does not exist. Figure 2 shows the relationship between registered gross vehicle weight and operating vehicle weight.

A correspondence matrix may be developed from traffic loading data to facilitate computing registration fees paid by various vehicle operating weight groups. An example of a correspondence matrix is shown in Table 5. The elements in each row of the matrix are obtained from an appropriate weight distribution curve such as that illustrated in Figure 2. The registration fee contributions of individual vehicle weight groups in a vehicle class i are calculated from the following equations:

$$\begin{bmatrix} R_1 \\ R_2 \\ \cdot \\ \cdot \\ \cdot \\ R_m \end{bmatrix}_i = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ a_{n1} & a_{n2} & \cdots & a_{nm} \end{bmatrix}_i^T \begin{bmatrix} r_1 \\ r_2 \\ \cdot \\ \cdot \\ \cdot \\ r_n \end{bmatrix}_i \quad (1)$$

that is

$$[R]_i = [a]_i^T [r]_i \quad (2)$$

where

R_j = registration fee contribution of vehicle weight group j, $1 \leq j \leq m$
m = total number of vehicle weight groups in vehicle class i,
r_k = registration fee paid by registered vehicle group k, $1 \leq k \leq n$
n = total number of registered vehicle groups in vehicle class i, and
a_{pq} = coefficient of correspondence matrix, $1 \leq p \leq n$, $1 \leq q \leq m$.

Traffic Data

Traffic data included traffic volume information, traffic stream composition, vehicle axle configuration, and operating axle weight information. These data were required for each of the six highway classes and were needed for computing traffic loadings in terms of equivalent single axle loads (ESALs) for the allocation analysis of pavement costs, developing correspondence matrices for revenue contribution calculation, and deriving the vehicle miles of travel (VMT) for each vehicle weight group within each highway class.

An in-depth examination of cost allocation analysis by the study team found that the outcomes of the analysis depend strongly on the relative magnitudes of VMT values of various vehicle weight groups and vehicle classes. The summary of cost allocation criteria presented in Table 6 clearly indicates why this is so. A detailed description of these criteria can be found elsewhere (*6–8*). Because the Σ ESAL value of each vehicle weight group can be considered as a factored sum of its VMT, the VMT distribution directly influences the cost allocation of almost every expenditure item.

Because of the importance of VMT information, county-by-county traffic volume data were obtained from the Indiana Department of Transportation (INDOT). The VMT of a given vehicle class was computed simply as the product of its total traffic volume counts in the analysis period and the highway mileage, as indicated below:

$$(\text{VMT})_{ij} = 365(\text{AADT})_{ij}(L)_j \quad (3)$$

where

$(\text{VMT})_{ij}$ = VMT of vehicle class i on highway section j,
$(\text{AADT})_{ij}$ = average annual daily traffic of vehicle class i on highway section j, and
$(L)_j$ = length of highway section j in miles.

The above computation was performed by highway class and vehicle class for each of the 92 Indiana counties. The statewide VMT values were obtained by summing the results from the 92 counties.

Expenditure Data

Most cost allocation studies have used actual expenditure instead of needed expenditure as the costs to be allocated. The pri-

TABLE 4 REVENUE SOURCES FOR FISCAL YEAR 1988

Revenue Sources	Revenue (in million dollars)
1. State Gasoline Tax	380.95
2. State Special Fuel Tax	82.80
3. Diesel Surtax	43.22
4. Motor Carrier Fuel Use Tax	6.89
5. Vehicle Registration, License and Title Fees	105.04
6. International Registration Plan	22.21
7. Oversize/Overweight Permits	3.53
8. Federal:	
a. Gasoline Tax	118.10
b. Diesel Tax	78.70
c. Heavy Vehicle User Fee	17.22
d. New Truck and Trailer Sale	23.26
e. Tire Tax	8.75
9. Local Option Tax	12.00
TOTAL	$902.67

mary reason for not using needed expenditure is the absence of fixed criteria about the level of highway needs that must be satisfied. On the other hand, the actual expenditure is the amount spent that can be directly related to the revenue contribution of the same period.

The actual highway expenditure for fiscal year 1988 was considered in the present update analysis. Only the expenditures supported by user revenue contribution were included in the cost allocation analysis. Expenditure data were collected separately for state highways, county roads, and city streets. A breakdown of the expenditures for the state highway and local road systems, supported with user revenue, by major cost categories for fiscal year 1988 is presented in Table 7.

Highway Facility Data

Physical characteristics of highway facilities (including roadway geometry, pavement structure thickness, and drainage

TABLE 5 EXAMPLES OF CORRESPONDENCE MATRIX BETWEEN VEHICLE REGISTRATION AND OPERATING WEIGHTS

Vehicle Class No. 7 Registration Weight (lbs)	Operating Weight Group of Vehicle Class No. 7												
	1	2	3	4	5	6	7	8	9	10	11	12	13
< 26,000	0.06	0.20	0.15	0.05									
26,000 - 29,999	0.30	0.20	0.20	0.15	0.10	0.05							
30,000 - 35,999	0.10	0.10	0.15	0.20	0.17	0.15	0.10	0.03					
36,000 - 41,999	0.06	0.06	0.09	0.12	0.15	0.15	0.15	0.11	0.08	0.03			
42,000 - 47,999	0.05	0.05	0.07	0.10	0.14	0.14	0.15	0.10	0.08	0.08	0.03	0.01	
48,000 - 53,999	0.04	0.05	0.06	0.10	0.14	0.14	0.15	0.10	0.09	0.08	0.03	0.02	
≥ 54,000	0.03	0.05	0.06	0.08	0.09	0.12	0.14	0.14	0.14	0.06	0.04	0.04	0.02

Notes: (1) Each value in table represents the fraction of given operating weight group vehicles present in the specified registration weight category.

(2) Vehicle Class No. 7 represents 3- or 4-axle combination trucks. Operating weight group details are given in Table 2.

(3) All empty cells have values of zero.

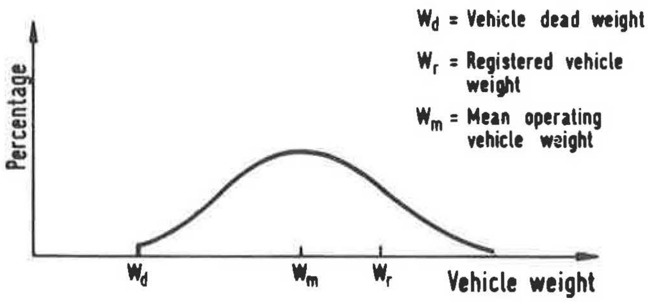

FIGURE 2 Schematic diagram showing the relationship between registered gross vehicle weight and operating vehicle weight.

features, etc.) were obtained from inventory records of the INDOT (Indiana Department of Transportation). The sources included highway inventory files, road life records, and construction reports. Pavement performance data were derived from the INDOT annual roadmeter roughness records.

REVENUE AND COST RESPONSIBILITY ANALYSIS

The derivation of revenue contributions by different vehicle classes and weight groups from aggregated revenue data has been explained earlier. These derived revenue contributions are useful for revenue-cost equity analysis by comparing them with corresponding vehicle class or weight-group cost responsibilities.

The cost responsibility of a vehicle group is affected by such factors as the type of pavement, the functional class of highway, and the nature of work for which individual expenditures were made during the analysis period. The breakdown of highway expenditures was documented by jurisdictional system, then by highway functional class, and finally by expenditure area and expenditure item. There were two jurisdictional systems in Indiana—state highway system and local highway system. For the state highway system, cost information was gathered by analyzing INDOT data files—road file records, construction reports, itemized cost estimate files, monthly

TABLE 6 COST ALLOCATION CRITERIA FOR EXPENDITURE ITEMS

Expenditure Item	Attributable Costs		Non-Attributable Costs	
	Proportion	Cost Allocator	Proportion	Cost Allocator
A. Highway Construction				
1. Pavement & Shoulder	100%	ESAL	-	-
2. Right-of-Way	100%	VMT & PCE-VMT	-	-
3. Earthwork	100%	VMT & PCE-VMT	-	-
4. Drainage	100%	VMT & PCE-VMT	-	-
5. Miscellaneous	-	-	100%	VMT
B. Highway Rehabilitation				
1. Pavement & Shoulder	66 - 98%	ESAL	2 - 34%	VMT
2. Right-of-Way	100%	VMT & PCE-VMT	-	-
3. Earthwork	100%	VMT & PCE-VMT	-	-
4. Drainage	100%	VMT & PCE-VMT	-	-
5. Miscellaneous	-	-	100%	VMT
C. Highway Maintenance				
1. Pavement & Shoulder	66 - 98%	ESAL	2 - 34%	VMT
2. Right-of-Way	-	-	100%	VMT
3. Drainage	-	-	100%	VMT
4. Miscellaneous	-	-	100%	VMT
D. Bridge Construction Replacement & Rehabilitation				
1. Superstructure	100%	Axle Load		
2. Substructure	25 - 35%	Axle Load	65 - 75%	VMT
3. Drainage	-	-	100%	VMT
4. Excavation	-	-	100%	VMT
5. Miscellaneous	-	-	100%	VMT
E. Bridge Maintenance				
1. Roadway	66 - 98%	ESAL	2 - 34%	VMT
2. Structure			100%	VMT
3. Miscellaneous			100%	VMT

Notes: ESAL = Equivalent single axle load
VMT = Vehicle miles of travel
PCE = Passenger car equivalent

TABLE 7 EXPENDITURE SOURCES FOR FISCAL YEAR 1988

A. State Highway System (Interstate, Primary and Secondary)

1.	Highway Construction	$201,229,460
2.	Highway Rehabilitation	$131,440,745
3.	Highway and Bridge Maintenance	$142,495,591
4.	Bridge Construction and Replacement	$ 13,070,833
5.	Bridge Rehabilitation	$ 64,586,263
	Total (State Highway System)	$552,822,892

B. Local Road System (County Road and City Street)

1.	Road Construction	$ 29,968,730
2.	Road Rehabilitation	$ 60,830,560
3.	Road and Bridge Maintenance	$162,096,710
4.	Bridge Construction and Replacement	$ 526,500
5.	Bridge Rehabilitation	$ 26,003,500
	Total (Local Road System)	$279,426,000
	Total (State and Local)	$832,248,892

expenditure files, and routine maintenance files. For the local highway system, the corresponding data were derived by sampling records from a number of counties and cities, as well as INDOT local road inventory files and local assistance project reports. The total state highway system expenditure was divided into three functional classes—Interstate highways, state primary, and state secondary routes. The total expenditures on the local highway system was classified into county roads and city streets. It was necessary to perform cost responsibility analysis for each expenditure item by highway class.

The total cost responsibility of a vehicle group was obtained by summing its cost responsibilities over individual expenditure items. This concept of step-by-step aggregation of cost responsibility is illustrated in Figure 3, which depicts the flow of computation of statewide cost responsibilities for state highways. The computation began within each block where the cost responsibilities for individual expenditure items were computed separately and then aggregated for different vehicle weight groups. Next, cost responsibilities of Interstate, State Primary, and State Secondary were aggregated by vehicle weight group for construction, rehabilitation, and maintenance expenditures, respectively. Finally, aggregation of cost responsibilities was performed to combine the three expenditure areas and give the vehicle weight group cost responsibilities for state highways.

The same cost responsibility calculation and bookkeeping aggregation process was repeated for city streets and county roads, and for bridges. The computation involved in determining the overall statewide cost responsibilities of vehicle weight groups is given in Figure 4. The above computation can be represented as follows:

$$F_{ij} = \sum_k \sum_l \sum_m \sum_n (D_{ijklmn} \times E_{klmn}) \quad (4)$$

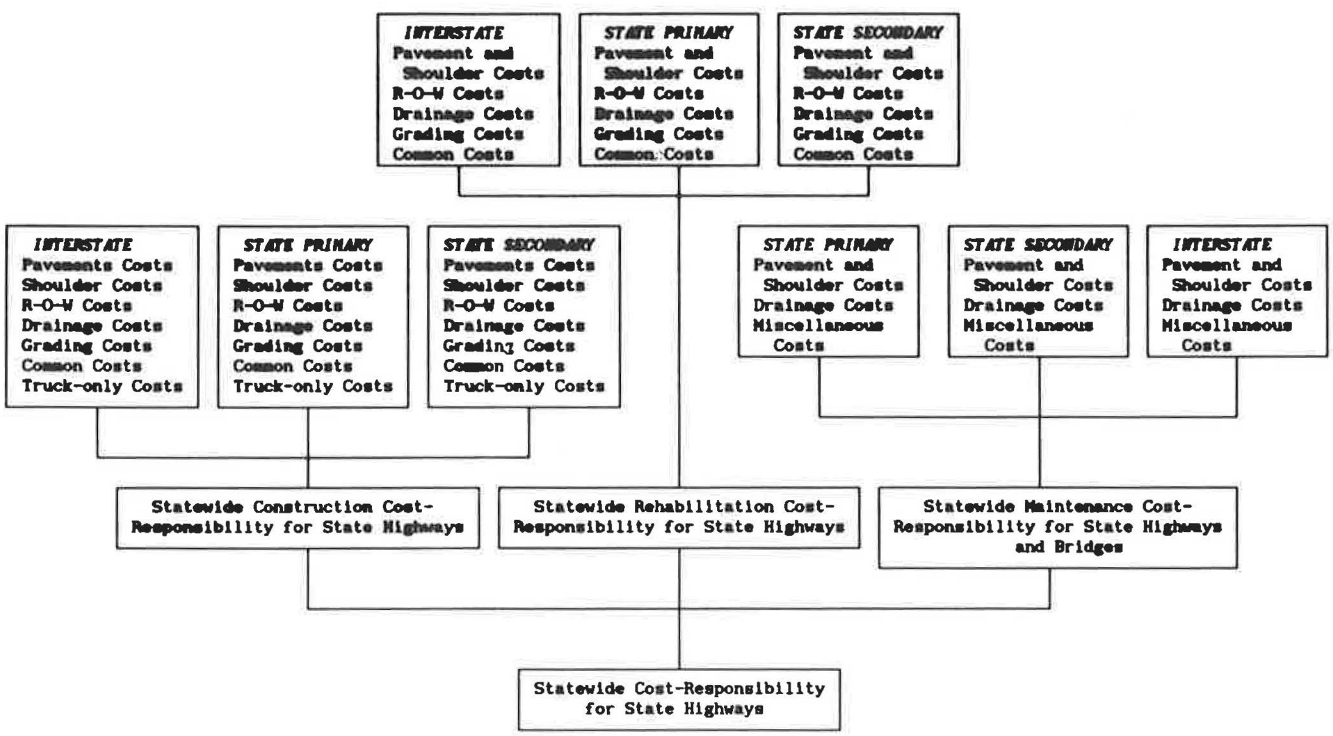

FIGURE 3 Computation of statewide vehicle weight group cost responsibilities for state highways.

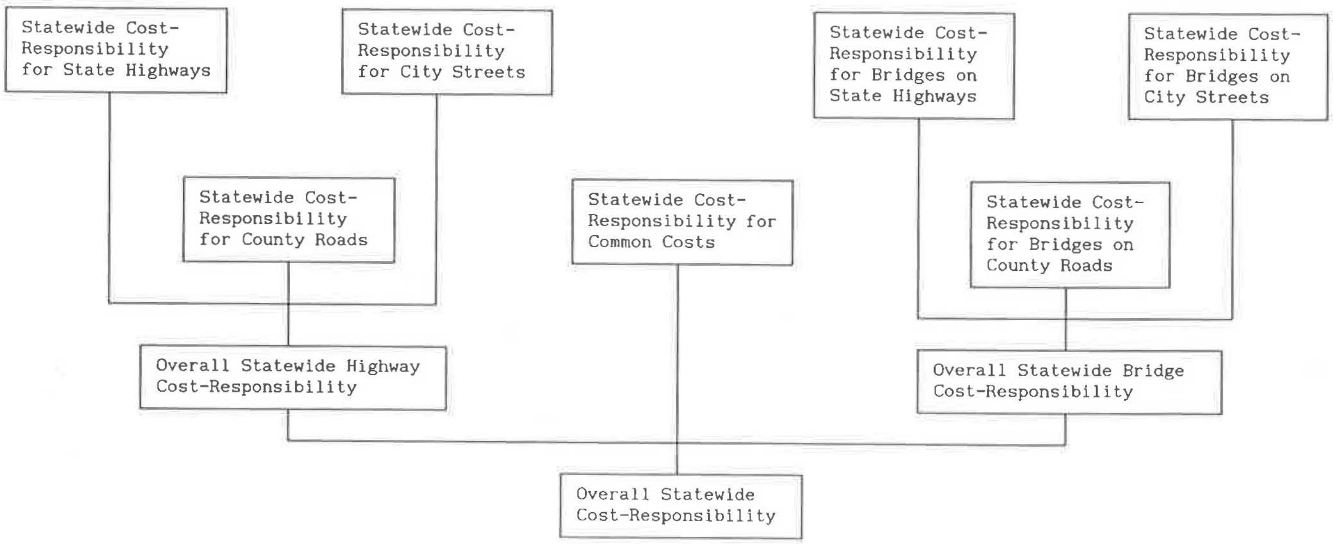

FIGURE 4 Computation of overall statewide vehicle weight group cost responsibilities.

where

F_{ij} = cost responsibility of vehicle weight group i in vehicle class j, dollars:

D_{ijklmn} = cost responsibility of vehicle weight group i in vehicle class j on pavement type l of highway class k for expenditure item n of expenditure area m, percent and

E_{klmn} = analysis period expenditure amount of expenditure item n of expenditure area m for pavement type l of highway class k, dollars.

The ranges of indices i and j were determined from Tables 1 and 2, and those of indices m and n from Table 3. The index k ranges from 1 to 6, and l from 1 to 3 to represent flexible, rigid, and overlaid pavements.

It can be noted from Figure 4 that user group cost responsibilities for state highways, county roads, and city streets were kept separated up to the final step. These highways were constructed and are maintained by different jurisdictional agencies that keep separate cost accounts and records.

In the update analysis, the methodologies for computing cost responsibilities (i.e. values of D_{ijklmn} in Equation 4), were the same as those developed in the 1983 study. Details of the methodologies are given elsewhere (*6–9*).

Revenue-Cost Equity Analysis

The widely accepted concept of equity in highway cost allocation analysis is one based on revenue-cost ratios of user groups. This concept has been particularly useful for analysis and formulation of highway user taxes because it directly relates the tax payment of individual highway user groups to their respective cost responsibilities.

The revenue-cost ratio of a user group (or vehicle weight group) may be obtained by comparing its revenue contribution with its cost responsibility for highway expenditures. It is usually calculated by dividing the percentage revenue contribution of the vehicle weight group by its percentage cost responsibility:

$$\frac{\text{Revenue}}{\text{cost}}\text{ratio} = \frac{\left(\dfrac{\text{revenue contribution}}{\text{total user revenue}}\right) \times 100\%}{\left(\dfrac{\text{cost responsibility}}{\text{total highway expenditure}}\right) \times 100\%} \qquad (5)$$

A revenue-cost ratio of unity implies that the user group concerned is paying its fair share of cost responsibility. A revenue-cost ratio greater than unity indicates overpayment, and a ratio smaller than unity means underpayment.

RESULTS AND FINDINGS

Results of the 1988 update study are summarized in Table 8. Only the results for the 11 vehicle classes are presented. Detailed results for all vehicle weight groups are given elsewhere (*10*).

Cost Responsibility by Vehicle Class

All the cost responsibilities reported in Table 8 are expressed in terms of percentages of total highway expenditure in the analysis period. As explained above, this form of expressing cost allocation analysis results offers a direct, easily understood comparison with vehicle revenue contribution.

The overall cost responsibilities in fiscal year 1988 were 44.60 percent, 2.20 percent, 14.30 percent, and 38.90 percent for passenger cars, buses, single-unit trucks, and combination trucks, respectively. Comparing these figures with their corresponding percentage VMT values, it is apparent that the passenger car was the only user group that had a smaller numerical value of percentage cost responsibility than its percentage VMT value. This was because the other three categories of user groups had larger PCE (passenger car equivalent) values, heavier vehicle weights, and very much higher ESAL factors. As can be seen from Table 6, vehicle weight was the main cost allocator for bridge superstructure and

TABLE 8 SUMMARY OF RESULTS OF 1988 INDIANA UPDATE ANALYSIS OF HIGHWAY COST RESPONSIBILITY AND REVENUE CONTRIBUTION

Vehicle Category	Vehicle Class	Percentage VMT	Percentage Cost Responsibility	Percentage Revenue Contribution	Revenue-Cost Ratio
Passenger Car	1	32.50	13.70	14.68	1.071 (0.743)
	2	55.92	30.90	42.82	1.385 (1.363)
		88.42	44.60	57.50	1.289 (1.235)
Bus	4	0.57	2.20	2.00	0.909 (0.830)
Single Unit Truck	3	1.91	4.90	5.99	1.222 (1.185)
	5	1.00	3.40	3.55	1.044 (0.848)
	6	0.34	6.00	5.46	0.910 (1.490)
		3.26	14.30	15.00	1.050 (1.133)
Combination Truck	7	1.30	6.10	4.24	0.695 (0.505)
	8	5.65	29.00	18.65	0.643 (0.625)
	9	0.22	0.70	0.61	0.871 (0.981)
	10	0.49	2.30	1.50	0.652 (-)
	11	0.09	0.80	0.50	0.625 (0.468)
		7.75	38.90	25.50	0.655 (0.621)

Note: Revenue-Cost ratios in parentheses are results of 1983 Indiana Cost Allocation Study.

substructure costs, while ESAL and PCE were important in allocating pavement construction, maintenance, and rehabilitation costs.

Revenue Contribution by Vehicle Class

The revenue contributions of individual vehicle classes presented in Table 8 are expressed as percentages of the total revenue collected in fiscal year 1988. The revenue contributions made by passenger cars, buses, single unit trucks, and combination trucks were 57.50 percent, 2.00 percent, 15.00 percent, and 25.50 percent, respectively. It can be noted that the revenue contributions had the same general trend as the cost responsibility. For example, the three vehicle classes with the highest revenue contributions were Vehicle Class 2 (large cars), Vehicle Class 8 (five-axle combination trucks), and Vehicle Class 1 (small cars). The same trend was also observed in cost responsibility figures.

Equity by Revenue-Cost Ratios

On the basis of the revenue-cost ratios computed in Table 8, the update analysis revealed that passenger cars, including pickups and vans, were overpaying by about 28 percent, while heavy combination trucks were underpaying by as much as 35 percent. Single-unit trucks as a group overpaid slightly, whereas buses underpaid by about 9 percent. The net effect was that passenger cars and single unit trucks subsidized buses and combination trucks.

The results also revealed a considerable inequity within each vehicle class. For example, within the vehicle class of single-unit trucks, the revenue contribution by three-axle single-unit trucks was almost equal to its cost responsibility (revenue-cost ratio = 1.044), but two-axle and four-axle single-unit trucks overpaid and underpaid by about 22 percent and 9 percent, respectively. For passenger cars, there was also a large difference in the extent of overpayment between the two vehicle classes that composed this vehicle category. Large cars overpaid by about 39 percent while small cars overpaid by only 7 percent. The underpayment of combination trucks was consistent among all vehicle classes within this category, although the extent of underpayment varied among the classes.

The revenue-cost ratios obtained from the 1983 cost allocation study are also presented in Table 8 for comparison purposes. The following differences between the 1988 update analysis results and the 1983 study results can be observed: Considering the four major vehicle categories, a general improvement in overall revenue-cost equity was achieved in 1988. Discrepancies of revenue-cost equity among the vehicle classes in each vehicle category have been greatly reduced. These findings confirmed the beneficial effects of the tax structure revision implemented in Indiana as a result of the 1983 study (*3*).

KEY ELEMENTS IN COST ALLOCATION UPDATE ANALYSIS

Based upon the experience and findings of the 1988 highway cost allocation update study in Indiana, the following key elements have been identified as important for implementing a scheme that allows efficient update cost allocation analysis to be conducted periodically.

Efficient Links to Other Data Bases

A large proportion of the data required for cost allocation is available in existing data bases maintained by different departments of a highway agency. Data collection efforts in an update cost allocation study could be considerably reduced by developing a data base that will automatically receive pertinent information from existing data bases in the highway agency.

Because most available data from other data bases are usually not recorded in a format directly useable in a cost allocation analysis, it is desirable that some processing of this information be performed before storing it in the cost allocation data base. Using the acquisition and storage systems for highway and transportation data in Indiana as the reference, Figure 5 shows the information links required between a cost allocation data base and existing information systems. Figure 5 further illustrates that much of the information required in the data collection phase (see Figure 1) in an update cost allocation analysis could be made readily available with the establishment of such a data management system.

The use of a cost allocation data base would considerably shorten the time required to perform a full-scale update cost allocation analysis. A data base would make periodic assessments of cost responsibility and of revenue contribution practical and feasible. It is estimated that, with the aid of an efficient data base, an update analysis could be completed within three months. The constantly updated information in the cost allocation data base would also enable one to determine if there have been significant shifts in expenditure pattern, changes in travel pattern, or changes in revenue contribution that warrant an update analysis of cost allocation.

Acquisition of Critical Data

Certain input information to cost allocation analysis cannot be obtained with sufficient detail and accuracy from existing data bases. Such data include VMT information on various highway functional classes by vehicle weight group, and distribution of the magnitudes of operating axle load for each vehicle weight group. The usefulness of the results of a cost allocation analysis depends critically on the quality and accuracy of these data. The VMT input has direct influence on the cost responsibility computation of almost every expenditure item. Reliable axle load input is crucial for allocating bridge and pavement costs. Operating axle load information forms the basis to derive correspondence matrices between vehicle registration and operation weights. Apparently, a detailed field survey is necessary for collection of reliable input data when an update cost allocation analysis is to be performed.

Updating of Cost Allocation Methodology

Several areas exist in cost allocation study in which the limits of current knowledge do not allow technical analyses to be carried out fully. Subjective judgments are involved in allocating some expenditure items. One of the most controversial topics is undoubtedly the determination of attributable and

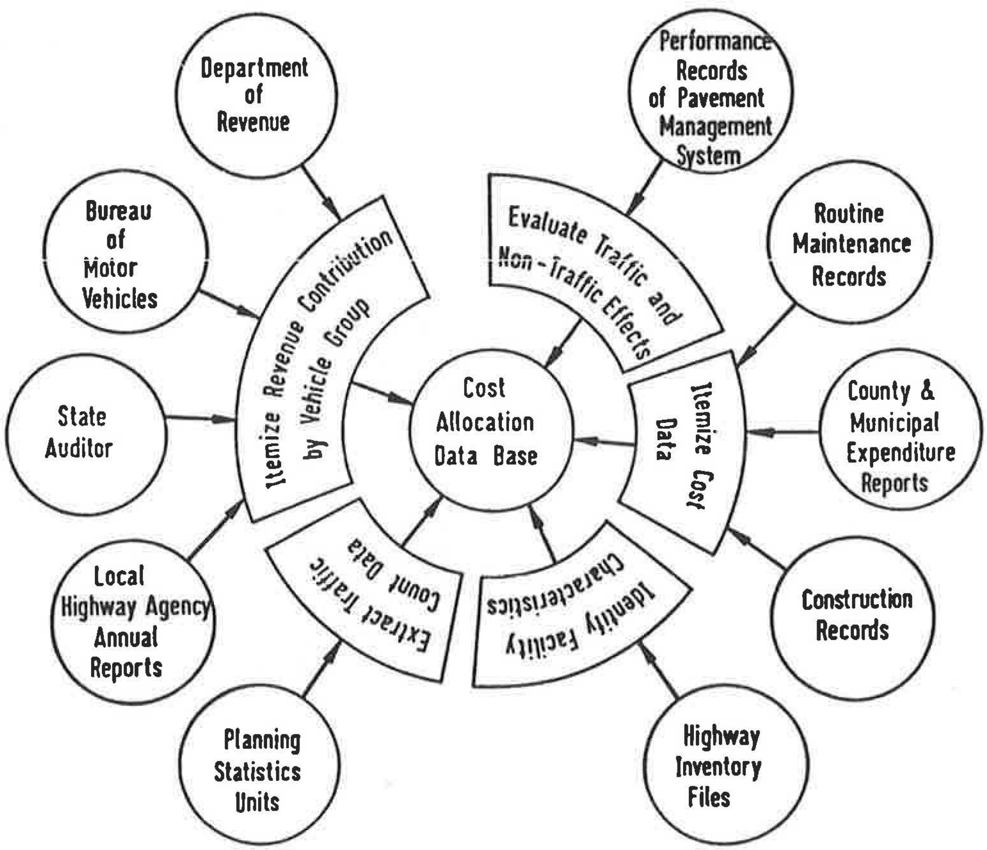

FIGURE 5 Links between cost allocation data base and other data storage systems.

non-attributable components of an expenditure item. Non-attributable costs refer to expenditures that result from non-traffic causes such as the action of environmental forces, and expenditures incurred based upon aesthetic or political considerations. These costs cannot be attributed to any particular user groups. Attributable costs are those that can be attributed to one or more highway user groups. Further research on traffic and non-traffic-related effects on factors such as pavement performance and bridge deterioration is required to help identify the relative proportions of attributable and non-attributable costs. Allocation of safety improvement costs is another area in which clear-cut procedures are not available. Updating of cost allocation methodology in these areas should be carried out as more information becomes available.

CONCLUSIONS

A detailed description of the procedures involved in the 1988 update analysis of the cost allocation study in Indiana has been presented. Results and findings of the analysis are presented and discussed. Based on the analysis conducted, several key elements involved in an update analysis of highway cost allocation were identified. The experience derived from the study has shown data collection and processing to be the most crucial phase in an update cost allocation analysis. It was the phase that had direct impact on the outcome of the analysis. It was also the phase that required the most resources and time.

Because cost allocation is an important element of the process of pricing and financing highway services in many states, and because the dynamic nature of the problem makes periodic updating of such analysis desirable, the authors stress the need to establish a data base consisting of relevant information extracted from other systems that exist in a typical highway agency. This would enable periodic cost allocation update analysis to be conducted efficiently and would help provide state highway agencies with a tool to formulate financing schemes to meet highway and transportation needs.

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Publication of this paper sponsored by Committee on Application of Economic Analysis to Transportation Problems.

Depreciation of Motor Vehicles in New Zealand

CHRISTOPHER R. BENNETT AND ROGER C. M. DUNN

Motor vehicle depreciation can be a significant component of total vehicle operating costs. It is therefore important to consider depreciation in economic appraisals of road improvement projects. The results of a study into motor vehicle depreciation in New Zealand are presented in this paper. Depreciation equations that predict the rate of depreciation as a function of the vehicle age and kilometerage were developed from resale data. These equations were developed for passenger cars, light commercial vehicles, and medium and heavy commercial vehicles. The stability of depreciation over time was investigated by performing the analysis on data from 17 months earlier. It was found that depreciation was unstable with respect to time, leading to the recommendation that a simpler technique be adopted for calculating depreciation costs. The technique recommended was capital recovery, a straight-line depreciation technique that considers the effect of time on capital. The depreciation equations were used to investigate the allocation of depreciation between time and vehicle use. It was found that the majority of the depreciation costs are due to time, not vehicle use.

There are two broad groups of vehicle operating costs. The first category contains the costs associated with the consumption of readily quantifiable resources, such as fuel and tires. The second category includes costs associated with vehicle ownership, including maintenance, depreciation, and the opportunity (or interest) cost of vehicle ownership.

Depreciation costs can constitute a significant portion of the total vehicle operating costs, for some vehicle classes as much as 30 percent (*1*). Depreciation costs are therefore an important consideration in economic appraisals of road improvement projects. Depreciation is the loss in value of an asset that is not restored by repairs and maintenance. It arises due to vehicle use, the passage of time, and changes in vehicle technology. Within these three broad factors, a number of specific items contribute to motor vehicle depreciation, including

- Vehicle characteristics,
- Utilization,
- Service life,
- Operating conditions,
- The demand for, and availability of, new vehicles,
- Changes in the capital costs of new vehicles, and
- Improvements in new vehicle technology.

Because of the nature of depreciation, it is not appropriate to use depreciation relationships developed in different countries for estimating depreciation costs. A study was thus undertaken in New Zealand to develop relationships suitable for local vehicles (*2*). The study results for three classes of vehicles are presented here, namely:

- Passenger cars,
- Light commercial vehicles, and
- Medium and heavy commercial vehicles.

Although maintenance, depreciation, and interest costs are interrelated, maintenance costs were not considered in the project.

The paper begins with a discussion of some of the major research conducted on depreciation, both overseas and in New Zealand, and is followed by a presentation of the results of the present study of depreciation costs of New Zealand vehicles. The allocation of depreciation between age and use is then considered. Finally, recommendations for calculating the depreciation costs of vehicles are presented.

PREVIOUS RESEARCH

Many studies have investigated motor vehicle depreciation. Macdonald (*3*) summarizes the conclusions of these various studies. Two distinct approaches have been used for quantifying depreciation. The first is based on accounting practices, and the second is based on resale prices of motor vehicles.

Among the accounting-based techniques used or proposed for motor vehicle depreciation are the "sinking fund," "declining-balance," and "sum-of-the-years-digits" techniques (*4*). However, the most commonly used technique is the "straight-line" technique, where the initial capital value of the vehicle is divided by the lifetime utilization to obtain a per kilometer cost. A variation of this technique based on a capital recovery factor has been used in South Africa (*5*). This factor converts the new vehicle cost to an annual cost, and a sinking fund factor is used to convert the residual cost to an annual cost. It is identical to straight-line depreciation, except that it considers the effect of time on capital.

Among the projects that have used field data for developing depreciation relationships are the four major international road-user cost studies conducted in Kenya (*6*), the Caribbean (*7*), India (*8*), and Brazil (*9*). Each study investigated the full range of vehicle operating cost components, besides depreciation. A summary of the relationships from these studies is given elsewhere (*10*). Figure 1 illustrates predicted passenger car depreciation using these relationships. This figure shows

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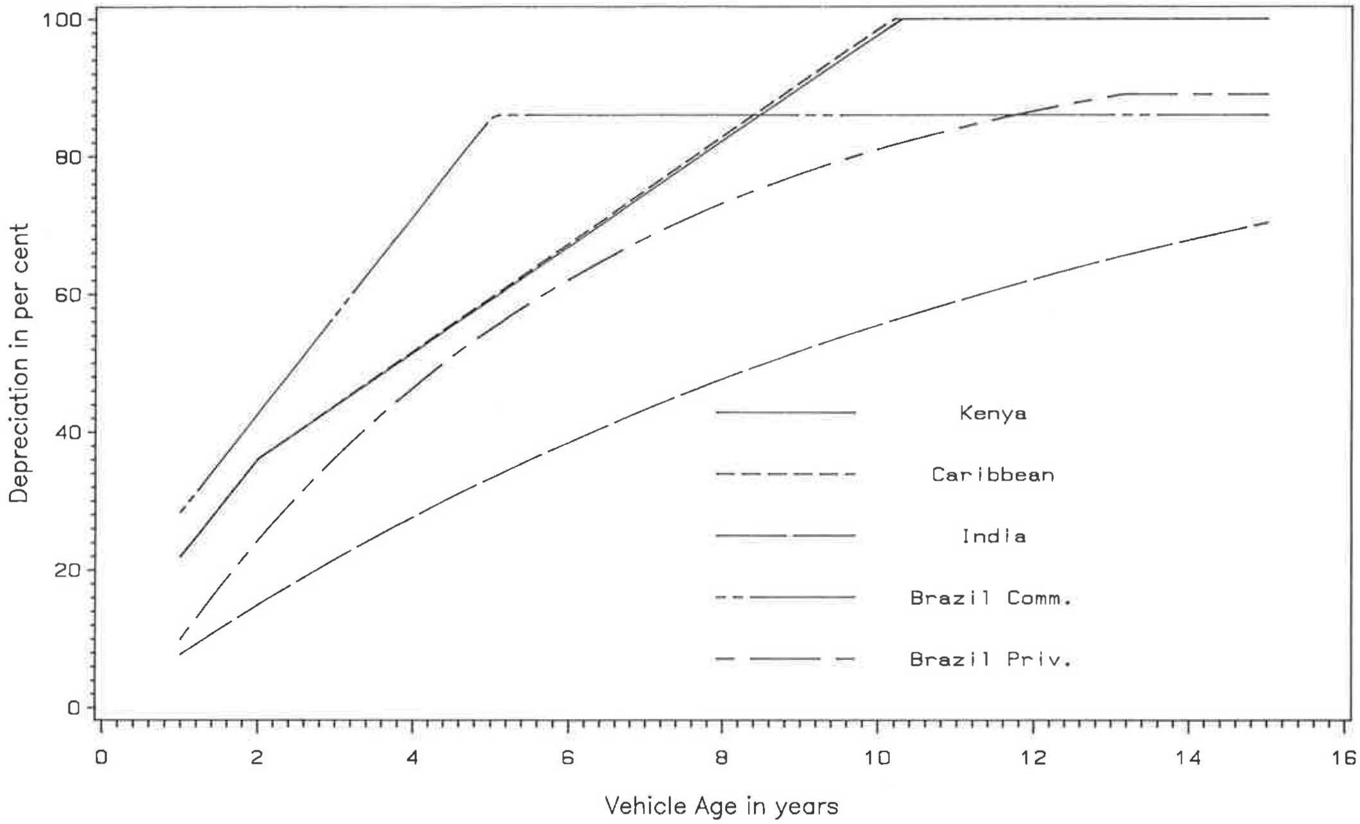

FIGURE 1 Road user cost study depreciation predictions: passenger cars.

the distinct differences between the depreciation relationships from these different countries.

In New Zealand, a study of private motor vehicle depreciation was undertaken in Wellington during 1979 (*11*). Data were collected on 446 passenger cars over five weeks from local newspapers. The data included the engine capacity, kilometerage, age, and whether the vehicle had an automatic transmission.

Depreciation was defined as the difference between the current selling price and the original vehicle price. The original vehicle price was updated to current dollars using the Consumer Price Index (CPI). The price was taken as of July 30 in the year of manufacture, and the sales tax was excluded, before update. The current sales tax was then added to the updated price and a 10 percent markup was added to obtain a current economic value. Vehicles with high levels of depreciation were excluded from the study, reducing the number of data points to 343. The following equation was fitted to the data:

$$\text{DEPREC} = 0.7173\,(\text{AGE})^{0.5018}\,(\text{KM})^{0.3018} \quad (1)$$

where

DEPREC = depreciation as a percentage
AGE = vehicle age in years
KM = total vehicle kilometerage in km

A similar study of commercial vehicles was conducted in 1984 (*12*). Data were collected on 97 commercial vehicles, and using the same updating technique (*11*), the depreciation was established. The following two relationships were presented:

$$\text{DEPREC} = 2.3944 - 3.2064\,(\text{AGE})^{-0.1282}\,(\text{KM})^{-0.0324} \quad (2)$$

$$\text{DEPREC} = 0.0973\,(\text{AGE})^{0.4137}\,(\text{KM})^{0.0955} \quad (3)$$

Equation 2 predicts a non-zero depreciation for zero age and utilization. Although the structure of Equation 3 precludes such an occurrence, it was recommended that Equation 2 be used in preference to Equation 3 because of its better overall predictive ability (*12*).

As with the earlier passenger car study (*11*), the weighting of the exponents indicated that the depreciation was again more sensitive to age than to utilization. It was recommended that 80 percent of the commercial vehicle depreciation be attributed to age and 20 percent to use (*12*).

Different countries have different depreciation relationships. (Figure 1). This is anticipated given the dependence of depreciation on such factors as tax rates and other country-specific factors. There is thus a need to develop locally calibrated and validated relationships. Although such relationships were developed in New Zealand (*11,12*), the major changes in the New Zealand economy since these studies were conducted brings into question their relevance under current economic conditions. Consequently, a more up-to-date study of the depreciation of motor vehicles was conducted. The results are presented in the following sections.

DEPRECIATION OF MOTOR VEHICLES IN NEW ZEALAND

The results of two New Zealand studies, one conducted in 1979 into passenger car depreciation and a second conducted in 1984 for commercial vehicles have been presented. Since these studies, a number of major changes occurred in the New Zealand economy that may have influenced the depreciation characteristics of vehicles. Among these changes have been

- Reduction in the import restrictions on used motor vehicles.
- Changes in the tariffs and taxes on motor vehicles.
- Fluctuations in the value of the New Zealand dollar.
- Elimination of distance restrictions for heavy commercial vehicles.

It is anticipated that these changes, among others, would alter the rate of motor vehicle depreciation. Thus, it was deemed desirable to further study the depreciation costs of New Zealand vehicles.

Data were collected on advertised resale prices for passenger cars, light commercial vehicles, and medium and heavy commercial vehicles from newspapers and the *Dealer's Guide*. The latter, a trade publication, gives prices for vehicles sold among dealers and was used to gather the medium and heavy commercial vehicle data. The passenger car data was adjusted to reflect the fact that the vehicles sell for less than their advertised price. The dealer prices were also adjusted to remove the dealer markups.

Because of changes in import restrictions on passenger cars, two sets of data were collected, one from early 1987 and the second from May/June 1988. These data sets were used to evaluate stability of depreciation over time. For the other vehicle classes, the data was from May/June 1988.

Analysis Technique

For passenger cars and light commercial vehicles, two analysis techniques were employed. The first is termed the "replacement value" techique, while the second is the "economic" technique. Only the economic technique was used for the medium and heavy commercial vehicles. The replacement value technique is the same as that used by the Transport and Road Research Laboratory (TRRL) in Kenya, the Carribean, and India (*6,7,8*). This technique defines depreciation as the difference between the current market value of a similar vehicle and the resale value.

The economic technique was used in the previous New Zealand studies (*11,12*). The original sales price of the vehicle is converted to an economic cost by deducting the sales tax applicable in the year of manufacture. This value is then updated using the CPI to the current year, and the current year sales tax is then added to the updated price to get the current economic cost. Depreciation is defined as the difference between the updated economic cost and the current resale price. In both instances, depreciation was defined as a percentage of either the replacement value or the updated economic cost.

To facilitate the analysis, a computer program was written. The program reads in a string of data containing the make, model, age, kilometerage, and advertised resale price. These data are compared with a data file that contains the original sales prices (or replacement values) for the vehicles. When a match of input and file data is found, the program calculates the depreciation for the vehicle. Before the analysis could be performed, it was necessary to modify the data to reflect the fact that vehicles are sold for a lower than advertised resale price. A number of private advertisers were contacted to obtain the actual sale price as opposed to the advertised price. It was found that the average actual sales price was 91.31 percent of the advertised price.

Results

Table 1 presents the summary statistics for each vehicle class. A relationship between the depreciation and both the vehicle age and kilometerage was postulated. This was found to be the case in the two earlier New Zealand studies (*11,12*). Before vehicle age and kilometerage could be used in the analysis, it was necessary to determine whether they were collinear. Collinearity occurs when there is a high degree of correlation between independent variables and indicates that the variables are measures of the same underlying process. It is therefore inappropriate to use collinear variables in a regression model.

Correlational analyses were used to investigate the relation between depreciation, vehicle age, and kilometerage. For all three vehicle classes, it was found that the depreciation was highly correlated with age and only slightly correlated with kilometerage. There was a low correlation observed between age and kilometerage. This was unexpected because various overseas studies (*6–8*) had found high correlations between age and kilometerage. Because these variables were not highly correlated, it was possible to include both age and kilometerage as independent variables.

A non-linear regression was performed using a SAS personal computer statistics package. A variety of models were tested, and the models that best represented the data are presented below. The standard errors are given beneath each of the coefficients in the equations.

Passenger Cars

$$\underset{(1.6910)}{\mathrm{DEPRV} = 12.0000}\,(\mathrm{AGE})^{\underset{(0.0119)}{0.2751}}(\mathrm{KM})^{\underset{(0.0137)}{0.1108}} \quad R^2 = 0.99 \tag{4}$$

$$\underset{(1.6881)}{\mathrm{DEPEC} = 12.4586}\,(\mathrm{AGE})^{\underset{(0.0114)}{0.2637}}(\mathrm{KM})^{\underset{(0.0131)}{0.1079}} \quad R^2 = 0.99 \tag{5}$$

Light Commercial Vehicles

$$\underset{(1.2192)}{\mathrm{DEPRV} = 31.0542}\,(\mathrm{AGE})^{\underset{(0.241)}{0.4105}} \quad R^2 = 0.98 \tag{6}$$

$$\underset{(1.3256)}{\mathrm{DEPEC} = 39.4946}\,(\mathrm{AGE})^{\underset{(0.0216)}{0.2843}} \quad R^2 = 0.98 \tag{7}$$

Medium and Heavy Commercial Vehicles

$$\underset{(4.7743)}{\mathrm{DEPEC} = 11.1900}\,(\mathrm{AGE})^{\underset{(0.0488)}{0.4625}}(\mathrm{KM})^{\underset{(0.0375)}{0.0709}} \quad R^2 = 0.95 \tag{8}$$

TABLE 1 SUMMARY STATISTICS FOR VEHICLES IN STUDY

Variable	Mean	Median	S. Dev.	Min.	Max.
Passenger Cars - 402 Observations					
Age	5.92	5.50	3.04	0.25	16.50
Kilometreage	73715	74500	32959	5000	228000
Replacement Value Dep.	65.14	67.95	14.97	9.40	95.20
Economic Dep.	64.31	65.25	14.07	10.50	92.10
Light Commercial Vehicles - 106 Observations					
Age	3.89	3.50	2.58	0.50	12.50
Kilometreage	58269	58500	30023	4000	150000
Replacement Value Dep.	51.09	50.15	17.37	10.80	88.40
Economic Dep.	55.22	54.50	14.38	20.70	87.20
Medium and Heavy Commercial Vehicles - 95 Observations					
Age	3.89	3.50	2.58	0.50	12.50
Kilometreage	144621	102988	10900	25000	469000
Economic Dep.	51.76	49.70	18.96	17.60	95.10

where

DEPRV = depreciation as a percentage of the replacement value,
DEPEC = depreciation as a percentage of the economic value,
AGE = vehicle age in years, and
KM = total distance travelled in km.

For light commercial vehicles, the analysis could not produce appropriate equations (that is, with correct signs for the coefficients) using both utilization and age as independent variables. Hence, Equations 6 and 7 only use age as the independent variable. Only the economic depreciation was investigated with medium and heavy commercial vehicles. A residuals analysis showed that the equations gave a good representation of the field data and that there were no observable biases in the predictions. The maximum residual values were on the order of 25 percent, although the majority fell within a band of ±10 percent.

While the various equations predict zero depreciation at zero age and utilization, in practice new vehicles depreciate rapidly. After examining the data set and information on dealer markups, it is recommended that the minimum depreciation be set at 20 percent. This will reflect the depreciation that occurs shortly after the purchase of a new vehicle. Similarly, it is possible to have equations predicting a depreciation greater than 100 percent. This is clearly unreasonable and on the basis of the data, it is recommended that the maximum depreciation be set at 90 percent. The passenger car and medium and heavy commercial vehicle equations indicate that the depreciation is much more sensitive to age than to utilization. This was also found in the previous two New Zealand studies (*11,12*). The issue of allocating the depreciation between the time and use components is discussed below.

Replacement Value and Economic Techniques

The replacement value and economic techniques are distinct methods for calculating depreciation. Both techniques have conceptual merits, and both have disadvantages. From the perspective of highway investments, the economic technique would be most favored. It deals with the change in the economic value of a commodity over time. However, because the current resale values are probably not based on the vehicle's original economic value, some researchers argue that it is inappropriate to use this technique.

Conversely, the replacement value technique relies on matching a current value for a similar vehicle to the resale price. This method is fraught with difficulties because such matching is subject to the opinions of the analyst and may not adequately reflect the public's decision-making patterns. Also, because considerable changes in vehicle technology have occurred over time, it is impossible to match two vehicles exactly, even when they are the same model differing by only a few years.

Thus, it is important to examine the differences in the depreciation equations resulting from these two techniques. In comparing the passenger car equations, it will be observed that the coefficients of the replacement value and economic depreciation equations are very similar.

Coefficient	*Replacement value*	*Economic*
Constant	12.0000	12.4586
Age	0.2751	0.2637
Kilometerage	0.1108	0.1079

The two equations give similar predictions for low ages; however, as the vehicle age increases, the economic depreciation technique predicts a much lower rate of depreciation. Both equations give reasonably similar predictions for the effects of kilometerage on depreciation. For light commercial vehicles, the two techniques resulted in equations with much larger differences; however, it is considered that this is primarily because of difficulties in specifying a replacement vehicle for some of the light commercial vehicle data.

Because both techniques yield similar results, either could be used to analyze resale data. The economic technique has an advantage that is important in highway evaluations—it is based on the changing value of a commodity over time. The economic technique also uses the original sale prices for vehicles in the calculations. Original sales prices are easier to obtain and probably more meaningful than the estimates of similar current vehicles used with the replacement value technique. Consequently, it is recommended that the economic technique be used in preference to the replacement value technique.

Time Stability of Passenger Car Depreciation

As discussed earlier, passenger car data were collected from both January 1987 and May/June 1988. These data provided for an investigation of the time stability of depreciation. The analysis was performed using the 1987 data, and a new depreciation equation was developed. Because of time constraints, only the economic technique was employed. There were 301 depreciation observations in the 1987 passenger car data file. The data had similar age and kilometerage statistics to those of the 1988 data. The 1987 data had a higher correlation between age and kilometerage than was observed with the 1988 data; however, it was considered not of sufficient magnitude to cause problems with collinearity.

A model was fitted to the data using the same technique as for the 1988 data. Table 2 summarizes the coefficients for the 1987 and 1988 economic passenger car depreciation relationships. The economic depreciation relationship coefficients developed in another study are also presented (*11*). It can be observed from this table that the coefficients from these three models are substantially different, even for the 1987 and 1988 data sets.

A comparison of the predictions for the 1979, 1987, and 1988 passenger car economic depreciation relationships as a function of age is presented in Figure 2. The curves are for a vehicle with an assumed use of 5000 km/year for each year

TABLE 2 COMPARISON OF PASSENGER CAR ECONOMIC DEPRECIATION MODEL COEFFICIENTS

	Year of Depreciation Relationship		
Coefficient	1979[a]	1987	1988
Constant	0.7173	4.1179	12.4586
Age Exponent	0.5018	0.4270	0.2637
Km. Exponent	0.3108	0.1650	0.1079

Notes: [a]/ This relationship is given in (11).

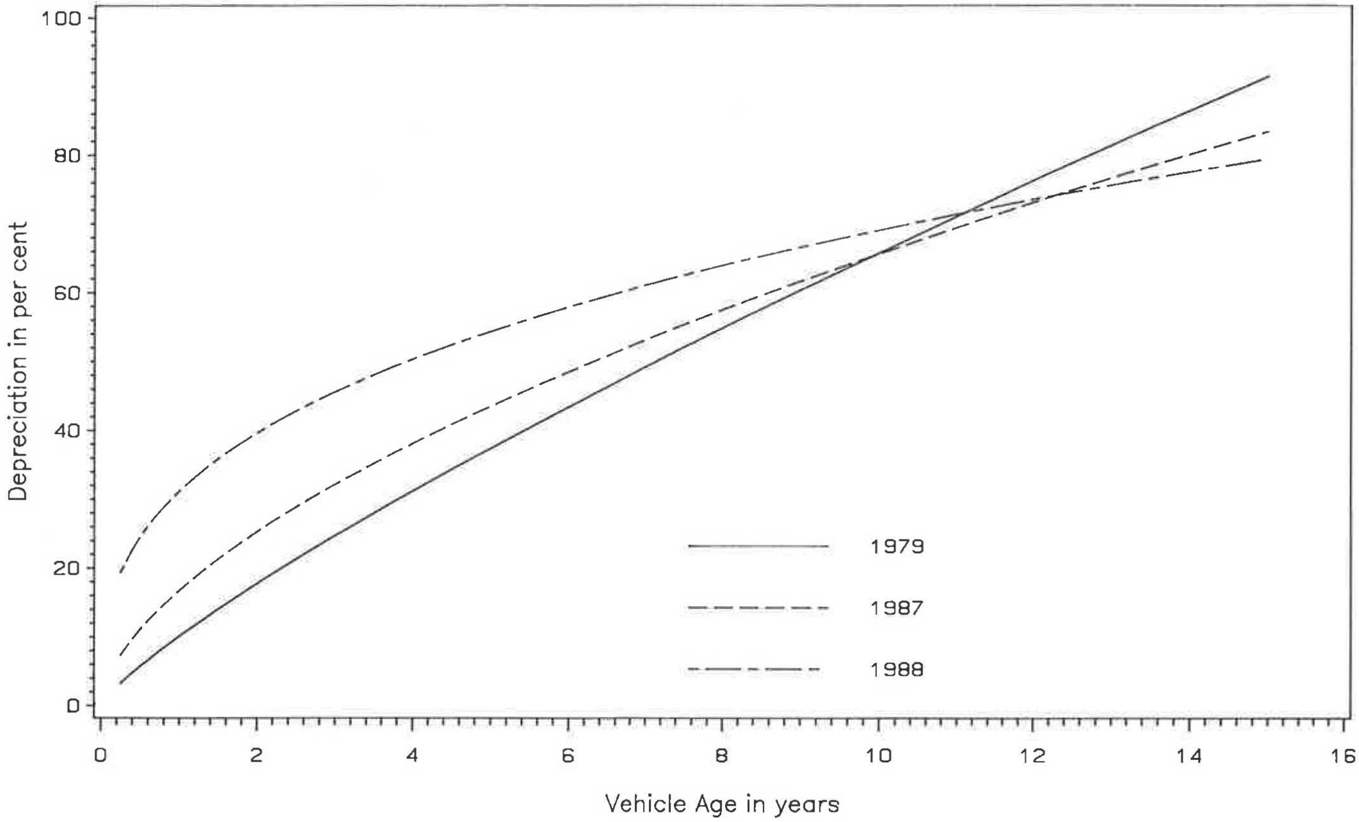

FIGURE 2 Line stability of depreciation.

of its service life. This is at the lower bound of annual utilization for New Zealand passenger cars; however, because the equations are relatively insensitive to utilization, the value assumed had little influence on the results.

Given the significant differences in the predictions of the three depreciation equations, the rate of passenger car depreciation appears to be unstable with respect to time. This is true even for data collected only 17 months apart. Thus, the usefulness of developing detailed equations for predicting depreciation is questionable if they are only pertinent for a short period.

DEPRECIATION COSTS OF VEHICLES IN NEW ZEALAND

Although this project developed relationships that predict depreciation as a function of the vehicle age and utilization, these equations are unstable with respect to time—a major shortcoming. As illustrated earlier, the 1988 passenger car economic equation is significantly different from the equation developed from 1987 data. Both equations are different from the one developed in 1979 (*11*). Because of these differences, it is recommended that these depreciation equations not be employed to calculate the depreciation costs of vehicles. Rather, a simpler technique should be adopted.

It is recommended that the capital recovery technique be used to calculate motor vehicle depreciation. This technique, presented by Schutte (*13,14*) and later modified by Pienaar (*15*), allows for a direct calculation of per kilometer depreciation costs. It is straight-line depreciation allowing for the effects of time on capital. The total depreciation costs are defined as the difference between the cost of the new vehicle, less tires, and the vehicle's residual value. Both the new and residual values are adjusted for the effects of time on money and converted to an annual cost. This annual cost is then adjusted to take utilization into account.

The capital recovery technique is illustrated in the cash-flow diagram given in Figure 3. A capital recovery factor is used to convert the new vehicle cost to an annual cost, while a sinking fund factor converts the residual cost to an annual cost. Pienaar (*15*) gives the following equation for calculating the per kilometer depreciation costs. His equations, as previously published (*5*), are as follows:

$$\text{DEPCRT} = \text{NVPLT}\ ik[(1 + ik)^{LKM} - 0.05)/((1 + ik)^{LKM} - 1)] \quad (9)$$

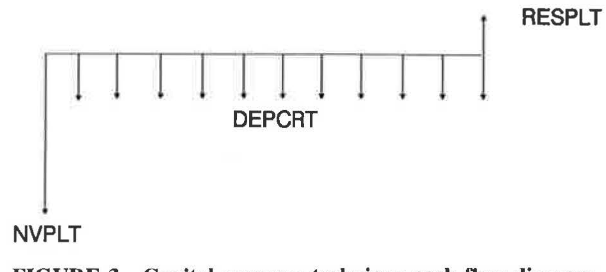

FIGURE 3 Capital recovery technique cash-flow diagram.

where

DEPCRT = the monthly or annual depreciation cost in dollars using the capital recovery technique,
ik = the interest rate per kilometer (in decimals),
LKM = total lifetime kilometerage, and
NVPLT = the new vehicle price less tires.

The per kilometer interest rate is calculated using the following identity:

$$(1 + ik)^{AKM} = 1 + i \quad (10)$$

where

AKM = baseline annual utilization (in km),
i = interest rate (in decimals), and
ik = interest rate per km (in decimals).

This results in Equation 11. (Terms defined above.)

$$ik = (1 + i)^{1/AKM} - 1 \quad (11)$$

Equation 9 contains a coefficient 0.05. This value represents the residual value of the vehicle assumed to be 5 percent of the new vehicle price.

The depreciation costs are usually expressed on a per km basis (DEPKM) so the depreciation is given as:

$$DEPKM = DEPCRT/AKM \quad (12)$$

Using the capital recovery technique in conjunction with values for the vehicle utilization and service life, the per kilometer depreciation can be expressed solely as a function of the new vehicle price less tires. This cost must then be modified to consider the allocation of depreciation. This allocation is discussed in the following section. A similar technique can be used for calculating the interest costs. This vehicle initial capital cost is treated as an arithmetically declining series. Using an appropriate factor, this series can be converted into an annual cost.

ALLOCATING DEPRECIATION COSTS BETWEEN TIME AND UTILIZATION

It is necessary to allocate the depreciation costs between the time- and distance-based components. The time-based component is an overhead cost, while the utilization-based component is a running cost. Only the latter should be included in an highway economic appraisal. Table 3 presents estimates of allocations from various sources. There is little consistency in these estimates, that range from 100 percent distance-based to 80 percent time-based.

The depreciation equations developed in this study indicate the rate of change of depreciation with respect to time and utilization. Because of the nature of the depreciation relationships, allocation between time and distance is not constant over the life of the vehicle; it changes in a non-linear form. However, the changes are very small, so it is possible to assume a constant value for the allocation.

Because the light commercial vehicle equation only uses age as an independent variable, allocation could only be investigated for passenger cars and heavy commercial vehicles. With the latter vehicles, the estimates will have a greater degree of uncertainty due to the relatively high values for the standard errors of estimate. The allocation was established by assuming an annual utilization rate for the vehicles. For simplicity, it was assumed that the utilization was constant for the entire service life. As illustrated in the earlier New Zealand study (*12*), this is not an accurate assumption, because utilization decreases with increasing age; however, the assumption does not have a significant effect on the results.

Depreciation was calculated for two scenarios. In the first, it was assumed that the vehicle was not used over a 12-month period. In the second, it was assumed that the annual utilization occurred instantaneously. Comparing these two scenarios indicated the allocation between time and distance components. To allow for comparision, the calculations were performed using the results of the earlier New Zealand studies (*11,12*). The resulting allocations are presented in Table 4.

Despite the differences between the 1987 and 1988 passenger car predictive relationships, the allocation between the time and distance components remained fairly constant at just over 70 percent due to time and 30 percent to use. This is, however, a substantial change from the 1979 study in which 60 percent of the depreciation was found to be due to time and 40 percent to use. The allocation was found to be similar for both the 1988 replacement value and economic equations.

For medium and heavy commercial vehicles, there has been a similar shift, with the current allocation being approximately 87 percent time and only 13 percent use. This compares with previous values of approximately 80 percent time and 20 percent use from the 1984 study. It is recommended that the medium and heavy commercial vehicle allocation be used for light commercial vehicles, buses, and trailers. Although the light commercial vehicle equations did not find utilization significant, a small proportion of the depreciation will undoubtedly arise from vehicle use. This also applies to buses and trailers. Thus, it is recommended that the following values be used for allocating the depreciation costs between time and distance.

	Percentage of Depreciation Due to	
Vehicle class	*Time*	*Distance*
Passenger cars	70	30
Other vehicle classes	85	15

Daniels (*20*) proposed a technique using knowledge of the vehicle service life and utilization for estimating the allocation of depreciation. This technique was applied by Butler (*21*) to vehicles in the United States. It is anticipated that future studies will compare the predictions using the method developed by Daniels (*20*) with the allocations from the equations developed in this study. This could serve to validate the applicability of this latter technique, and allow monitoring of the allocation developed here without having to conduct complicated studies like those undertaken in this project.

CONCLUSIONS

This paper has discussed the depreciation costs of vehicles in New Zealand. Equations were developed for predicting the

TABLE 3 REPORTED ALLOCATIONS OF TIME AND DISTANCE DEPRECIATION COMPONENTS

Country	Source	Percentage of Depreciation Allocated to Time	Distance
U.S.A.	AASHO (16)	50	50
U.S.A.	AASHTO (17)	Varies[a]	Varies[a]
W. Germany	Macdonald (3)	50	50
G. Britain	Macdonald (3)	60	40
Denmark	Macdonald (3)	0	100
Australia	Abelson (18)	60	40
N.Z.	MOT (11)	60[b]	40[b]
N.Z.	MOT (11)	30[c]	70[c]
N.Z.	Bennett (12)	80[d]	20[d]
N.Z.	MOT (19)	33[e]	66[e]

Notes: a/ The allocation is a function of utilisation and speed.

b/ For passenger cars.

c/ This allocation was used by the Ministry of Works and Development in cost-benefit studies. It was further assumed that 50 per cent of the distance depreciation was due to use and 50 per cent to trip related activities.

d/ For heavy commercial vehicles.

e/ For light and heavy commercial vehicles. Various authors cited by (12) also recommend this split for commercial vehicle depreciation.

rate of depreciation as a function of age and utilization for passenger cars, light commercial vehicles, and medium and heavy commercial vehicles. They were based on data collected from newspapers and the *Dealer's Guide*.

Two methods were used to calculate the depreciation—the replacement value method and the economic method. The former defines the depreciation as the difference between the cost of a current similar vehicle and the current resale price, while the latter defines the depreciation as the difference between the updated original sales price and the current resale price. Only the economic method was used for heavy commercial vehicles.

Both techniques were found to yield generally similar results. Thus, it is possible to employ either technique and be confident of the results. From an analyst's perspective, the economic technique is easier and more consistent to employ because it is based on "hard" data available from researching past sales histories. It is difficult to ensure consistency when applying the replacement value method, and the results may be due in large measure to the analyst's judgment.

It is therefore recommended that where necessary, the economic technique be used in preference to the replacement value technique for calculating the depreciation. In all instances, it was found that age was the dominant effect in motor vehicle depreciation, particularly for light commercial vehicles where the utilization coefficients were not found to be significant.

An investigation was made of the stability of depreciation over time. This was accomplished by performing the same analysis on a data base dating from early 1987 (17 months earlier). It was found that the 1988 depreciation relationship was significantly different from the one developed from the 1987 data. Given the changes in the New Zealand car market that had occurred during this period, some difference was expected, but not of the magnitude observed in this study. When these equations were compared with those from an earlier study conducted in Wellington during 1979, it was again found that the results were significantly different.

Because of the significant differences in the depreciation equations, it appears that the rate of depreciation is not stable over time. As a result, there appears to be little need to

TABLE 4 PREDICTED DEPRECIATION ALLOCATION

Vehicle	Year	Technique	Percentage of Depreciation Time	Distance
Passenger Cars	1979[a]	Economic	60	40
Passenger Cars	1987[b]	Economic	73	27
Passenger Cars	1988[b]	Economic	72	28
Passenger Cars	1988[b]	Rep. Value	72	28
Heavy Trucks	1984[c]	Economic	80	20
Heavy Trucks	1988[d]	Economic	87	13

Notes: a/ Using equation given in (11).

b/ Using equation from this study.

c/ Using equation given in (12).

d/ Using equation from this study.

develop complicated models that will only apply for a short time. It was therefore recommended that these models be dispensed with and a simpler method be adopted.

It is recommended that 70 percent of the passenger car depreciation be allocated to time and 30 percent to use. For all other vehicles, 85 percent of the depreciation should be allocated to time and 15 percent to use. Because of the instability of the depreciation equations with time, it was recommended that the capital recovery technique be used to calculate the depreciation costs. This technique is a straight-line depreciation that allows for the effects of time on capital.

ACKNOWLEDGMENT

This research was undertaken for the Road Research Unit of Transit New Zealand. Copies of the complete report or the software developed for the project can be obtained from the authors. There is a small charge to cover copying costs and postage.

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Publication of this paper sponsored by Committee on Application of Economic Analysis to Transportation Problems.

Relations Between Transportation and Production

William L. Garrison and Reginald R. Souleyrette II

Ways in which transportation improvements enhance production are investigated in this paper. The production of residential housing is used as a case in point. Several approaches to analysis are proposed. The one adopted emphasizes productivity improvements from technological change. After considering several ways that transportation services may relate to technological change, the authors provide an analysis of the diffusion of wallboard construction. Overall, the study concentrates on methodology and magnitudes. It provides a way of thinking about transportation and production relations, and indicates that service improvements may yield social savings of large magnitude.

The concern here is with the ways that transportation improvements enhance the uses of old resources and make new ones available, expand the scopes of markets and labor sheds, provide new production and consumption choices, and generally shape and improve social and economic aspects of life. To simplify, the word "production" is substituted for these transportation-related activities and the relations between transportation and production are analyzed.

The inquiry is unusual in two ways. First, the objective is to explore taken-for-granted relations in a crisp, analytic fashion. That is much easier said than done as this report on the work will indicate. Beginning with conventional analytical approaches, paths are explored through a maze. The path followed to its end related transportation services to innovation and innovation diffusion processes.

The inquiry is also unusual because its concern is with the ways that transportation services energize non-transportation activities. This is in contrast to today's situation in which transportation is mainly regarded as a necessary evil, and the evil is emphasized. It is evil because it gobbles energy, insults the environment, and takes money and time. In response, analyses, technologies, projects, and policies are developed to reduce costs and enhance safety, control environmental insults, and improve energy efficiency.

This study did not set out to quarrel with today's emphasis on costs and the consideration of externalities because such emphasis is always appropriate. It seeks to go beyond that emphasis to richer views of the necessity-demand side. We would like to fill in the blanks in statements such as, "Reduce costs or improve service quality in order to ____________." A slice of production, the construction of residential housing, is used as a case in point, which was eventually narrowed to the use of wallboard in housing construction. Although factual rather than fictitious, the housing production study should be read as a parable. It is intended to explore and illustrate principles.

The presentation begins by providing some information on the housing production industry. Next, several paths for formal analysis suggested by conventional analytical approaches are reviewed. However, examination of the data suggested formulating a new approach, and our formulation of a new approach is discussed in light of the data and the study's main objective. The analysis and findings follow. The closure reflects on the study. It suggests expanding existing principles to include transportation's role in innovation and productivity changes, comments on today's relations between transportation and production, and asks for a richer consideration of the needs for transportation improvements.

A simple statement of the conclusion is that in one small instance, transportation improvements enabled social savings measured in billions of dollars. That is part of our message, for it says that transportation improvements do consequential things for production. However, the larger part of the message has to do with methods. This is why the text to follow stresses the ways the problem was approached, how the analysis treated an instance from some larger set of relations, and the inferences derived from our results.

RESIDENTIAL HOUSING PRODUCTION

Housing production was selected as a case for study because it is an old, large, and ubiquitous activity. Housing is necessary for everyday life, and a housing problem is widely recognized. Housing production is transportation-intensive, and housing is produced using a complex of technologies. Dowall and Lynch refer to it as dispersed, diverse, discontinuous, and detached (*1*). Production is undertaken by many scattered firms of varied size, and the product and its environment vary (dispersed and diverse). It is a job-to-job business, sometimes seasonal (discontinuous). It uses contract labor and components produced away from the housing production sites (detached).

Modes of Production

In the United States, about 5 percent of residential construction uses modules. The modules are constructed at a factory, transported by truck, placed by crane, and assembled on-site. Somewhat similar is panelized construction, accounting for 12 to 22 percent of production. Panels for walls, floors, roofs,

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and so on, are prepared in a factory and assembled on-site. More work is done on-site than is the case for modular construction. Manufactured or mobile home type construction accounts for about 12 to 22 percent of production. Site-built homes account for 51 to 74 percent of housing units. Classifications overlap because some prefabricated units are used in almost all construction. This and variations among classifications account for the ranges of percentages (*1,2*).

Speculation, or contract builders, produce one or a few units at a time. Larger production builders purchase large tracts of land, subdivide it, and produce the housing product. In all cases, specialized crews work on-site installing framing, plumbing, and so on. The amount of work done on-site varies by mode of production, of course.

As the sketch suggests, there is considerable variability in production ranging from near-complete on-site to near-complete off-site. The timing and place of material and labor inputs vary accordingly. On average, off-site employment of labor in construction is about 13 percent of on-site labor employment, and labor required to install manufactured products comprises about 90 percent of on-site employment (*1,3*).

In Trouble

It is widely agreed that productivity gains are nil, if not negative, in housing production and construction in general. There is agreement despite the difficulty of measuring productivity and productivity changes in these activities. The industry is diverse, and data collection is difficult. Housing is not a highly standardized product. There are regional and other differences in the product and its inputs at any time. The housing product has changed over the years.

It appears that productivity gains occurred from about the end of World War II to the late 1960s, and declined subsequently. One source reports construction productivity improvements of 3.4 percent per year between 1948 and 1965 with a decline of 1.8 percent per year thereafter (*4*). Another source reporting on housing estimated an increase of 2.4 percent per year from 1950 through 1968 and a decline of 2.8 percent per year from 1969 through 1978 (*5*). In both cases, the rate declined 5.2 percent per year. Similar trends in highway construction productivity are well known to the transportation community.

The structure of housing production yields limited research and development, difficulties of transferring technology, and a varied market for products and processes. These are cited as the main causes for the productivity problem. Increases in land, energy, and capital costs, and the loss of economy of scale are also cited as causes. Declining productivity adversely affects real costs and housing prices. Beyond that, the decline adversely affects improving living standards and real economic growth.

Interestingly, transportation services are seen as a minor part of the housing productivity problem. Services get minor mention when manufactured housing is discussed, and if services appear at all in other discussions, they are far down laundry lists of problems. Yet reflecting on past changes in the industry, it is clear that transportation improvements had much to do with the availability of materials and with the mobility so important to the assignment of tools and specialized labor to on-site tasks. The past is out-of-sight and out-of-mind.

TRANSPORTATION AND HOUSING

As the brief sketch suggests, housing production provides rich topics for the transportation analyst. Working from existing principles and conventional methods of analysis, three approaches to topics will now be discussed: investigating relations between transportation and land for housing, the housing production system, and the producer's choice of production mode. Although these approaches were not followed in this work, it is important to say why they were not. Also, our approach was complementary, and future work combining approaches might be fruitful.

General principles have been stated here and there. For instance, Adam Smith pointed out in 1776 that transportation improvements yield increased specialization and associated efficiencies (*6*). Based on an extensive review, Ringwalt's 1888 study yielded 14 conclusions about transportation in the United States (*7*). His conclusions took the form: "Where ever a railroad goes, . . . " There is also DuPuit's insight of 1844: "The ultimate aim of a means of communication must be to reduce not the costs of transport, but the costs of production" (*8*). Although statements are available, there apparently is no systematic list of principles that might provide a starting point for this work, so the authors proceeded by stating problems for analysis and imagining principles that might be appropriate.

Land Use Relations

There is the well-known relation between land rents and transportation services; the relation ties transportation services to the supply and value of land at different locations. Land costs are, say, 15 to 25 percent of housing production costs, so matching transportation and land supply to housing markets is an important matter.

The interpretation of changes in location rents as a measure of something transportation does that is worth doing has been of long-standing interest to transportation professionals. The 1956 Interstate legislation calling for a cost allocation study asked that there be investigations of the user (on-system) and nonuser (off-system) benefits of highway investment. That call yielded studies of user cost savings and studies of nonuser benefits, the latter under the rubric of highway impacts on land development. But even at that time, the impact studies and the conjecture that funding might be tied to impacts were hardly new. They date at least from George Stevenson's 1856 remarks on the development of the London-Birmingham railroad and the 1790 funding scheme of George Washington and Thomas Jefferson for the development of Washington, D.C. (*9,10*).

Today, attention to the relation has reemerged under the rubric of value capture. Land owners whose property values are enhanced by improved transportation services are expected to contribute to facility investment costs. That was not the result of the 1956 study. It ignored nonuser benefits and emphasized user costs and the impact of vehicles of different types on facility costs.

The impact studies triggered by the cost allocation study triggered, in turn, reexamination of the theory of location rents. That theory leaves no room for nonuser benefits as something apart from user benefits: nonuser benefits appear as consumers' surplus created by transportation improvements (*11*). The modern debate, to the extent there is debate, may be no more than a debate about who gets the surplus.

Even so, this study began with the thought that there was more to the principle of nonuser benefits; that although user (on-system) benefits overlapped with nonuser (off-system) benefits, distinctive nonuser benefits existed that ought to be recognized in theory and practice. A close investigation of well-known principles would clarify the situation, principles such as these: transportation makes land available for housing; it offers opportunities for labor, tool, and product specialization; and it enables the movement of products for final assembly at the construction site.

Production and Economy of Space

There is no choice about where the final housing product will be produced; it is produced at the market. But as the brief discussion of housing production noted, a range of spatial production modes exists. Toward one extreme, the mobile home, almost all production is done off-site. On-site production is toward another extreme. These "toward-extremes" production formats are realizations from a tree-like production pattern. As noted, off-site processing may yield modules, finished units, or prefabricated components. On-site production largely skips these production paths, although there is much preprocessing off-site.

To what extent can analysis using the principles be investigated in the frame of the spatial structure of production? An approach based on concepts from spatial economics, regional science, and geography seems appropriate. The production space is endowed with markets and resources. With the usual assumptions, production location and output decisions interacting with resources and markets yield an optimal production pattern. The analytic task is to specify the production system in an equation system and investigate how transportation services affect the system.

Choice of Production Mode

As mentioned, the housing producer may choose among production modes—use of modules, panelized construction, and so on. Once the first choice of production mode is made, choices follow of a make-or-buy character (e.g., subcontract foundation work or not), choices among products to be installed, and choices among and about the specialized labor to be used. A choice analysis is suggested, a nested choice analysis of the type used in transportation mode choice analysis.

Choices are made among products and inputs, and in model specification it seems important to include space and time considerations because the production requires significant amounts of space and time, and these parameters may bear on choices made. Transportation services might bear on space-accessibility and enter in a logistics-time way, in addition to direct relations to available inputs.

FIRST EMPIRICAL INVESTIGATIONS

Having identified approaches to analysis, exploration began on the history of housing production and data sets that might be brought to formal system specifications. Two results were expected. First, production is complicated by the many paths and products in the production stream, and, second, there are sharp limitations on data availability. These expected results were to be dealt with through in-depth exploration of fragments of information.

Unexpected Information

Although the fragments of information were explored, the ambitious plan to treat the system as a whole was set aside when the data began to suggest relations that did not fit the process specifications very well. It is not practicable to reproduce the mass of data here, so examples of unexpected results will be given. (Occasionally data were found specific to residential construction; most available data are for construction of all types.)

Examining the labor inputs to production revealed a number of trends similar to those shown in Figures 1 and 2. [The

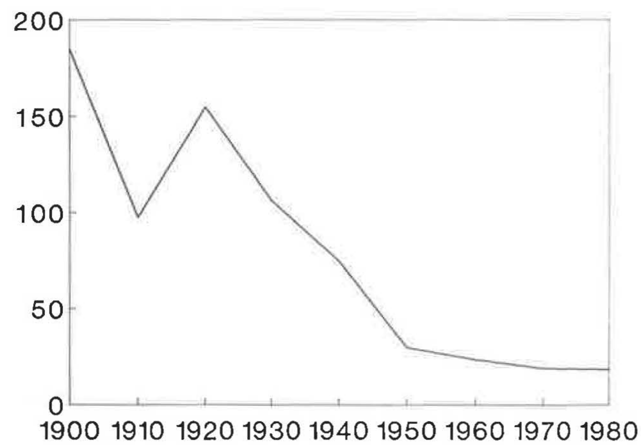


FIGURE 1 Carpenters per million 1967 dollars building value.

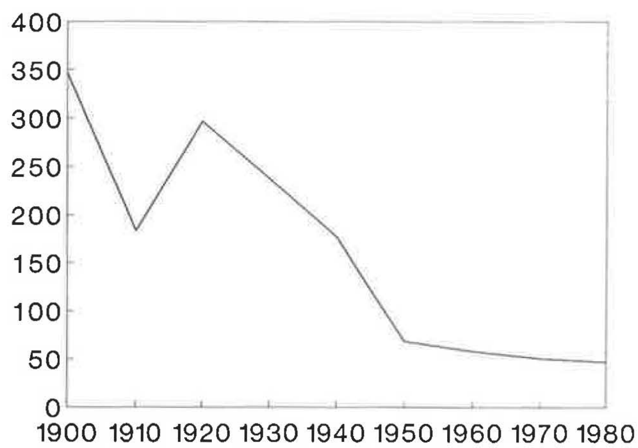


FIGURE 2 Total workers in six specialized trades (per million 1967 dollars building value).

curves shown in Figures 1–5 were calculated from Census Bureau data (*12,13*).] It was expected that the use of automobiles and small trucks to move labor to and among construction sites would improve the efficiency of labor inputs. Indeed, a 1921 report on the advantages of motor vehicle use stated that contractors' use of vehicles increased productivity by 51 percent (*14*). But that is much less than the almost order-of-magnitude improvement suggested by the figures.

Figures 3 and 4 display another unexpected result. Transportation improves access to resources and increases competition, so lower materials prices were expected. However, the figures display a long term increase in real prices, with variations around a set point since about 1950. Again, these data are fragments from a larger set.

Explaining the Unexpected

One option for dealing with these unexpected results was to return to the process specifications and begin to introduce plausible factors that might have yielded the findings. In the case of materials, for instance, one might suppose that real income increases, working with demand for improved quality, might have interacted with transportation's provision of increased access to products to yield increasing materials costs.

But two considerations pressed for another option. The first was the symmetry between realizations of transportation services and realizations of housing's production input processes. Examining truck service, for instance, suggests a rough correlation between the period of its rapid deployment and changes in inputs to housing construction. (Compare Figure 5 with previous figures.) In addition to such aggregate relations, bits and pieces of fragmentary data link the realizations. For instance, the development of canals enabled the marketing of building stone far from quarries, with labor at the quarry providing for stone finishing. This process ran as canals were deployed, and its realization must have tapered as the canals tended to full deployment. Housing producers shifted to a more expensive, higher quality product. Preprocessed, the product reduced demand for on-site labor. Though not discussed here, many similar relationships appeared for the rail, water, and highway modes.

Consideration of forces prevailing during the period that the transportation and housing development processes have been at work also pressed for an alternative approach. This was a period of great technological change. Capturing those changes in the process specifications considered in the previous section of this paper would require an exhaustive inventory of past and present processes. Models would need to be constructed to incorporate choices of one process or another and one production place or another. At first approximation, that is a vast task. Suppose, for instance, 50 processes in the production stream might take place in 50 places. This yields 50^{50} possible arrangements of processes. That number is an upper bound because processes are interdependent; some feed to others.

TRANSPORTATION AND TECHNOLOGICAL CHANGE IN HOUSING PRODUCTION

An investigation of the evolution of housing production technology was made to explore how technological change might enter the analysis.

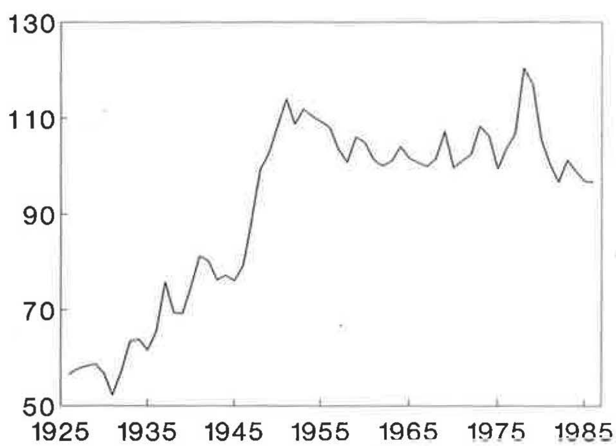


FIGURE 3 Real price of millwork (index: 1967 = 100).

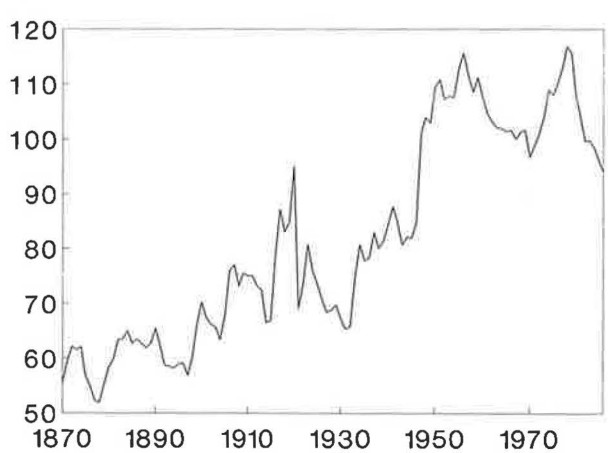


FIGURE 4 Real price of construction materials (index: 1967 = 100).

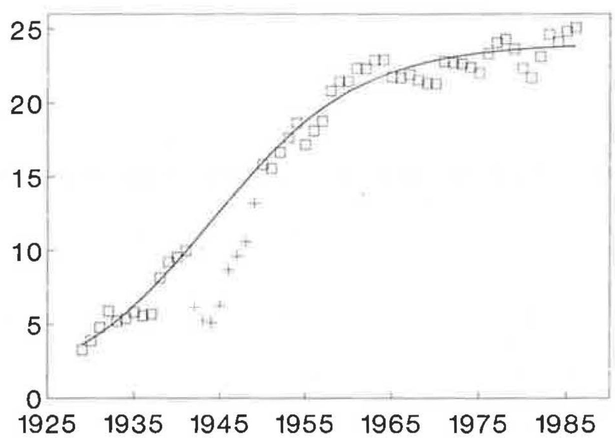


FIGURE 5 Motor truck freight as a percent of all intercity freight.

Inventory and Classification

Assuming that useful insights about transportation-housing production technologies would emerge from examining examples, the housing technology investigation began with an inventory of housing innovations. About 225 innovations were identified, beginning with the transition from earth- to sill-mounted footings about year 1200 and ending with today's interest in robotics. As would be expected, the completeness of the list was not known, and entries were variable in type and importance. Some technologies were clearly derivative of earlier ones; double counting was a problem.

Attempting to make the list usable, classifications were imposed. First, entries were arrayed on a time line. As mentioned, some technologies are derivative of others. This was found to be the case, and transportation relations entered in mixed ways. For instance, wallpaper became popular in the early 1700s, a development turning on fashion trends and the innovation of printing with transportation making the product available. The development of the Howe truss about 1840 followed earlier developments of truss framing and knowledge of the behavior of structures. The need for transportation structures no doubt played a role in its innovation.

A time line was also used because the authors were curious about the presence of innovation bursts and their relations to transportation and long wave theory. Invention is a continuous process, but invention-based innovations occur in temporal bursts (*15*). In turn, these bursts are related to long waves in the economy (*16*). One explanation for the relation is that economic down-cycles and depressions create opportunities for innovations. The resulting burst of innovations, followed by demand for new products and increased employment and investment opportunities, then drives an up-cycle in the economy. The empirical and theoretical underpinnings of long wave theory are much debated; transportation innovation and deployment have no special place in the debate. A line of inquiry was suggested, but not pursued. Even so, it was briefly mentioned because the concepts are discussed again later in this paper.

A second classification was attempted, one on process-versus-product technologies with an effort to scale transportation intensiveness within those categories. This effort was not very successful. Some technologies could not be neatly assigned to the process or product categories. The question of transportation intensiveness was fuzzy; an example illustrates the problem. The powered-nail gun is a product, yet it is a product for use in the construction process. It is easy to transport, so at first glance, assign it to a not-transportation-intensive category. But on second thought, that assignment is not so neat. Surely the development and marketing of a specialized product of this type turns on transportation access to a large market. Its efficient use at a site is tied to transport and use of labor. The ability to move the gun from site to site also makes for its efficient use.

Processes of Innovation

Problems encountered in striving to develop useful classifications turned attention to considerations of processes of innovation and diffusion. The classic view of the innovation process has a design flair: building blocks are arrayed in a new design. Stevenson's first railroad, for example, combined physical building blocks from tramways and steam engines with canal and road common carrier concepts and franchise and financing concepts from public works generally. In a sense, the building blocks are clay, and they are molded into bricks (*17*).

That classic view applies in a straightforward way to the transportation modes (*18,19*). Extending it to products transported for use in housing production is one option; that is, think of transportation services as a building block for products, a transportability building block. This may be reflected in the size and weight characteristics of a product, in a companion packaging innovation, or in the product design. A product, such as an automatic washing machine, is built to survive the forces acting on it as it is used and when it is shipped. How do improved transportation services result in product innovations and improvements?

It has been pointed out that railroads were the first of the large modern businesses, and many railroad innovations were adopted in subsequent business developments. Railroad organization, corporate control, and uses of information have received particular attention (*20*). The subject is much broader, however. The development of transportation spawned generic public utility law; product testing, standards, and certification procedures; large scale financial markets; governments' roles in safety and labor affairs; accounting procedures; and many other things. All such innovations threaded their way through the economy. So another question that may be posed relates to the ways transportation innovations have been shaped and used in non-transportation sectors.

Finally, transportation (and communications) plays a role in the diffusion of innovations. Many innovations are embodied in products, and innovations are diffused as products are transported. Considering diffusion and the ways transportation may relate to the forms of products or services, one may think of transportation innovation as a companion innovation to innovations in other sectors. Transportation works with other sectors to provide new ways of doing things.

WALLBOARD

To move from generalizations to data-based analysis of the relations among transportation, innovation, and productivity gains, a case study was conducted of the substitution of wallboard for lath and plaster.

Wallboard (gypsum plaster board or drywall) was patented in 1895 and began to substitute for lath and plaster interior wall construction in the 1920s. Its installed cost is approximately one-eighth the cost of lath and plaster, and its cost comprises 5 to 15 percent of the cost of residential construction, depending on the type of housing. Wallboard is one of several products, such as millwork, fabricated off-site for installation on-site. Relative to lath and plaster, its installation is rapid and uses low cost labor.

Transportation relations bear in many ways. The patterns of gypsum mining, processing plants, and distribution are transportation dependent and have shifted as transportation services have changed. Today's product is a sheet of plaster covered with paper; it is sized 4 × 8 or 4 × 12 ft. The product is larger than it was in earlier days, and its strength, covering, and size appear to have responded to the transportation services available.

Process Specification

It was mentioned that transportation development might affect innovations in other sectors. Other sectors might emulate transportation innovations, configure products or services to the nature of the transportation services available, and/or use transportation to aid innovation diffusion. The innovation of wallboard appears to be affected in these ways. However, the emphasis in the analysis to follow is limited to the role of truck freight service in the diffusion of the wallboard innovation. This is a partial investigation of the ways transportation serves as a companion innovation to innovations in other sectors. A conservative, straightforward analysis was sought, one that could be compared with Robert Fogel's analysis of the contribution of railroads to economic growth (*21*).

Fogel posed the counterfactual hypothesis that river and canal services developed in the absence of railroad development. He then undertook a detailed geographical analysis to compare the cost of transportation by water-based services (fed by animal-drawn vehicles) with the cost of rail transportation. He concluded that railroads made only a minor difference although water service cost was slightly higher than rail cost, some areas could not be easily served, and seasonal flow disruptions on canals and rivers were bothersome. American economic development would have been much the same without the aid of railroads.

Fogel's emphasis was on settlement and agriculture, and his terms of reference and careful analysis leave little room for quarrel. However, great technological change occurred during the period Fogel studied. As Beniger pointed out, the railroad (and the telegraph) enabled continuous flow, large scale production, and the creation of large efficient industries (*22*). Basalla's discussion of the slow invasion of the market by the McCormick reaper points out that its wide adoption waited on railroad-based settlement (*23*).

The following analysis proceeds in the style of Fogel. That is, the counterfactual hypothesis is posed that truck-highway service did not develop; shipment of wallboard was by rail and animal-drawn vehicles. With the McCormick reaper case in mind, it is assumed that the productivity gain from the use of wallboard would have pulled its eventual adoption. The question, then, is, What is the difference between the speed and degree of the achievement of wallboard-derived productivity gains with and without truck service?

Market Penetration Analysis

To explore innovation diffusion rates and degrees of market saturation, a technology substitution analysis was made: How did wallboard substitute for lath and plaster construction? One estimate of social savings was made. To indicate how the quantity of social savings might change if assumptions used in the analysis were changed, the sensitivity of the result to model parameters was explored.

The Fisher-Pry model, a three-parameter logistics equation, was chosen for application (*24*). The functional form of the model is:

$$X(t) = \frac{K}{1 + \exp(-\alpha t - \beta)} \qquad (1)$$

where

$X(t)$ = the value of the dependent variable at time (t) (plaster or wallboard production for a given year),
K = the saturation value for the dependent variable X (total amount of plaster or wallboard),
α = a parameter controlling the rate of growth, and
β = a parameter positioning the function in time.

Although the physical interpretations for the parameters given above are clear, the values for α and β are not intuitively apparent. To facilitate specification of parameter ranges, a transformation used by Nakicenovic was applied to the parameters (*25*).

Because the logistic function is symmetrical, the maximum rate of growth occurs at the inflection point, t_{50}, where the value of the function reaches half the saturation value, ($X = 0.5 \cdot K$). Substituting into Equation 1 and solving for t gives $t_{50} = -\beta/\alpha$. Next, a growth rate, δ_t, is defined as the time required for the function to grow from 10 to 90 percent of the saturation value, $t_{90} - t_{10}$. Solving Equation 1 for t_{90} (t at $X = 0.9 \cdot K$) and t_{10}(t at $X = 0.1 \cdot K$) yields $\delta_t = (\ln 81)/\alpha = 4.394/\alpha$. In terms of these more intuitive redefined parameters, the original parameters can be derived:

$$\alpha = 4.394/\delta_t \qquad \beta = \frac{4.394 \cdot t_{50}}{\delta_t} \qquad (2)$$

The equation may be normalized by setting $X(t)/K = f(t)$. This reduces the number of parameters to two if K is known. For the wallboard case, there has been simple substitution of one commodity (wallboard) for another (lath and plaster). The saturation value K is the size of the market (1.00), and $f(t)$ and $1 - f(t)$ represent market shares for wallboard and plaster, respectively.

Annual statistics for the production of gypsum and gypsum products were obtained from the U.S. Bureau of the Mines. To measure the magnitude of plaster and lath construction, figures for the production of building plaster were tabulated (*26*). The definitions for building plasters changed over the time of interest. Definitions used included: stucco, plaster of paris, Keenes cement, prepared finishes, and neat, base-coat, molding, sanded, fibered, insulating, and mixed plasters (*27*). Although wallboard does not directly substitute for all these plaster applications, those it does not replace comprise only a small fraction of the total. Plaster used for partition tiles or for other tiles or blocks was not included. Production figures were given by weight (in tons).

Figure 6 presents data for production of plaster and wallboard from 1921 to 1985 in tons per building value. [The curves shown in Figures 6–8 were calculated from data obtained elsewhere (26).] Output was normalized to building value because of the wide variation in building volume over the time of interest. Although measures more appropriate for comparison of the two products may be specified (e.g., square feet of wall/ceiling covered or number of homes built using

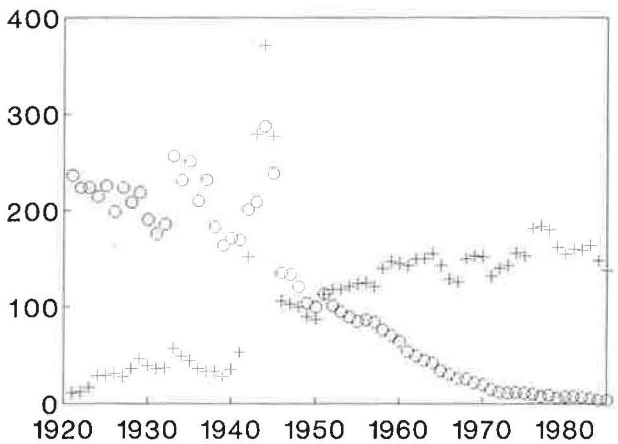


FIGURE 6 plaster (o) versus wallboard (+) production (tons per million 1967 dollars building value).

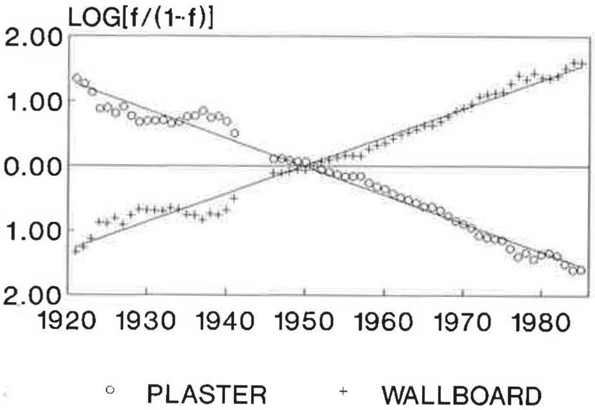


FIGURE 7 Substitution of wallboard for plaster (by weight).

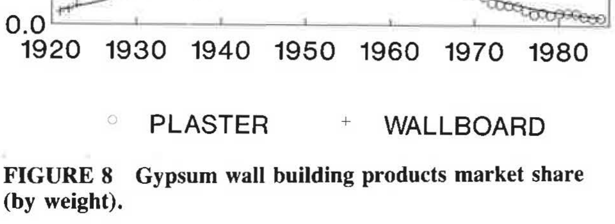


FIGURE 8 Gypsum wall building products market share (by weight).

each product), due to the availability of data, weight was chosen as the comparison measure. It was assumed that the weight per ft^2 for plaster and wallboard has not changed during the time of interest. Systematic error is therefore limited to the estimation of total market size for plaster and wallboard. Assuming one ton of wallboard replaces one ton of plaster, market shares may be computed.

Using ordinary least squares, the parameters of the logistic substitution model were estimated. The data were normalized by setting $f(t) = X(t)/K$. By the time of this study, wallboard had captured essentially 100 percent of the interior wall finishing market, therefore the value used for saturation value, K, was 1.00. Resulting parameters were calculated as: t_{50} = 1950 (time at 50 percent substitution = $\beta \cdot \delta_t/4.394$) and δ_t = 43 years (time between 10 and 90 percent wallboard substitution = $4.394/\alpha$). (See Figure 7; data for 1942–1945 were not used in the regressions because the relative production of plaster and plaster products seems to have responded to World War II needs for temporary buildings.)

Wallboard construction took 33 years to penetrate 10 percent of the plaster and lath market (1895–1928). The substitution of wallboard for plaster and lath then proceeded at a rapid pace, reaching 50 percent in an 22 additional years (in 1950). Wallboard had attained 90 percent market saturation by 1972.

A graphical interpretation of the analysis presented above is given in Figure 8 showing market shares for plaster and wallboard (actual and estimated by the model).

Estimate of Social Savings

Three parameters control the curve used to approximate the substitution of wallboard for plaster and lath construction. These parameters affect the rate (δ_t), the placement in time (t_{50}), and saturation value (K) of the substitution process. Social savings are calculated as the difference between the actual substitution curve (best fit) and a curve for a hypothetical case assuming the truck-highway system had not been deployed. While the exact shape of the hypothetical curve is uncertain, some conservative estimates can be made for its parameters.

Over the last 70 years or so, wallboard substituted for plaster. Because wallboard and plaster/lath are relatively direct substitutes, construction cost savings can be taken as the motivation for substitution. So, it is appropriate to estimate the savings represented by the adoption of wallboard in the average house. The cost of wallboard represents about 5 percent of the cost of the average new house. Plaster and lath costs about eight times as much. Assuming that the average new house costs \$50,000 (constant 1989 dollars, conservatively low), the savings are calculated to be \$17,500. (Elasticity is ignored; the demand for higher-priced, plastered homes would be less than for lower-priced, wallboard homes.)

As noted, substitution of drywall for plaster would have taken place even without the deployment of the truck-highway system. It is assumed only that had the truck-highway system not been deployed, the substitution of drywall for plaster would have proceeded less rapidly (δ_t = 50 years instead of 43 years), a few years later (t_{50} = 1955 rather than 1950), and to a saturation value of less than 100 percent (90 percent).

The savings obtained by the substitution of wallboard for plaster in any particular year are given as:

$$X(t) \cdot \$17{,}500 \cdot U \qquad (3)$$

where U is the number of housing units produced that year, and $X(t)$ is the market penetration for either the actual or hypothetical case. Summing these savings from the early years of substitution to the present for both cases and computing the difference gives the portion of social savings provided by the drywall innovation attributable to truck-highway service.

Based on the hypothetical case parameters, it is calculated that the 1985 value of the social savings attributable to trucks for just this one housing innovation are \$4.1 billion, and the savings since 1921 are \$181 billion. (For comparison, \$4.1 billion is about 1.3 percent of the nation's annual freight transportation expenditures.)

Figure 9 shows the actual substitution of drywall for plaster, the best fit technological substitution curve, and the curve demonstrating the substitution rate for the hypothetical no-truck deployment case.

Critique of the Analysis

The sensitivity of the results to the numerical assumptions may be easily stated. The magnitude of the savings is most sensitive to changes in the parameter t_{50}, time at 50 percent market saturation. For each change of one year in t_{50}, the savings change by \$16.5 billion or 9.1 percent of the total (Figure 10). The calculations used 1955 as the 50 percent market saturation without truck service, compared to 1950 with truck service. That lag is regarded as reasonable because of the 30 years it took for the wallboard innovation to achieve 10 percent market penetration and, especially, because the period of slow market penetration corresponds to the beginnings of truck service, as shown in Figure 5.

Of next greatest sensitivity is the parameter K. Each 1 percent drop in the saturation level, K, results in nearly \$7.5 billion (4.1 percent) in additional cumulative savings (Figure 11). The savings are least sensitive to the parameter δ_t, time between 10 and 90 percent substitution. Each year's increase in δ_t results in only about \$1.5 billion (0.8 percent) in total savings (Figure 12).

A broad critique of the analysis is also straightforward. Several ways transportation might interrelate with innovation processes were stated. Seeking a conservative, simple analysis, only one of these interrelations was investigated: the role of transportation in innovation diffusion. This limited analysis does not fully examine wallboard as a companion innovation to truck services. It also does not consider how modern transportation enables the continuous flow wallboard production process.

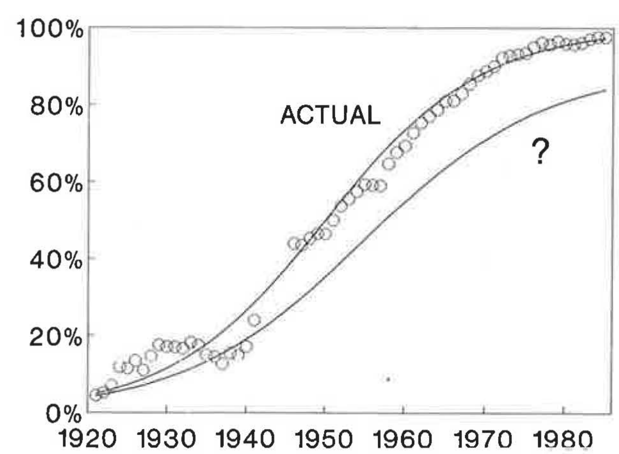
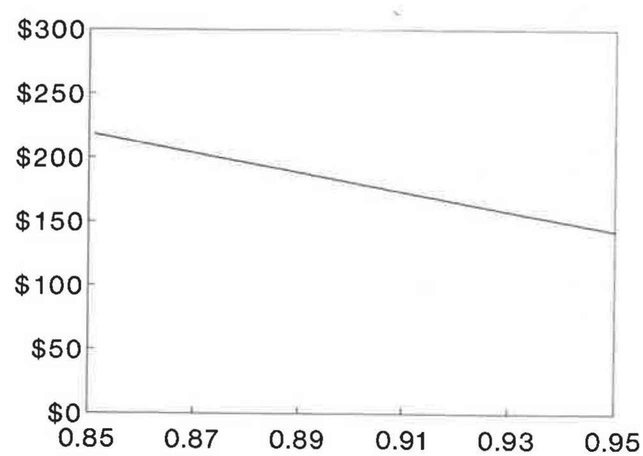


FIGURE 9 Wallboard market penetration.



penetration).

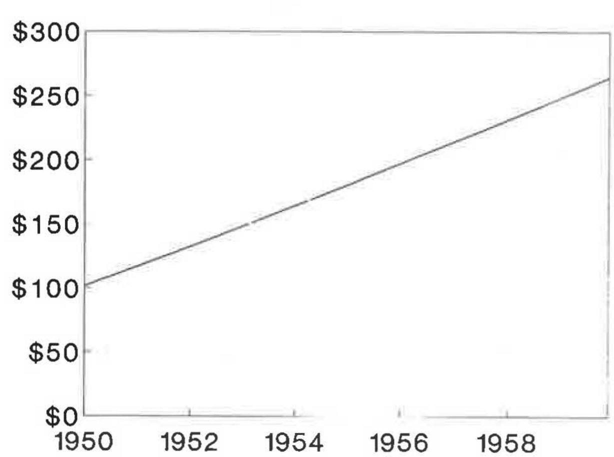


FIGURE 10 Sensitivity of savings to t_{50} (time at 50 percent market penetration).

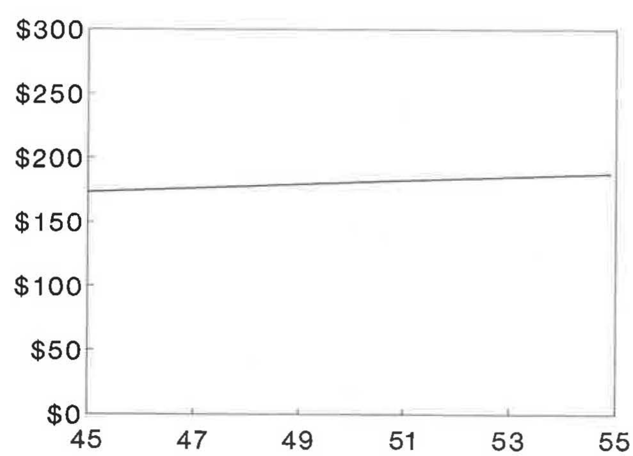


FIGURE 12 Sensitivity of savings to δ_t (Time required for market penetration).

There are many arguable details of the analysis. For instance, housing producers' options were not limited to wallboard versus plaster because wood planks were available and used to cover interior walls. It was not known how rail and collector/distributor services might have evolved absent truck services. Only an estimate is available of today's difference between the costs of installing plaster and wallboard; yesterday's costs might differ. Many other points can be made.

The many options for critique say that the estimate of social savings is very rough; it is a "ballpark" figure. The estimate of social savings might have been greater if the analysis extended beyond the diffusion process. The estimate might have been greater or less if better information was available on the rate of diffusion and the extent of market penetration absent truck services and if details of the substitution process had been included in the analysis. But even with these possibilities, the estimate points to a sizable relation; that is the important finding from the analysis.

REFLECTIONS

This section makes much use of such words as "perhaps" and "might" as it reflects on the study and strives for inferences.

The introduction emphasized general statements or principles illuminating the "what transportation does that is worth doing" question; it stated that principles were being sought. As currently stated, perhaps the operative word describing principles is "organization." Improved services yield more efficient organizations; for instance, this resource is from here rather than there. Persons seeking employment can organize the search for employment differently, or customers can skip the corner store to shop for a greater variety of products in a large shopping center. Such changes as these are welcome because progress is made through better organization.

But innovation is a major engine of progress, and perhaps a beginning has been achieved on principles that link service improvements to innovations. Perhaps the usual list of principles, such as the "bringing new resources to the economy" principle, ought to be followed by sentences of this sort: "In doing these things, transportation improvements permit doing old things in new ways, the diffusion of improved technologies, and the carrying out of new combinations producing new products. It is in these ways that transportation improvements mainly contribute to economic and social progress."

The "mainly" in the second of the two statements is quite strong, and is meant to be. Transportation interacting with the wallboard innovation made a sizable contribution to housing productivity, and it seems likely that many other such contributions could be found in housing and other endeavors. Our "carrying out of new combinations" in the first sentence is from Schumpeter, and the second sentence responds to the increasing recognition of the role of innovation and technological change in progress, Schumpeter's thesis (*28–31*). Existing principles stress improved organizations for existing activities, but new combinations are a larger force for progress.

The discussion mentioned innovation waves and the hypothesis that innovation waves are linked to long waves in the economy. Andersson has proposed that transportation technological revolutions occasion sharp increases in production (*32*). He suggests we would do well to think of the commercial and industrial revolutions as transportation revolutions. That seems proper from the timing of developments, and perhaps the linking mechanism is transportation's role in providing opportunities for innovation and innovation diffusion. Perhaps, too, transportation revolutions drive or are driven by long waves of economic development.

If transportation is instrumental in technological development and diffusion, as is suggested here, the present situation in transportation is extremely troublesome. It is even more troublesome if transportation drives long waves in the economy, as the discussion above suggests. Transportation systems have well-defined technological structures, and many are well deployed in the more developed nations. Should the inference be drawn that the maturity of transportation systems is limiting progress? Some inquiry might help define the extent to which that is true. Perhaps one would find that limiting-by-conditioning is the situation. Society runs on flows of mass and information, and the recipes for organizing and controlling flows are complex. At a time when information flow opportunities are increasing sharply, transportation's stagnation may be limiting and conditioning opportunities.

As it proceeded, this discussion considered a number of directions for inquiry and steered along an ever-narrowing path. Paths not followed were not rejected, just not followed. Following them might be fruitful. It might be useful, for instance, to respecify the land relation to recognize that transportation services may permit new combinations of uses of land. It might be useful to examine some cases in which transportation is an explicit building block for innovations, the offshore drilling platform is an example, because how it is to be transported and erected at the site bears on what can be done. In undertaking investigations, of course, one must avoid claiming too much. That there would be little social and economic development without transportation is not the issue, because such statements can be made about many things. It is the marginal improvements in service that must be judged.

With respect to housing, figures were presented showing a rough correlation between the deployment of transportation and improvements in the housing production process. Surely the relationship is not accidental. The parallel between today's situations in housing and transportation also may not be accidental: housing production productivity gains are nil or negative; land transportation is technologically mature and facilities are largely deployed; and productivity gains are nil or negative (*33*). This observation suggests that today's housing problems are incompletely stated. Transportation has not offered opportunities recently, so it is out-of-mind. But perhaps it ought to be put on problem lists and a good part of today's housing problem recognized as a transportation problem. Perhaps there are other sectors whose problems are transportation problems? Again, the modern world runs on flows of mass and information, and one might suspect that transportation problems are broad indeed. It was noted in the introduction that cost reductions or service enhancements steer transportation investments. One can not quarrel with that because efficiency is always desirable. Even so, there may be a problem.

It is understandable that the calculi of cost reduction or service improvements are applied to the traffic that can be seen and measured, and this focuses investments on the transportation uses of existing activities. There are few or no signals for investments that might enhance doing old things in new ways or doing new things. So perhaps there is an unfortunate bias in investment programs; they preserve the old through ever-decreasing marginal improvements rather than enhance the new. Put another way, they enhance only one route for progress—greater efficiency of existing activities—and ignore innovation as the major route for progress.

More incisive work on the demand for transportation seems merited. In theory, that could be done through increased attention to elasticity of demand, because such attention would flag new developments clamoring for service. But without some sense of the origins of new developments, such work would have a fishing-expedition character. So perhaps work on the demand for transportation should begin with innovation considerations, and perhaps policy should give greater emphasis to new transportation services rather than enhanced old services. In part, work might be done by paying close attention to and giving weight to new things creating new demands. It might also pay closer attention to general principles incorporating innovation considerations, and give weight to investments that enhance innovation possibilities.

These suggestions are easy to make, but difficult to implement. The vision of a link between transportation services, innovation, and productivity gains through the economy is not widely held, and the literature of innovation overlooks transportation (e.g., *34, 35*). The situation is understandable: relations are complex and the relative maturity of transportation systems places them out-of-view.

Perhaps improved transportation services had their major impacts yesterday, and today's marginal improvements are rather irrelevant. How to energize transportation development in a way that energizes production relations is, perhaps, a large part of today's transportation problem.

ACKNOWLEDGMENT

This research was supported by the Institute of Transportation Studies and the Transportation Center at Berkeley (*36*).

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Publication of this paper sponsored by Committee on the Application of Economic Analysis to Transportation Problems.

Roadway Vehicle Delay Costs at Rail-Highway Grade Crossings

TIMOTHY A. RYAN

The purpose of this research was to develop a practical methodology for computing the lengths of delays and costs of delays to roadway vehicles at rail-highway grade crossings (RHGCs). A practical methodology is defined here as one using only United States Department of Transportation Rail-Highway Grade Crossing Inventory (Inventory) data or other data known to be readily available to agencies responsible for RHGCs. The methodology developed makes use of Inventory data and a common deterministic delay model. Default values were developed for train length, diurnal distribution of roadway traffic, directional distribution of roadway traffic, and roadway speed limit. Costs were computed through the use of a procedure developed by the Federal Highway Administration in 1980. The methodology was applied to 1985 conditions for all public RHGCs in Maryland. The results of this application indicate that annual delay costs at RHGCs cover a wide range, from a minimum of $0 to a maximum of $407,441. Comparison of annual delay costs and annual accident costs indicate that accident costs are generally higher than delay costs.

The purpose of this research was to develop a practical methodology for computing lengths of delays and costs of delays to roadway vehicles at rail-highway grade crossings (RHGCs). A practical methodology is defined here as one using only those data known to be easily accessible to the agencies responsible for RHGCs and easily used by those agencies.

Although some agencies certainly maintain additional information about their RHGCs, the only known data base readily available to all agencies is the United States Department of Transportation Rail-Highway Grade Crossing Inventory (Inventory), a computerized description of every public and private crossing in the country. The Inventory provides a great deal of information for each crossing, with most of the information pertaining to the characteristics of the traffic control devices and railroad elements of the crossing. Relatively little information pertains to the highway elements of the crossing.

Conventional queuing theory would allow for straightforward computation of delays at RHGCs, if accurate data were available regarding the diurnal distribution and lengths and speeds of trains, and if accurate data were available regarding diurnal distribution and speeds of roadway traffic. Unfortunately, the Inventory does not provide all these data. Therefore, data collection efforts were undertaken, and analyses conducted, in an effort to develop values to be used in the methodology.

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DELAY PARAMETERS

Train Length Analyses

Naturally, one of the key factors in determining delay to roadway vehicles at an RHGC is the length of each train; the longer the train, the greater the delay, all other factors being equal. Unfortunately, the Inventory provides no information regarding train lengths. In addition, the very nature of railroad operations works against any type of systematic prediction of train lengths, particularly in the vicinity of railroad yards, where trains are assembled and dismantled. During assembly of a single train, for example, one locomotive might cross an RHGC several times, with the number of attached cars ranging from zero to the maximum number of cars in the final train.

Figure 1 illustrates this problem, showing the variation in lengths of the 87 trains that, on July 31, 1986, travelled on one or more of the Old Main Line, Washington, Alexandria, Metropolitan, or Georgetown subdivisions of CSX Transportation's Baltimore division. (These data were obtained from CSX Transportation records; the date was selected at random from weekday records). As Figure 1 shows, more than half the trains were quite short, consisting of seven or fewer cars. However, 25 trains had 60 or more cars. The mean length was 35 cars.

Based upon these data, it was decided that 35 cars would be used as the average train length. Based on discussions with CSX personnel, it was decided that 60 feet, a very representative car length, would be used as an average length for each car in a train.

Train Speed Analyses

The Inventory provides three pieces of information regarding train speeds: maximum timetable speed, typical maximum speed, and typical minimum speed. For the purposes of these analyses, it was decided that the arithmetic mean of the typical minimum speed and the typical maximum speed would be used as the default speed at each RHGC.

Diurnal Distribution of Trains

The Inventory provides four pieces of information regarding the diurnal distribution of trains: number of daylight through trains, number of daylight switch trains, number of night through

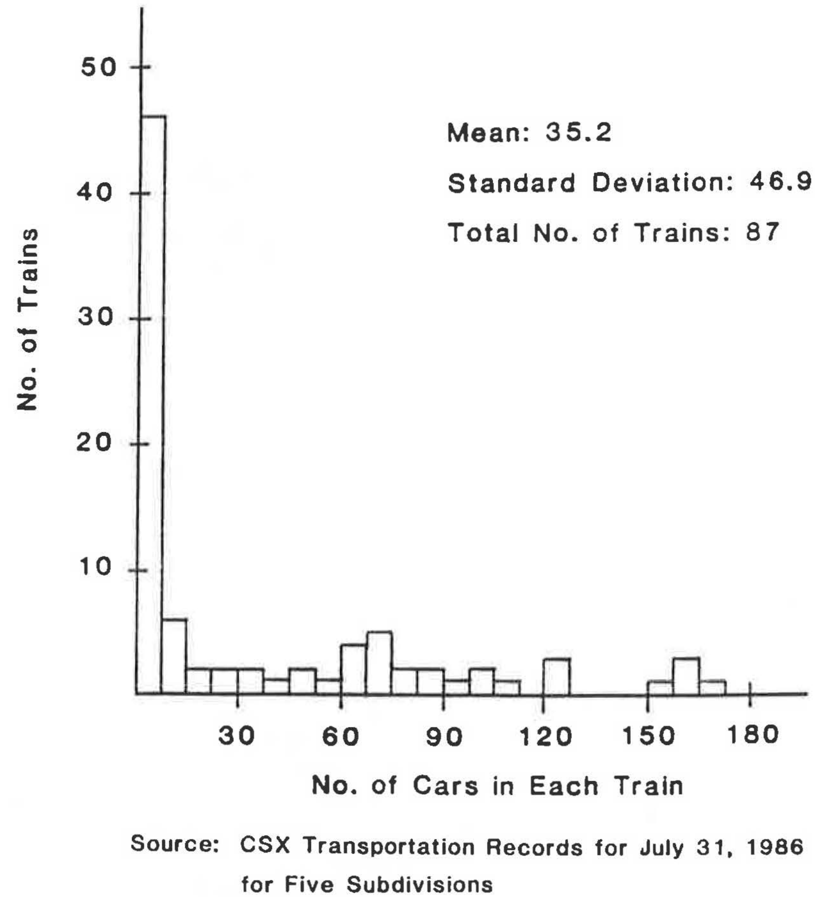


FIGURE 1 Train lengths.

trains, and number of night switch trains. A more detailed breakdown would show wide variation among crossings, with part of that variation depending upon location. In Maryland, for example, according to CSX Transportation, train activities tend to occur earlier in the day in the western part of the state than in the eastern part, as trains bring loads to the east for further shipment later in the day. There is also some variation in the number of trains per day in each subdivision, with activity typically being lowest on weekends and Mondays, and then gradually increasing through the remainder of the week.

Based upon this information, the following assumptions were made for the methodology:

- All trains cross RHGCs on weekdays (Mondays through Fridays).
- Daylight trains cross RHGCs from 6 a.m. to 6 p.m.
- Night trains cross RHGCs from 6 p.m. to 6 a.m.
- Train arrivals are distributed uniformly across the given 12-hour period.

Diurnal Distribution of Roadway Traffic

As discussed previously, the Inventory provides very little information regarding roadway or traffic characteristics. In terms of traffic, only the annual average daily traffic (AADT) and the percentage of trucks in the AADT are provided.

Data collection and analysis efforts were undertaken in an attempt to develop a diurnal distribution for roadway traffic. The first group of RHGCs for which data were requested consisted of the RHGCs in the Philadelphia and Washington subdivisions of the B&O Railroad. This group was supplemented by a number of RHGCs in Baltimore City, Maryland, and Baltimore County, Maryland, for which data were readily available. All the data came from the files of the Maryland State Highway Administration (SHA), Prince George's County, Howard County, Baltimore County, and Baltimore City.

Analyses were conducted to determine if the diurnal distribution for one type of RHGC differed significantly from that for a different type of RHGC. A total of 42 RHGCs were used in these analyses. The AADTs at these RHGCs ranged from a low of 244 to a high of 28,590.

Because the diurnal distribution of train traffic can only be broken into daylight or night components, the diurnal distribution of roadway traffic as well need only be broken into those two components. The percentages of the AADT that occurred during each hour were computed for each RHGC; the percentages of the AADT occurring during daylight hours (6 a.m. to 6 p.m.) and during night hours (6 p.m. to 6 a.m.) were computed for each RHGC by adding the appropriate hourly percentages. Four groupings of the RHGCs were established: RHGCs in cities, RHGCs not in cities, urban RHGCs (as defined by the functional classification of the roadway in the Inventory), and rural RHGCs (as defined by the functional classification of the roadway in the Inventory). Then, *t*-tests were performed on the in city versus not in city groups and urban versus rural groups. The results of these analyses are shown in Table 1. Examination of Table 1 reveals that none of the values of *t* are significant at the 0.05 level and that the values for the in city versus not in city groups are substantially closer to the 0.05 level than the values for the urban versus rural group.

Thus, based on these data, there is no reason to believe that the diurnal distribution of roadway traffic at one type of RHGC is different from that at another. For this reason, the arithmetic means of the percentage of AADT occurring during each hour at all 42 RHGCs were computed and then used in the methodology. These default values are shown in Figure 2.

Because the diurnal distribution of railroad traffic cannot be determined from the Inventory with any more accuracy than to be broken into day or night groups, the diurnal distribution of roadway traffic needs to be used in the same fashion. Thus, for the methodology, the percentages of daily traffic occurring from 6 a.m. to 6 p.m. were averaged to obtain the average daylight hourly volume; the percentages from 6 p.m. to 6 a.m. were averaged to obtain the average nighttime hourly volume.

TABLE 1 *t*-TESTS: DIURNAL DISTRIBUTION OF ROADWAY TRAFFIC

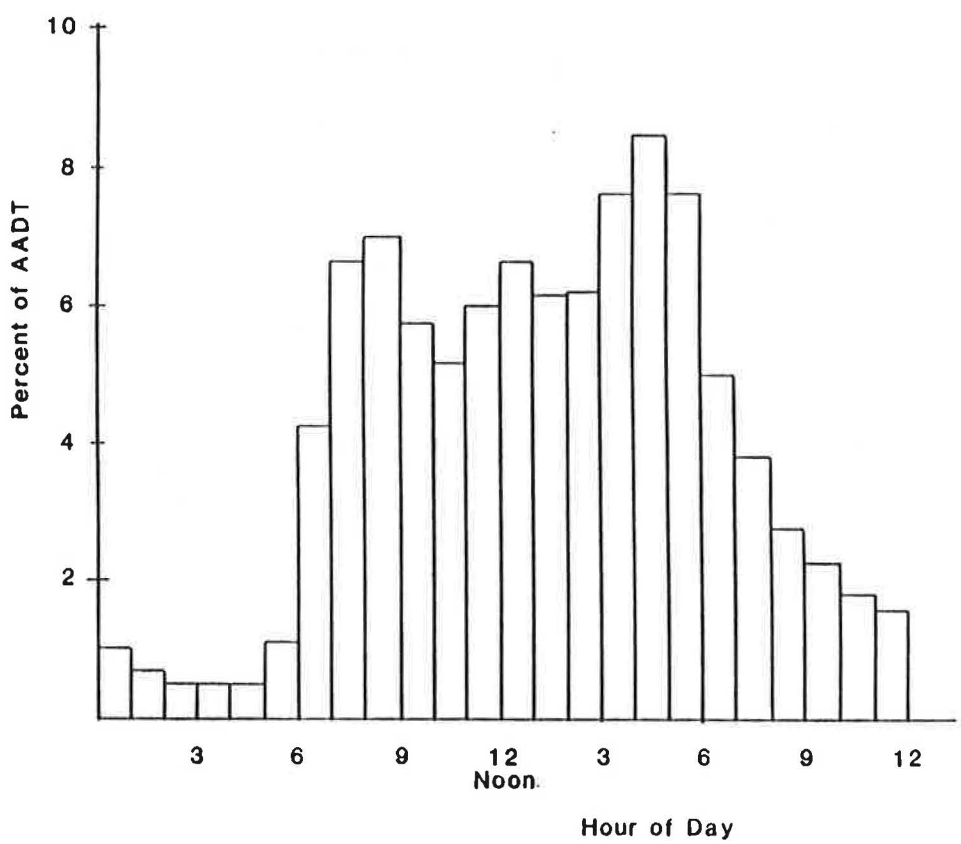
		Day Percentage		Night Percentage	
Inventory Parameter	Number of Cases	Mean	t-Test Prob.	Mean	t-Test Prob.
In City	20	80.0		19.7	
Not in City	22	76.3	0.088	23.7	0.068
Urban	38	78.4		21.5	
Rural	4	75.1	0.373	24.9	0.359

Source: Files of Maryland State Highway Administration, Baltimore City, Baltimore County, Howard County and Prince George's County

RHGC Blockage Time

The amount of time that a given train blocks an RHGC is comprised of two elements: the amount of time the train physically blocks the RHGC, and the amount of time the RHGC is "blocked" by traffic control devices or flaggers prior to the train's arrival. The physical blockage time at each RHGC is determined simply by dividing the length of each train by its average speed. The advance blockage time is somewhat more difficult to obtain.

Advance blockage time depends upon the type of traffic control device used at the RHGC. Passive devices such as crossbucks and stop signs cause little or no advance blockage



Source: Files of Maryland State Highway Administration, Baltimore City, Baltimore County, Howard County,and Prince George's County

FIGURE 2 Diurnal distribution of roadway traffic at 42 RHGCs.

time, while automatic gates without constant warning time capability may cause advance blockage times in excess of one minute. Based on observations of driver behavior at RHGCs and discussions with CSX personnel, the parameters described in Table 2 were established for use in this methodology. The following explanations should help readers understand Table 2:

- "Constant Warning Time Capability" means that the track circuit that detects the presence of a train can determine the speed of that train and adjust the actuation of the traffic control devices accordingly.
- "Crossbucks or Other Signs" category assumes that a driver is made aware of an oncoming train by sight or sound at least 5 sec prior to the arrival of that train at the RHGC. Based on observations of motorist behavior, it is assumed that no driver accepts any gap smaller than 5 sec and that no driver rejects any gap larger than 5 sec.
- "Flagger Disembarking Train" category assumes that, once the flagger has stopped all roadway traffic, 20 sec elapses before the train accelerates from a standing start and reaches the RHGC.
- Flashing light signals must be activated at least 3 sec before automatic gates begin to drop, according to CSX Transportation. Automatic gates must take from 9 sec to 12 sec to drop. A train can occupy an RHGC anytime after the gates finish dropping. The actual time prior to train arrival at which the signals begin flashing is adjusted by a CSX technician on the basis of sight distance or other site-specific conditions. For purposes of this methodology, a value of 15 sec from start of flashing light signal operation to completion of gate drop was assumed, based upon a 9 sec gate drop, a minimum 3 sec interval of flashing light signal operation prior to commencement of gate drop, and an additional 3 sec interval of flashing light signal operation prior to commencement of gate drop due to site-specific conditions.
- Flashing light signals used without gates must be in operation at least 20 seconds prior to the crossing being occupied by a train, according to CSX Transportation.

Directional Split of Roadway Traffic

On most roadways, volume in one direction of travel is heavier than volume in the other direction during peak hours and sometimes during other hours as well. During peak hours, this directional split can be as high as 80 to 20 percent or even higher, in areas with a single type of land use (such as residential), or as low as 55 to 45 percent, or even lower, on major arterial roadways. During off-peak hours, the directional split tends to be more even. Most of the diurnal data analyzed gave no information regarding directional split; thus, an assumption is necessary. Based upon observations of traffic volumes within Maryland, the directional split of traffic is assumed to be 60 to 40 percent during all hours. The direction of heavier flow is immaterial to the methodology.

TABLE 2 ADVANCE BLOCKAGE TIME PARAMETERS

	Advance Blockage Time (sec)	
Highest Protection Class at RHGC	with Constant Warning Time Capability	without Constant Warning Time Capability
Crossbucks	n/a	5
Flagger Disembarking Train	n/a	20
Flashing Light Signals or Highway Signals	20	20 x (Max. Speed)/ (Avg. Speed)
Automatic Gates	15	15 x (Max. Speed)/ (Avg. Speed)

n/a = not applicable

Source: Observations of driver behavior and conversations with CSX personnel

Roadway Speed Limit

Because the delay cost computations (described later) assume that traffic will travel at the speed limit unless forced below that speed by a train or a queue caused by a train, this factor is somewhat important. Unfortunately, the speed limit is not given in the Inventory; thus, some data collection seemed necessary. Data were again collected at the RHGCs in the Philadelphia subdivision and the Washington subdivision of the B&O Railroad. The resulting data are summarized in Figure 3. Examination of Figure 3 reveals that the mean speed was 28.5 mph.

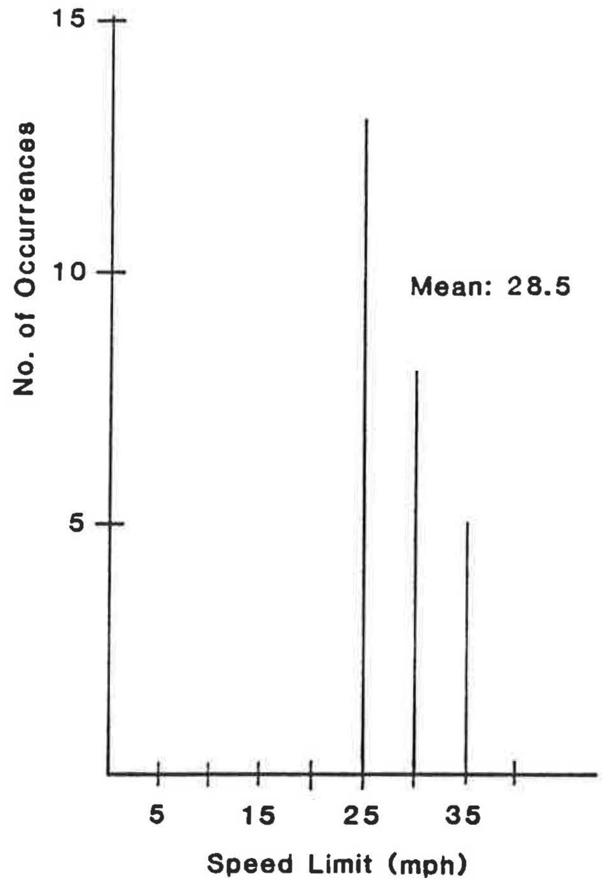
Statistical tests were performed to determine if different values were appropriate for use with different types of RHGCs. As was the case with the diurnal distribution analyses, in city versus not in city and urban versus rural (as defined by the roadway's functional classification in the Inventory) were thought to offer potential means of grouping the RHGCs.

The results of the t-tests are shown in Table 3. Examination of Table 3 reveals that the difference in mean speed limit is not significant at the 0.05 level for urban versus rural, but is significant at the 0.001 level for in city versus not in city. Thus, two default speed limits (25 mph for "in city" crossings and 30 mph for "not in city" crossings) were used for all subsequent analyses.

Delay Model

The computation of delay to roadway vehicles was performed by using the simple, deterministic model illustrated in Figure 4. This model was not developed expressly for this research; similar, if not identical, models can be found in texts regarding queuing theory or traffic control signal operation. According to this model, roadway traffic arrives at the RHGC at a rate of q. When a train arrives (A), a queue begins to form. The queue grows in length until the train clears the RHGC (B), and then diminishes as vehicles depart at a saturation flow rate of s (assumed to be 1 vehicle per 2.1 sec). The queue is completely dissipated at C, when the arrival line intersects the departure line. The number of vehicles in the queue at any given time is the vertical distance between AB or BC and the arrival line. The total delay caused by the presence of a train is the area of triangle ABC.

It is recognized that this model is quite simple and does not consider the probabilistic characteristics of traffic flow and site-specific geometrics. However, given the simplifying assumptions required to estimate train length, train speed,



Source: Field Observations of RHGCs in Philadelphia Subdivision and Washington Subdivision

FIGURE 3 Speed limits at RHGCs.

TABLE 3 *t*-TEST RESULTS: SPEED LIMITS

Inventory Parameter	Number of Cases	Mean	t Value	Significant at
In city	11	25.4	4.91[1]	<.001
Not in City	15	30.7		
Urban	20	27.8	-1.75	.09
Rural	6	30.8		

[1] Modified t-test used. F-test showed usual t-test should not be used.

Source: Field observations of RHGCs in Philadelphia Subdivision and Washington Subdivision

and total blockage time, this shortcoming was not thought to be severe. The model is applicable to a single-lane, single-direction approach at an RHGC blocked by a train.

The following steps were taken to compute roadway vehicle delay over the course of a year, using the model described above:

1. The average daylight hourly volume on each approach was determined by using the assumed 60 to 40 directional split.
2. The number of lanes on the roadway was obtained from the Inventory, and the approach volume was evenly divided among those lanes.
3. The total blockage time per daylight train was determined as described earlier, and roadway delay per daylight train was computed.
4. The delay obtained during the preceding step was multiplied by the number of daylight trains to obtain total daily daylight delay.
5. Steps 1–4 were repeated for night conditions.
6. The delay obtained in Steps 4 and 5 were summed and the sum was multiplied by 260 (52 weeks per year at 5 days per week) to obtain total yearly delay.

Weekends were not expressly considered in the analyses. On most roadways and rail lines, volumes are substantially lower on weekends than weekdays, resulting in considerably less delay to roadway vehicles. In addition, even less information is available regarding weekend volumes than is available regarding weekday volumes. For these reasons, only weekdays were considered in the analyses. It should be noted that delay at RHGCs is not linear with respect to train length, but rather is proportional to the square of train length. Com-

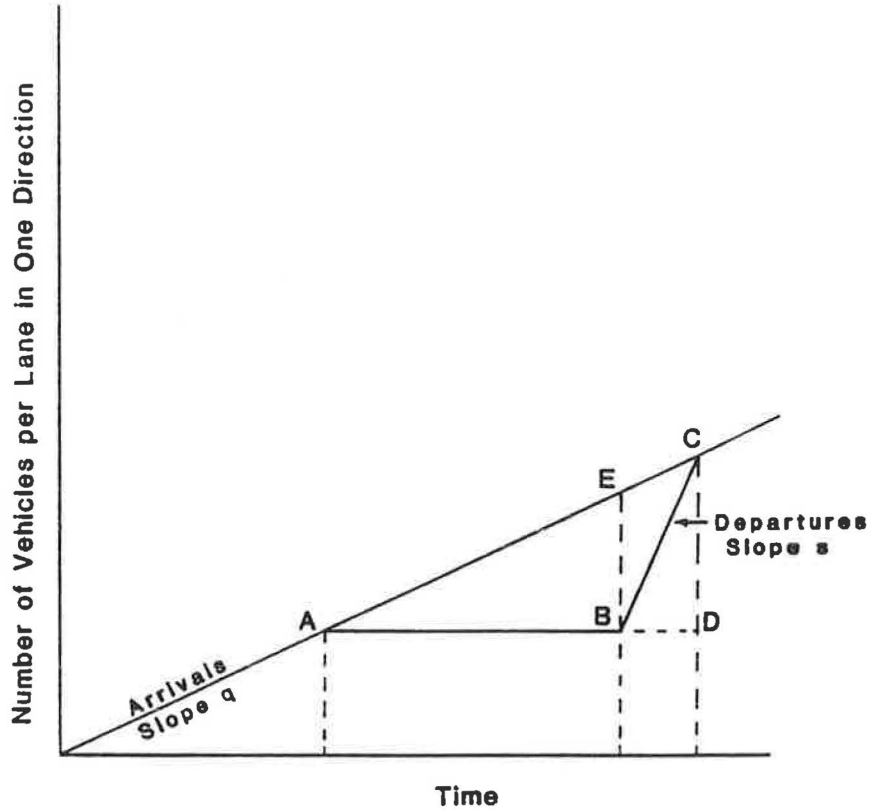


FIGURE 4 Delay model.

putations using the data shown in Figure 1 reveal that the mean delay occurs for a train consisting of 58 cars, rather than for a train consisting of the 35-car mean length. For purposes of the methodology, it was decided that the mean train length would still be used in the delay computations, due to the relatively small sample available for comparison of train lengths and the sensitivity of a "mean-delay train length" to the distribution of train lengths in the sample. (A distribution of train lengths with a standard deviation smaller than that of the distribution shown in Figure 1 could yield the same mean train length but a considerably shorter mean-delay train length.)

Computation of Delay Costs

The user costs caused by delays at RHGCs were computed by using a procedure developed by the Federal Highway Administration (FHWA) in 1980 (*1*). Reduced to its simplest terms, this procedure provides graphs and tables that can be used to estimate, for each light-duty vehicle, user costs for stopped conditions and for each speed-change cycle. This procedure was applied to the methodology through use of the following steps with references made to Figure 4:

- Only vehicles that arrived during the total blockage time (*AB*) were assumed to stop. Vehicles arriving while the queue discharged (*BD*) were assumed to be slowed, but not stopped.
- All vehicles were assumed to approach the RHGC at the posted speed and depart at the posted speed. All vehicles slowed but not stopped were assumed to reach a low speed of half the posted speed.
- Tables and graphs were incorporated into the computer program used to execute the methodology.
- Unit costs were updated, using the procedures outlined by FHWA (*1*).

In addition to the procedure described above, traveltime costs were computed by taking the area of triangle *ABC*, assuming a value of $6 per person-hr of traveltime and an average vehicular occupancy of 1.6 persons. The $6 value was developed by updating value of traveltime data included in the FHWA document (*1*) and making an additional adjustment based on local conditions. The average vehicular occupancy was also based upon observations of local conditions. It may be noted that delay costs are linear with respect to both value of traveltime and average vehicular occupancy. Thus, the effect of varying either or both of these parameters may be readily determined.

APPLICATION

Roadway vehicle delay costs were computed for each public RHGC in Maryland using 1984 Inventory data and the methodology described above. For purposes of these computations, it was assumed that the 1984 Inventory data were fully representative of 1985 conditions. The results of these analyses are shown in Figure 5. Examination of Figure 5 reveals:

- Annual delay costs cover a wide range, from a minimum of $0 to a maximum of $407,441, with a mean value of $4,180.
- Eighty-three crossings had annual delay costs in excess of $10,000.
- Annual delay costs below $500 were found at 814 RHGCs.

In order to assess the relative importance of these costs, additional analyses were conducted involving the costs of accidents at the same RHGCs in 1985. Anticipated accident costs were developed through the use of an accident-prediction formula produced by the Transportation Systems Center (unpublished data provided to Kidde Consultants Inc. by the Maryland Department of Transportation, State Highway Administration), a severity index that is part of the Rail-Highway Crossing Resource Allocation Procedure (*2*), and NHTSA cost estimates for various types of accidents (adjusted by the Consumer Price Index to reflect 1985 conditions). Each fatal accident was computed to have a cost of $1,286,029.60. Each injury accident was computed to have a cost of $315,298.57. Each property damage only accident was computed to have a cost of $23,350.58.

The data thus developed are shown in Figure 6. Comparison of Figure 5 and Figure 6 reveals that accident costs generally are greater than roadway vehicle delay costs, with the mean

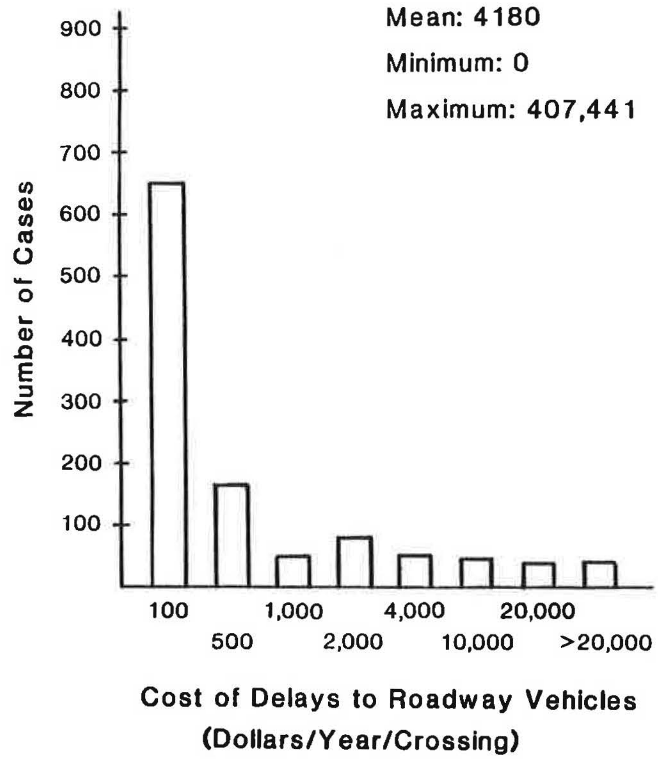


FIGURE 5 Delay costs, 1985 conditions.

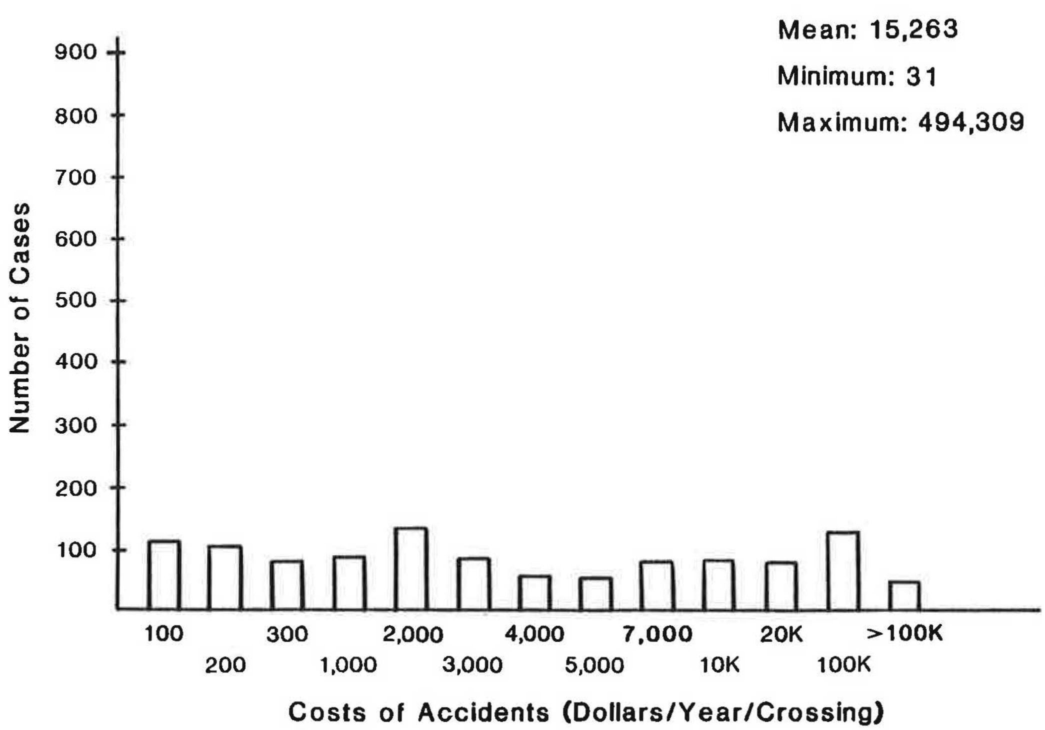


FIGURE 6 Accident costs, 1985 conditions.

value being almost four times greater. Thus, it would appear that delay costs for roadway vehicles, though potentially substantial, are not as large as accident costs.

It should be noted that the large number of simplifying assumptions made in this project undoubtedly bias the results provided by the methodology. The exclusion of weekend data, the use of average train length and average train speed, and the use of a single diurnal distribution for all roadways certainly diminish the accuracy of the numerical results. Without more accurate data, it is difficult to estimate the size of the bias introduced by these assumptions.

SUMMARY

The purpose of this research was to develop a practical methodology for computing lengths of delays and costs of delays to roadway vehicles at RHGCs. The methodology developed here accomplishes this objective, subject to the limitations of available data. Application of the methodology indicates that roadway vehicle delay costs may be substantial, but are generally lower than accident costs.

ACKNOWLEDGMENT

The author wishes to thank Everett Carter for his guidance with this project and the staff of the Academic Computing Center of the University of Maryland, Baltimore County, for their assistance with the data analyses and computer programming.

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Publication of this paper sponsored by Committee on Application of Economic Analysis to Transportation Problems.

Quick Approach To Estimate Law Enforcement Cost on Urban Roads

FADI EMIL NASSAR AND FAZIL T. NAJAFI

Law enforcement costs on urban roads is a seldom-considered public cost, although it averages two to three times higher than maintenance costs. When law enforcement costs are considered, a typical value used by planners is about $5,000 per lane-mile. This value may be adequate for rural roads, but it significantly underestimates the costs on urban roads, as demonstrated through the study cases described in this paper. Law enforcement costs are not included in the cost calculation of urban roads due to the lack of an effective and simple procedure. This paper presents a "quick approach" for estimating law enforcement costs on urban roads, a step-by-step procedure that is both simple to understand and easy to apply. All the needed data can be obtained through a few telephone calls. The calculations are quickly performed on templates provided in this paper. The quick approach provides valid answers because it takes into account all the important parameters related to law enforcement activities. It is also based on sound, justifiable logic and contains few assumptions. The quick approach gives an average value for law enforcement cost per lane-mile of the city highway network. However, this value could be adjusted to represent the costs on a specific urban road.

A research study conducted at the University of Florida to compare the public costs involved in building a new highway versus providing a fixed transit system found that two types of public costs specific to highway projects are inadequately covered in the existing literature and available records. These are the costs of law enforcement and risk management of the highway system. While extensive up-to-date statistics are kept on the various costs of construction, operation, maintenance, and equipment for both the highway and the transit system, very little information is available on the costs of highway law enforcement and risk management.

When comparing the public cost of highway and transit systems, law enforcement and risk management costs are important to consider for the highway alternative because they are implicitly included in the rail transit operational budget. Although the Law Enforcement Cost (LEC) per lane-mile of highway is on average much higher than the maintenance cost, LEC was seldom considered in previous studies.

This paper focuses on evaluating the LEC and presents an easy, quick approach to estimate LECs on urban roads.

BACKGROUND

The public costs involved in law enforcement on the highway network can be subdivided into various cost components; including, patrolling roads, directing traffic, assisting traffic accident victims, filing reports, investigating accidents, pursuing traffic law violators, writing fines, and testifying in traffic-court hearings. In summary, highway law enforcement activities are those related directly to traffic law enforcement, traffic control, and traffic accidents. LECs are the direct and indirect public expenses generated entirely by highway traffic.

Most studies estimating the public cost of a new highway fail to consider law enforcement costs. On average, LEC per lane-mile of roadway in an urban area is roughly two to three times the maintenance cost. The cumulative value of the annual LEC over the useful life of the road is significant. It should be estimated and taken into consideration when analyzing the cost-effectiveness of a specific highway or when comparing alternative investments.

From discussions with planners, it was found that LEC was considered in only a few instances. The most common LEC value used was about $5,000 per lane-mile of roadway. Although this value is appropriate for rural roads, it significantly underestimates the LEC on urban roads, which averages two to three times higher.

Study Objective

The quick approach proposed in this paper presents a methodology to estimate the LEC per lane-mile of urban road. The approach takes into account all relevant parameters specific to the study location. It is also simple to understand and easy to apply. The needed data can be obtained through a few telephone calls. The computations required are simple and can be performed on one standard sheet (a sample sheet is included in the tables). Planners, engineers, or technicians can apply the methodology to determine the LEC in any city and in a short period.

Study Approach

Two different techniques were investigated in order to determine the one that best satisfies the above-stated objectives. The first technique is based on a macro approach. The second is based on a micro approach.

The macro approach consists of determining the proportion of the city Police Department (PD) budget that is directly or indirectly related to law enforcement activities on the city highways. This part of the budget is then divided by the total lane mileage that falls under the jurisdiction of the city's PD (usually that excludes interstate, state, and country roads). This provides an average cost of law enforcement per lane-mile of urban roadway. If the procedure is applied to a specific

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highway in the city, the average LEC should be adjusted by a factor computed as the ratio of the measured (or simulated) traffic volume on that road to the city's average traffic volume per lane-mile. Normally, the frequency of accidents is related to the vehicle miles of travel (VMT). However, if the road location causes a higher accident rate (i.e., hazardous intersection, narrow bridge, interchange, etc.), the LEC should be further adjusted with an appropriate factor determined from past observation of incidents and tempered by practical judgment.

The micro approach consists of adding the individual cost items that constitute the total cost of patrolling a particular road. These items include labor, equipment, vehicles, management, and overhead. The frequency of patrolling a specific highway is an important parameter for estimating the LEC per mile of roadway using the micro approach.

After careful analysis of both methods, the macro approach was found to be more appropriate for the quick approach technique because data needed for the macro approach are readily available and can be objectively analyzed, and calculations required by the macro approach are simple and easily performed.

On the other hand, data needed for the micro approach are extensive, not readily available, and difficult to assess. For example, the cost of equipment includes an annualized value of vehicles, computers, and telecommunication system costs. Furthermore, different police agencies may use distinct accounting methods that will considerably complicate the data-collection process.

One of the most important parameters in estimating LEC using the micro approach is the frequency of patrolling activities. Factors such as street location, traffic volume, and accident history may greatly affect the frequency of patrolling a particular road. However, because of the nature and difficulty of obtaining such data, the frequency of police patrolling cannot be reasonably assessed for all types of urban roads.

The micro approach depends on a large number of factors. It also deals with annualized costs that involve the value of time (interest and inflation). Consequently, calculations performed in the micro approach are tedious and complicated.

In conclusion, the macro approach is selected because it requires readily available parameters, accounts for all relevant factors, is easily applied, and is based on a sound logic.

DESCRIPTION OF MACRO APPROACH

As previously mentioned, the macro approach excludes from the PD budget all costs not related directly or indirectly to highway law enforcement activities. After excluding these costs, the remaining part of the budget is divided by the city road mileage under the PD jurisdiction. This is accomplished through the following stages:

1. Determine highway law enforcement-related budget.
   –Subdivide the PD work force into the various law enforcement units. Each unit should include the number of officers and supervisors.
   –Estimate the percentage of time that each police unit spends on highway law enforcement activities. These activities were defined earlier in the Background section. A cumulative percentage of weighted averages will determine the ratio of the PD's budget reserved for highway law enforcement purposes.
2. Determine Police Department assets depreciation.
   –The depreciation amount of the PD assets is determined by dividing the value of each asset by its estimated service life. The same ratio calculated for the operational budget will be applied to the annual depreciation. Because buildings and land have different service lives, and because the budget might include some renovation works, it was found that replacing this step with a 1.05 multiplier of the operational budget will simplify the approach without affecting the accuracy of the results.
3. Compute total lane mileage.
   –This is accomplished by multiplying the city road mileage by the average number of lanes in both directions. The city road mileage does not include interstate, state, or county roads.
4. Adjust lane mileage to police jurisdiction.
   –In some cities, the PD assists in patrolling highways under county, state, or federal jurisdictions. If this overlapping is significant (greater than 5 percent of the city mileage), an adjustment factor might be appropriate. However, in the majority of cases, adjustment is not needed because the state's Highway Patrol monitors these roads.

Macro Approach Assumptions

The macro approach involves two assumptions. First, the indirect costs (i.e., management, clerks, secretaries, maintenance, vehicles, equipment, and training) can be proportionally distributed to the work force size in each unit (number of officers plus supervisors). This is a valid assumption because officer salary and benefits constitute the major portion of the operational budget. Furthermore, organization of the police departments justifies a proportionate distribution of the indirect costs.

The second assumption is that revenues generated by traffic fine payments, which normally go to the city general budget, are not considered, for the following reasons: (a) revenues from the traffic fine payments were found to be roughly equal to the city cost for collecting the fines plus the court cost (judge and clerks) incurred in appealing those fines (this conclusion was drawn by estimating these costs and revenues for the study cases); and (b) any residual amount (revenues versus costs) of the traffic fines is insignificant compared with the PD overall budget. Therefore, neglecting revenue generated by traffic fines will have no measurable effect on the results.

Step-by-Step Procedure

Table 1 is a sample sheet to be used for the quick approach. The sheet format lists the needed data and shows how the calculations should be performed. The ranges and default values for the percentage of time that each police unit spends on highway law enforcement activities are given. The default values could be used for every police unit except the patrol unit because this value could vary greatly from one PD to another. Because the patrol unit is by far the largest unit in

TABLE 1 LAW ENFORCEMENT COST ON URBAN ROADS

CITY:	DATE:	USER:

POLICE UNIT.	NUMB.OF OFFICERS	% TIME LEH	% TIME RANGES	% TIME DEFAULT	RELAT. WEIGHT	% TIME WEIGHTED
(COLUMN)	(2)	(3)	(4)	(5)	(6)	(7)
(EQUATIONS)					(2)/(8)	(3)*(6)
PATROL UNIT			20%-70%	--		
MOUNTED PATROL			10%-30%	15%		
TRAFFIC UNIT			95-100%	100%		
COMMUNITY POL			20%-60%	40%		
ORGAN. CRIME			10%-20%	15%		
SPECIAL UNIT			0%-5%	0%		
K-9(DOG) UNIT			0%-10%	5%		
AIRPORT SECUR.			10%-40%	20%		
INVESTIGATIVE			3%-15%	8%		
MARINE UNIT			0%-0%	0%		
AVIATION UNIT			5%-15%	10%		
OTHERS:						
	SUM(8)					SUM (9)

BUDGET (10): $		YEAR:	
DEPRECIATION OF NET ASSETS (11):	5% OF (10)	OR	$
ADJUSTED CITY LANE-MILEAGE (12):		YEAR:	

COST OF LAW ENFORCEMENT PER LANE-MILE: EQ.= [((10)+(11))*(9)]/(12)	$ DOLLARS PER LANE-MILE

* LEH - Law Enforcement on Highway

all PDs, any small variation will greatly affect the results. If the time spent by the patrol unit on highway-related law enforcement activities is not readily available from the PD, Table 2 should be used to estimate this value. In no case should a default value be used for the patrol unit. For all other police units, using the default values given in Table 1 will not significantly affect the accuracy of the result.

The quick approach procedure consists of the following five steps:

Step 1.

From the Police Department accounting office, determine the number of officers and supervisors in each police unit in the department (column 2 of Table 1).

Step 2.

For each police unit, determine the percentage of time related to highway law enforcement activities (column 3 of Table 1). If the PD cannot readily provide these figures, ranges and default values could be used for all police units except the patrol unit. Calculate patrol unit in this case using Table 2.

The ranges and default values were determined by interviewing experienced police officers from the various units. In every city selected for the study cases, a "round table" meeting was held with 12 to 15 senior officers representing all the police units. An effort was made to achieve consensus on each of the values presented in Table 1.

Likewise, the data needed for Table 2 can be obtained by asking a senior patrol officer or by gathering the same information from two or three experienced patrol officers.

TABLE 2 PATROL UNIT HIGHWAY LAW ENFORCEMENT TIME

City:	Date:	User:

Police Patrol Unit			
Unit Activity	% time spent	% time LEH	cumulative percentage
(equations)	(1)	(2)	(1)*(2)
Preventive Patrol		85%	
Call For Service:			
- Accidents		100%	
- Report Writing		65%	
- Crimes in Progress		5%	
- Disturbances (family, neighbors, roommate,..)		0%	
Miscellaneous:			
- Special Assign.		50%	
- Court Testimony		85%	
- Training		0%	
TOTAL % OF TIME RELATED TO LAW ENFORCEMENT ON HWY :			

* LEH - Law Enforcement on Highway

Step 3.

From the Police Department accounting office, obtain the operational budget for the current year. The PD budget normally does not include detention and correction (jail) functions. This is usually performed by the county or the state, but if the budget includes such functions, as in Jacksonville, it is better to subtract the amount allocated for the correction and detention functions from the budget, and likewise, to subtract the number of correction officers from the police work force. Both values should be readily available.

If the annual depreciation of the PD net assets is readily available, use this figure to adjust the operational budget. Otherwise, add 5 percent to the budget to account for it. As mentioned earlier, 5 percent was found to be an adequate value that will not have a significant effect on the overall accuracy of the results.

Step 4.

From the Public Works Department, find the total lane mileage of the city highway network. From the PD, get a rough estimate of the mileage where the jurisdiction is overlapping (county, state, or federal roads patrolled by the city PD). If the overlapping is more than 5 percent of the city mileage, it is appropriate to adjust the total mileage by that value. In most cases, there is no need for adjustment because these roads are monitored by the state Highway Patrol.

If the city limits extend to large rural areas not frequently patrolled by the police units, the city lane mileage should be reduced to account for this situation.

Step 5.

Perform the calculations as outlined in Table 1. If an estimate of the time spent by the patrol unit on highway law enforcement activities was not provided by the PD, Table 2 should be used to estimate this value. The procedure's accuracy greatly depends on a good assessment of this value.

Performing the computations as indicated in Table 1 will provide a reasonable estimate of the city LEC per lane-mile of road. This average LEC can be adjusted to reflect the cost of a specific road by using two factors. The first factor is related to the traffic volume. The second factor accounts for unsafe or hazardous locations.

STUDY CASES

The quick approach was applied to four Florida cities. The information about each city's lane mileage, the PD budget, the annual depreciation of the net assets, and the number of officers in each police unit was easily obtained. In addition, two state documents summarized most of this information for all Florida cities was obtained.

In order to determine the percentage of time each police unit spent on highway law enforcement-related activities, round table meetings were organized with several senior officers representing all police units. The consensus served as the basis for determining these values.

For Jacksonville, it was necessary to subtract the detention and corrections budget from the total PD budget. The number of officers in that position was also subtracted from the PD total work force. Furthermore, because the city limits extend

TABLE 3 LAW ENFORCEMENT COST ON URBAN ROADS (Miami)

CITY: MIAMI, FL	DATE:	USER: F. N.

POLICE UNIT.	NUMB.OF OFFICERS	% TIME LEH	% TIME RANGES	% TIME DEFAULT	RELAT. WEIGHT	% TIME WEIGHTED
(COLUMN)	(2)	(3)	(4)	(5)	(6)	(7)
(EQUATIONS)					(2)/(8)	(3)*(6)
PATROL UNIT	423	22.5%	20%-70%	--	40.6%	9.1%
MOUNTED PATROL	16	10%	10%-30%	15%	1.5%	0.2%
TRAFFIC UNIT	137	95%	95-100%	100%	13.1%	12.5%
COMMUNITY POL	37	20%	20%-60%	40%	3.5%	0.7%
ORGAN. CRIME	39	10%	10%-20%	15%	3.7%	0.4%
SPECIAL UNIT	13	0%	0%-5%	0%	1.2%	0%
K-9 (DOG) UNIT	22	3%	0%-10%	5%	2.1%	0.1%
AIRPORT SECUR.	0	0%	10%-40%	20%	0%	0%
INVESTIGATIVE	141	3%	3%-15%	8%	13.5%	0.4%
MARINE UNIT	13	0%	0%-0%	0%	12%	0%
AVIATION UNIT	0	0%	5%-15%	10%	0%	0%
OTHERS:	202	3%			19.4%	0.6%
	1043 SUM(8)				100%	23.9% SUM (9)

BUDGET (10): $ 75,561,000		YEAR: 1987	
DEPRECIATION OF NET ASSETS (11):	5% OF (10)	OR	$ 5%
ADJUSTED CITY LANE-MILEAGE (12):	1,392	YEAR: 1988	

COST OF LAW ENFORCEMENT PER LANE-MILE: EQ.= [((10)+(11))*(9)]/(12)	$ 13,617 DOLLARS PER LANE-MILE

* LEH - Law Enforcement on Highway

to cover almost all of Duval County, it was assumed that half the city mileage falls in rural areas and is not regularly patrolled by the city police units. Consequently, Jacksonville city mileage was adjusted to reflect the actual patrolling operations.

Applying the quick approach method produced the following LEC for the selected cities:

City	*LEC per lane-mile ($)*
Miami City	13,600
Jacksonville	9,770
Fort Lauderdale	12,592
West Palm Beach	7,960

Although the data were easily obtained and the calculations quickly performed, the quick approach yielded good estimates of the LEC. These costs per lane-mile reflected the characteristics of each city's highway network, and the PD budget and structure. The work sheets for these cities are presented in Tables 3–6. Table 7 presents a detailed estimate of the percentage of time the patrol unit spent on law enforcement activities for Jacksonville.

In order to compare the magnitude of LEC on urban and rural roads, the Florida Turnpike (a toll road) was selected to estimate the LEC on rural roads. The turnpike is located in rural areas and exclusively patrolled by its own Highway Patrol force. Because the Turnpike Highway Patrol has no function other than enforcing the traffic law and assisting accident victims, the LEC per lane-mile was found by dividing the Turnpike Highway Patrol budget ($5,689,400 for 1988) by the Turnpike total lane-mileage (1,416 lane-miles in 1988). This resulted in a LEC of $4,015 per rural lane-mile, about one-third the average value found for urban roads.

TABLE 4 LAW ENFORCEMENT COST ON URBAN ROADS (Jacksonville)

CITY: Jacksonville, Fl	DATE:	USER: F.N

POLICE UNIT.	NUMB.OF OFFICERS	% TIME LEH	% TIME RANGES	% TIME DEFAULT	RELAT. WEIGHT	% TIME WEIGHTED
(COLUMN)	(2)	(3)	(4)	(5)	(6)	(7)
(EQUATIONS)					(2)/(8)	(3)*(6)
PATROL UNIT	514	58%	20%-70%	--	61%	35.4%
MOUNTED PATROL	4	15%	10%-30%	15%	0.5%	0.1 %
TRAFFIC UNIT	62	100%	95-100%	100%	7.4%	7.4%
COMMUNITY POL	18	45%	20%-60%	40%	2.1%	1.0%
ORGAN. CRIME	34	20%	10%-20%	15%	4.0%	0.8%
SPECIAL UNIT	24	0%	0%-5%	0%	2.8%	0%
K-9 (DOG) UNIT	7	3%	0%-10%	5%	0.8%	0%
AIRPORT SECUR.	0	0%	10%-40%	20%	0%	0%
INVESTIGATIVE	164	6%	3%-15%	8%	19.5%	1.2%
MARINE UNIT	4	0%	0%-0%	0%	0.5%	0%
AVIATION UNIT	12	5%	5%-15%	10%	1.4%	0.1%
OTHERS:	0	–				
	843 SUM(8)				100%	45.9% SUM (9)

BUDGET (10): $ 62,284,000		YEAR: 1987	
DEPRECIATION OF NET ASSETS (11):	5% OF (10)	OR	$ 5%
ADJUSTED CITY LANE-MILEAGE (12): 3,078		YEAR: 1987	

COST OF LAW ENFORCEMENT PER LANE-MILE: EQ.= [{(10)+(11)}*(9)]/(12)	$ 9,772 DOLLARS PER LANE-MILE

* LEH - Law Enforcement on Highway

TABLE 5 LAW ENFORCEMENT COST ON URBAN ROADS (Fort Lauderdale)

CITY: Fort Lauderdale, FL	DATE:	USER: F. N.

POLICE UNIT.	NUMB.OF OFFICERS	% TIME LEH	% TIME RANGES	% TIME DEFAULT	RELAT. WEIGHT	% TIME WEIGHTED
(COLUMN)	(2)	(3)	(4)	(5)	(6)	(7)
(EQUATIONS)					(2)/(8)	(3)*(6)
PATROL UNIT	195	34%	20%-70%	--	54.0%	18.4%
MOUNTED PATROL	5	15%	10%-30%	15%	1.4%	0.2%
TRAFFIC UNIT	14	100%	95-100%	100%	3.9%	3.9%
COMMUNITY POL	10	35%	20%-60%	40%	2.8%	1.0%
ORGAN. CRIME	22	10%	10%-20%	15%	6.1%	0.6%
SPECIAL UNIT	11	0%	0%-5%	0%	3.0%	0%
K-9(DOG) UNIT	9	3%	0%-10%	5%	2.5%	0.1%
AIRPORT SECUR.	13	15%	10%-40%	20%	3.6%	0.5%
INVESTIGATIVE	60	3%	3%-15%	8%	16.6%	5.0%
MARINE UNIT	11	0%	0%-0%	0%	3.0%	0%
AVIATION UNIT	5	5%	5%-15%	10%	1.4%	0.1%
OTHERS:	6	0%			1.7%	0%
	361 SUM(8)				100%	25.3% SUM (9)

BUDGET (10): $ 37,352,000		YEAR: 1987
DEPRECIATION OF NET ASSETS (11):	5% OF (10)	OR $ 5%
ADJUSTED CITY LANE-MILEAGE (12): 788		YEAR: 1987

COST OF LAW ENFORCEMENT PER LANE-MILE: EQ.= [{(10)+(11)}*(9)]/(12)	$ 12,592 DOLLARS PER LANE-MILE

* LEH - Law Enforcement on Highway

TABLE 6 LAW ENFORCEMENT COST ON URBAN ROADS (West Palm Beach)

CITY: West Palm Beach, Fl	DATE:	USER: F.N.

POLICE UNIT.	NUMB.OF OFFICERS	% TIME LEH	% TIME RANGES	% TIME DEFAULT	RELAT. WEIGHT	% TIME WEIGHTED
(COLUMN)	(2)	(3)	(4)	(5)	(6)	(7)
(EQUATIONS)					(2)/(8)	(3)*(6)
PATROL UNIT	110	37%	20%-70%	--	73.3%	27.2%
MOUNTED PATROL	0	0%	10%-30%	15%	0%	0%
TRAFFIC UNIT	20	100%	95-100%	100%	13.3%	13.3%
COMMUNITY POL	3	25%	20%-60%	40%	2.0%	0.5%
ORGAN. CRIME	5	15%	10%-20%	15%	3.3%	0.5%
SPECIAL UNIT	0	0%	0%-5%	0%	0%	0%
K-9(DOG) UNIT	4	5%	0%-10%	5%	2.7%	0.1%
AIRPORT SECUR.	0	0%	10%-40%	20%	0%	0%
INVESTIGATIVE	8	5%	3%-15%	8%	5.3%	0.3%
MARINE UNIT	0	0%	0%-0%	0%	0%	0%
AVIATION UNIT	0	—	5%-15%	10%	0%	0%
OTHERS:	0	—				
	150 SUM(8)				100%	41.9% SUM (9)

BUDGET (10): $ 13,555,000		YEAR: 1987	
DEPRECIATION OF NET ASSETS (11):	5% OF (10)	OR	$ 5%
ADJUSTED CITY LANE-MILEAGE (12): 749		YEAR: 1987	

COST OF LAW ENFORCEMENT PER LANE-MILE: EQ.= [((10)+(11))*(9)]/(12)	$ 7,956 DOLLARS PER LANE-MILE

* LEH - Law Enforcement on Highway

TABLE 7 PATROL UNIT HIGHWAY LAW ENFORCEMENT TIME (Jacksonville)

City: Jacksonville, FL	Date:	User: F. N.

Police Patrol Unit			
Unit Activity	% time spent	% time LEH	cumulative percentage
(equations)	(1)	(2)	(1)*(2)
Preventive Patrol	20%	85%	17%
Call For Service:			
- Accidents	10%	100%	10%
- Report Writing	31%	65%	20.2%
- Crimes in Progress	7%	5%	0.4%
- Disturbances (family, neighbors, roommate,..)	14%	0%	0%
Miscellaneous:			
- Special Assign.	4%	50%	2%
- Court Testimony	10%	85%	8.5%
- Training	4%	0%	0%
TOTAL % OF TIME RELATED TO LAW ENFORCEMENT ON HWY :			58%

* LEH - Law Enforcement on Highway

CONCLUSION

The quick approach for estimating the LEC on urban roads is both simple to understand and easy to apply. It could be used for estimating an average LEC per lane-mile of urban road. This value can then be adjusted to reflect the LEC of a particular road in the city. All the needed data could be obtained through a few telephone calls. Two standard calculation sheets (Tables 1 and 2) are provided to assist in the data-collection process and efficient application of the quick approach. The five step procedure covers all that is needed to acquire the necessary data and calculate the LEC of urban roadways.

As presented through the study cases, the quick approach provides a reasonable estimate of the LEC because it takes into account all the important parameters relative to law enforcement activities. Furthermore, the approach's sound, justifiable logic includes few assumptions.

Publication of this paper sponsored by Committee on Application of Economic Analysis to Transportation Problems.

Evaluation of Truck Impacts on Pavement Maintenance Costs

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To determine the factors that influence pavement maintenance costs of California state highways and evaluate the impact of heavy-truck traffic on maintenance cost is the purpose of this paper. More than 1,100 one-mile sections of state highways were randomly sampled, and data from various sources were integrated to form a data base containing information on traffic, weather, geometric conditions, and pavement maintenance costs for the sample sections. Following an extensive explorative analysis of the data, a model of pavement maintenance cost was formulated. The most significant finding is that heavy-truck (five or more axles) traffic has a much larger impact on pavement maintenance cost than does light-truck traffic or passenger-car traffic. The estimation results indicate that, on a typical roadway, the average annual maintenance cost per heavy truck per day amounts to $7.60 per mile per year, while the corresponding cost per passenger car is approximately $0.08. The study further shows that one additional heavy truck per day will cost an additional $3.73 per mile per year of roadway for pavement maintenance. An increase of 50 heavy trucks will cost $183.10 per year per mile. The corresponding cost increases due to passenger-car traffic are $0.04 and $2.18 per year per mile, respectively. This study thus establishes that one heavy truck is equivalent to about 90 light trucks or passenger cars in terms of its impact on pavement maintenance cost.

One important highway preservation issue that has surfaced in recent years is the rationale for allocating maintenance costs among various road users. State departments of transportation in the United States frequently prepare cost allocation studies that explore this subject in order to promote the development of revenues to support budget requests. It is recognized that heavy-truck traffic causes most pavement damage and is the key factor in roadway pavement design procedures. However, the extent of truck influence on pavement maintenance costs has not yet been satisfactorily supported. For example, current pavement cost allocation methods fail to incorporate environmental factors such as climate.

This study was proposed to develop a pavement maintenance cost model that would take into account environmental and geometric factors as well as traffic variables. The study's objective was to identify factors influencing pavement maintenance costs and evaluate the impact of heavy-truck traffic on the maintenance costs for California state highways.

The approach taken used a random sample of more than 1,100 one-mile sections of state highways and data from various sources to examine pavement maintenance costs in multivariate statistical contexts. It is considered crucial here that this examination be performed while all relevant factors are considered. A data base was prepared to support this examination by integrating the traffic, weather, geometric, soil type, and pavement maintenance cost information for the various sample sections.

Following a brief literature review, the next section documents in detail the procedure of data file preparation. Results of the model estimation effort are presented next, together with the description of the variables used in the analysis and basic statistics portraying the data file. Using the estimation results, the average pavement maintenance costs and additional costs due to traffic increases are evaluated, and the relative impacts of heavy trucks and passenger cars are determined. The following section summarizes the major conclusions, and the major recommendations are contained in the final section.

LITERATURE REVIEW

After state, national, and international literature was consulted, the following comments summarize the sources found to be most relevant to the issue of pavement maintenance cost allocation.

Contemporary interest in this topic began in 1978 and 1979. The Congressional Budget Office (CBO) (*1*, *2*) reviewed and discussed the subject of allocating all pavement maintenance costs by using an axle-load-equivalent approach. This method allocates pavement costs to classes of vehicles on the basis of the amount of pavement wear or deterioration they cause and uses the extensive AASHO Road Test data collected in the late 1950s. These data provide information on the relative amounts of pavement wear for which various types of vehicles were responsible. In particular, it was found that heavy trucks are responsible for pavement wear equivalent to that caused by an enormous number of automobiles. Two exceptions to using axle-load equivalents in pavement cost allocation exist: costs attributable exclusively to environmental factors and costs of a permanent, nondepreciating nature. Some questions regarding environmental factors, pavement depreciation, and AASHO Road Test reliability remain unanswered. However, the CBO concluded that costs should be allocated in the same way as they are when the road is paved.

In 1984, the Federal Highway Administration (FHWA) produced a guide (*3*) intended as a resource document to be used by states in constructing their own cost allocation studies.

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It does not recommend any specific allocation method, but rather explains the strengths and weaknesses of various methods. As a reference, this guide documents the information and analyses resulting from the federal cost-allocation study of May 1982. This source did not reveal significant information regarding pavement maintenance cost allocation methodology.

The state of Indiana in 1984 required a model that estimated pavement routine maintenance (e.g., patching and crack sealing) costs (*4*). A major purpose of the study was to predict costs without special purpose data. The average daily traffic (ADT) values were converted to equivalent single axle loads (ESALs), an index that converts all vehicle weights and types to representative 18-kip ESALs (1 kip = 1,000 lb). The best cost model for reinforced concrete pavement sections was

$$\log(\text{Cost}) = 0.005(\text{Age}) + 0.54\,[\log(\text{ESAL})]$$

Another model was available for resurfaced reinforced concrete pavement

$$\log(\text{Cost}) = 0.032(\text{Age}) + 0.57[\log(\text{ESAL})]$$

Both models gave good results. Major conclusions included the following:

- A strong correlation exists between routine pavement maintenance costs and pavement age and amount of traffic accumulated (ESAL).
- Estimated costs were close to the actual values as yielded by both models. This was true for both reinforced concrete and resurfaced-reinforced concrete sections.

In 1984 FHWA explained in detail, highway cost allocation assignments and a few new methods used to make these assignments (*5*). A new cost allocation method, the minimum pavement thickness method, was recommended for proportioning thickness costs for new pavements. This method uses each vehicle's ESAL value to estimate thickness responsibility. An incremental approach is used to assign new pavement costs. The minimum pavement thickness method assigns heavy trucks more new pavement costs than any of the compared incremental approaches. Another approach, using the AASHO Road Test equations for 100 percent of costs, overassigns costs to heavy vehicles. The effects of rehabilitated pavement assignment methods on overall cost assignments were also compared.

The basic purpose of highway cost allocation methodology in New Zealand (*6*) was to implement the taxation principle that the "user pays." Traditionally, New Zealand had allocated costs among the driver, road space, and pavement strength requirements. This 1984 material reported a departure from the "fourth-power rule" (sum of the fourth power of each axle weight divided by 10,000) in favor of the "third-power rule" for apportioning pavement wear costs. The primary result of the effort was to allocate costs on the basis of a fee assessment that, in turn, was based on equivalent design axles, truck fuel, and large tires. The allocation breakdown was 22 percent, 54 percent, and 24 percent, respectively. This source also raises an interesting question: Should nonuser benefits, derived from pedestrians, cyclists, flood control, and public utilities, be factored into the cost allocation models?

In 1984 the United Kingdom's Department of Transport allocated all roadway costs based on a type of "Delphi" concept using the opinions of highway engineers and research scientists (*7*). The allocation cost of 1.6 billion £ was weighted according to the following scheme:

Variable	*Percent*
Vehicle mileage	36
Gross vehicle weight mileage	14
Standard axle mileage	36
Pedestrians	14

A standard axle in tons was calculated from the fourth-power rule. Approximately 44 percent of all road costs was allocated among the three major maintenance activities: reconstruction and resurfacing, surface skid improvement, and pothole and minor repair. Of the 44 percent, 28 percent was allocated to reconstruction and resurfacing by standard axle mileage, 6 percent to surface skid improvement by vehicle mileage (0.8 weight) and by gross vehicle weight mileage (0.2 weight), and 10 percent to pothole and minor maintenance by vehicle mileage.

In California, SYDEC, Inc., in 1987 used a Delphi panel composed of selected experienced California Department of Transportation (Caltrans) maintenance personnel (*8*). The Delphi process submitted questions to this panel of experts regarding the amount of pavement maintenance cost attributable to various highway users. Results of this Delphi process were then averaged with results from the Caltrans Transportation Laboratory work, which were developed for the purpose of design, rather than maintenance. Approximately 66 percent of pavement maintenance was allocated to heavy (five or more axles) vehicles, and the balance was attributed to lighter vehicles.

In summary, there has been little literature using analytical techniques pertinent to highway pavement maintenance cost allocation methodology. In Indiana, analytical cost allocation has been performed for routine pavement maintenance (*9*), but these costs did not include maintenance efforts toward addressing poor ride quality, structural failure, or preventive maintenance actions, all major maintenance activities in California. Total pavement maintenance cost allocations have been done in several places using the concept of the Delphi process, which, again, is not an analytical method.

DATA FILE PREPARATION

The data file used in this project integrates various pieces of information obtained from several data sources. The data file preparation process is summarized in this section.

Caltrans data acquired for the project include

- 1986 annual ADT on the California state highway system (*10*),
- Fiscal years 1984–1985, 1985–1986, and 1986–1987 maintenance costs for selected maintenance measures by control section (*11*), and
- Highway geometric information (*12*).

In addition, an established set of weather classification categories is used for this study (*13–15*).

Traffic Data

A sample of roadway segments was prepared for the study by randomly selecting a 1-mi section for every 15-mi segment of the state highway system. The beginning 1-mi section was normally selected as the first section of each route. Some sections were chosen with somewhat different spacing when upstream and downstream traffic volumes differed substantially and the homogeneity of the sample section was questionable. The sampling process resulted in a total of 1,152 sample sections. The distribution of sample sections across the counties is shown in Table 1.

For each sample section, the following variables were extracted from the Caltrans report on annual average daily traffic (AADT) classification count data (*10*):

- Route number,
- District,
- County,
- Postmile,
- Total vehicle AADT,
- Total truck AADT,
- Total 5^{+}-axle truck AADT, and
- ESALs

The nature of the traffic count data is specified in the traffic volume file as either "verified" or "estimated." Verified means that the count is based on actual field data, whereas estimated values are obtained using data from nearby verified sites. The number of sample sections with 1984–1985, 1985–1986, and 1986–1987 verified traffic counts are 96, 115, and 95, respectively.

Weather Data

Detailed descriptions of climate conditions prevailing at the sample sections were obtained by establishing weather categories and by using weather data from the nearest stations. The sources used to establish weather classifications include *California's Many Climates* (*13*), *Characteristic Weather Phenomena of California* (*14*), and *Weather of Southern California* (*15*).

Synthesizing weather categories presented in these sources established four weather classes:

- Maritime,
- Mountain,
- Desert, and
- Valley.

In addition to this climate-type classification, the following measurements were incorporated into the data file:

- Annual precipitation,
- Average annual temperature,
- Average December temperature, and
- Elevation.

Average December temperature is used in this study because a previous study found a strong correlation between this variable and highway maintenance costs (*16*).

Data for each sample highway section were obtained from the weather station whose coverage area contained the sample roadway section. (There are 120 survey stations that provide weather information for the state.) Accordingly, weather data vary from section to section within each weather category.

TABLE 1 NUMBER OF SAMPLE SECTIONS BY COUNTY

Alameda	27	Monterey	20	Trinity	12
Alpine	2	Napa	8	Tulare	26
Amador	9	Nevada	7	Tuolumne	6
Butte	5	Orange	29	Ventura	24
Calaveras	7	Placer	13	Yolo	16
Colusa	7	Plumas	14	Yuba	6
Contra Costa	12	Riverside	45		
Del Norte	7	San Bernardino	71		
El Dorado	14	Sacramento	21		
Fresno	33	San Diego	48		
Glenn	8	San Francisco	10		
Humboldt	23	San Luis Obispo	26		
Imperial	23	San Joaquin	22		
Inyo	19	San Mateo	20		
Kern	57	Santa Barbara	29		
Kings	12	Shasta	23		
Lake	11	San Benito	7		
Lassen	15	Santa Cruz	10		
Los Angeles	102	Sierra	4		
Madera	11	Siskiyou	24		
Marin	7	Santa Clara	26		
Mariposa	9	Solano	19		
Mendocino	25	Sonoma	20		
Merced	19	Sutter	8		
Modoc	11	Stanislaus	11		
Mono	24	Tehema	15		

Maintenance Cost Data

The Caltrans highway maintenance cost data base for selected maintenance measures by control section was used in this study (*11*). The data for fiscal years 1984–1985, 1985–1986, and 1986–1987 were available to prepare the cost data file. Maintenance cost information was divided into two categories—flexible pavement and rigid pavement.

FORTRAN programs were written to extract to cost data from these Caltrans files for the 1,152 sample sections and match them with traffic and weather data. The data file resulting from the extracting and matching effort contained information on labor hours, labor dollars, equipment dollars, and material dollars.

Geometric Data

The geometric data used for this study include

- Roadway functional classification,
- Pavement type,
- Number of lanes,
- Shoulder width,
- Traveled way width, and
- Pavement age.

Pavement age is measured in terms of the recorded number of years since the last major pavement work. These data were extracted manually from the California State Highway Log and matched with the rest of data for the 1,152 sample sections (*12*).

Limitations of the Data File

Every effort was made to attain the highest possible data quality in the preparation of the data file for this project. However, because of problems in the existing data sources and the limited time allotted for the project, the data file is subject to certain limitations.

1. Verified traffic data were not available for all 1,152 sample sections. For 58 percent of the sample sections, traffic data "estimated" by Caltrans are used.
2. Verified traffic data were not necessarily available for the years for which maintenance cost data were available. Of the 42 percent of the sample sections for which verified traffic data were available, only 306 sections have data for 1984–1985, 1985–1986, or 1986–1987.
3. No computer-retrievable data sources apparently exist for certain geometric characteristics, structural characteristics, terrain and drainage, traffic regulations, and roadway maintenance and improvement histories.
4. Maintenance costs may have been prorated over a long span of roadway.
5. Roadway rehabilitation work may not have been classified as such (possibly due to funding categories) when the year of the last major pavement work was determined, which may have led to incorrect identification of the pavement age in the data file.

These limitations must be kept in mind when the results of this study are interpreted and generalized.

ANALYSIS OF DATA

An extensive set of variables (see Tables 2 and 3) was examined in the study to identify factors contributing to pavement maintenance cost (the VMS version of the BMDP statistical software package was used in the analyses presented in this paper). Following a preliminary analysis of the distributive characteristics of the variables in the data file using histograms, bivariate correlation coefficients, and contingency tables, pavement maintenance cost models were developed through multiple linear regression analysis.

Two types of models, linear and multiplicative, were considered, and numerous model formulations were tested in the process of model development. Results of the analysis indicated that linear models in general offered poor fits with occasional negative model coefficients that could not be theoretically supported. Multiplicative models, on the other hand, offered good fits and significant coefficients with theoretically consistent signs. Therefore only the analysis results using multiplicative models are presented in this paper.

Results of Model Estimation

Alternative models were estimated using the 1,007 sections in which the total 1984–1987 pavement maintenance expenditures were not zero and data were complete. The following discussion, therefore, is concerned with variations in pavement maintenance costs during 1984 through 1987 across those 1-mi sections where routine maintenance work was performed during that period.

The estimated coefficients of the best model chosen in the analysis are summarized in Table 4 together with goodness-of-fit statistics. The coefficient, β, applies to the variable as a power. For example, the constant term, 17.66, and the coefficient, 0.207, of ln (HT-AADT) imply that the dependent variable, ln (TOTALCOST), is expressed as

$$\ln(\text{TOTALCOST}) = 17.66 + (0.207)\ln(\text{HT-AADT}) + \ldots$$

or

$$\text{TOTALCOST} = (4.67 \times 10^7)(\text{HT-AADT})^{0.207} \ldots$$

The dummy variables (to which log-transformation is not applied) in these multiplicative models take on values of 1.0 or 2.718 (= *e*). For example, DISTRICT2 will take on a value of 2.718 for a roadway segment if it belongs to District 2, and a value of 1.0 otherwise. District 2 is in the north central and northeastern portions of the state. The variable does not influence the dependent variable if its value is 1.0. On the other hand, if its value is 2.718, it factors TOTALCOST by $\exp(\beta)$, where β is the coefficient of this variable. For example, the coefficient, 0.60, of DISTRICT11 implies that the total maintenance cost is multiplied by 1.82 [$= \exp(0.601)$], or is approximately 80 percent more, in District 11. This district is in the

TABLE 2 VARIABLES CONSIDERED IN DEVELOPMENT OF PAVEMENT COST ALLOCATION MODELS

Variable	Description
Traffic	
HT-AADT	Heavy truck (5 or more axles) average annual daily traffic
P&LAADT	Passenger car and light truck average annual daily traffic
Roadway Geometry	
NLANES	Number of lanes in one direction
SHOULDER	Shoulder width (in feet)
NOSHOULDER	2.718 if the segment has no shoulder; 1 otherwise
WIDTH	Traveled way width in one direction (in feet)
District	
DISTRICTi	2.718 if the roadway segment lies in Caltrans District i (i is 1 through 11; 1 otherwise
Climate	
RAINFALL	Annual precipitation (in inches)
AATEMP	Average annual temperature (° F)
DECTEMP	Average December temperature (° F)
HTEMP	The highest temperature (° F)
ELEVATION	Elevation of the roadway segment (in feet)
MARITIME	2.718 if the roadway segment lies in the maritime climate; 1 otherwise
MOUNTAIN	2.718 is the roadway segment lies in the mountain climate; 1 otherwise
DESERT	2.718 if the roadway segment lies in the desert climate; 1 otherwise
VALLEY	2.718 if the roadway segment lies in the valley climate; 1 otherwise
Surface Type and Age	
RIGID	2.718 if the entire roadway segment has rigid pavements; 1 otherwise
FLEXIBLE	2.718 if the entire roadway segment has flexible; 1 otherwise
BRIDGE	2.718 if the entire roadway segment is a bridge; 1 otherwise
AGE	Pavement age (in years since last major pavement work)
Functional Classification	
PART-PART	Principal arterial connecting to principal arterial
PART-MART	Principal arterial connecting to minor arterial
PARTCART	Principal arterial, no connecting link
MINORART	Minor arterial
MJCOLLCTR	Major collector
MNCOLLCTR	Minor collector
TOTALCOST	Total 1984-87 pavement maintenance cost (in dollars)

southernmost part of California, including San Diego and desert counties.

The most important finding is that the coefficient of heavy-truck AADT [ln(HT-AADT)] is positive and highly significant (heavy trucks are defined in this study as those with five or more axles). In fact, this variable has the largest *t*-statistic, implying that it is the single most important variable that influences pavement maintenance costs. The estimated coefficients also indicate that light-truck and passenger-car traffic does not contribute significantly to pavement maintenance costs.

It is also important to note that climate variables play only a minor role in this model. Many indicators of weather were examined during the model development (AATEMP, DECTEMP, RAINFALL, ELEVATION, MARITIME, MOUNTAIN, DESERT, and VALLEY). Only two, AATEMP and MOUNTAIN, are significant and were used in the final model. The results suggest that the variation in pavement maintenance costs due to climatic differences is minor in California. Investigation is continuing in efforts to validate this conjecture, and a more extensive set of climate variables and their transformations are being considered.

Variables in the model other than the traffic and climate variables are pavement type (BRIDGE), functional classification (MNCOLLCTR), roadway geometry (SHOULDER and NOSHOULDER), pavement age (AGE), and indicators of districts (DISTRICT2 and DISTRICT11). The coefficients of MOUNTAIN and MNCOLLCTR indicate that, other things being equal, fewer maintenance dollars tend to be expended in mountain areas and on minor collectors. The dummy variable for no shoulder (NOSHOULDER) indicates that, other things being equal, maintenance cost tends to be smaller for roadways with no shoulder.

Inclusion of the district indicators in the model suggests that maintenance cost per unit distance varies by district, presumably because of differences in maintenance practice.

TABLE 3 DESCRIPTIVE STATISTICS OF VARIABLES IN THE DATA FILES OF THE STUDY

Variable	N	Mean	Standard Deviation	Minimum	Maximum
HT-AADT	1119	987.5	1784.0	0	18250
P&LAADT(x 10^3)	1119	23.7	38.4	0	259.8
ELEVATION	1082	1157.5	1718.4	-119	9120
NLANES	1119	1.69	.92	1	6
WIDTH	1119	20.4	11.5	8	84
RAINFALL	1082	19.1	12.3	2.6	74.9
SHOULDER	1119	6.61	3.52	0	21
AATEMP	1082	58.99	6.01	39.2	73.3
DECTEMP	1081	47.17	6.69	26	57.4
AGE	1119	18.40	6.05	1	23
TOTALCOST(x 10^3)	1119	89.1	119.8	0	810.2

Climate Type	N
MARITIME	322
MOUNTAIN	188
DESERT	64
VALLEY	500
Total	1074

Surface Type	N
RIGID	100
FLEXIBLE	528
BRIDGE	45
MIXED	446
Total	1119

District	N
1	64
2	115
3	113
4	136
5	76
6	126
7	145
8	103
9	55
10	104
11	82
Total	1119

Functional Class	N
PART-TIME	415
PART-MART	104
PARTCART	121
MINORART	391
MJCOLLCTR	69
MNCOLLCTR	9
Total	1109

The estimated model coefficients reveal that maintenance costs per unit distance tend to be higher in Districts 2 and 11 by 93 and 82 percent, respectively. District 2 is in the sparsely populated northeastern portion of California, whereas District 11 is in the extreme south.

The age variable has a positive coefficient, as anticipated. However, its value is very small and only marginally significant, with a *t*-statistic of 1.8. The result suggests that the cost of routine maintenance does not vary substantially by the age of the pavement, given that maintenance work is performed at all. These results were confirmed in a weighted least-squares analysis performed to account for possible heteroscedasticity.

A similar modeling exercise was performed using 1,079 sample sections comprising all sections with complete data, including those 72 sections where 1984–87 maintenance costs were recorded to be 0. Although the coefficients of heavy-truck traffic (HT-AADT) were very similar between the two samples (0.207 and 0.210), discrepancies emerged in terms of the variables included and their coefficient values. This result suggests that whether any maintenance is performed on a given section of a roadway is governed by factors different from those influencing the cost of maintenance work. In addition, the estimated coefficient of light-truck (fewer than five axles) traffic was very small in this estimation result.

Evaluation of Maintenance Cost Due to Heavy-Truck Traffic

One of the properties of the multiplicative model used in the analysis is that each coefficient represents the sensitivity (or "elasticity") of roadway maintenance cost to changes in the explanatory variable. For example, the coefficient value of 0.21 for heavy-truck AADT implies that a 1 percent increase in heavy-truck AADT leads to a 0.21 percent increase in maintenance cost. Using the estimated coefficient values, a 1 percent increase in light-truck or passenger-car AADT will result in a much smaller 0.06 percent increase in maintenance cost.

The contribution of each additional vehicle to the absolute dollar cost of maintenance can also be evaluated using the estimated model. The results of this estimation, summarized in Table 5, indicate that, on a typical roadway section, each additional heavy truck per day costs $3.73 in maintenance per

TABLE 4 MULTIPLICATIVE MODEL OF PAVEMENT MAINTENANCE COST

	β	t
Constant	17.66	
ln (HT-AADT)	0.21	5.58
ln(P&LAADT)	0.06	1.13
ln(AGE)	0.17	1.80
ln(SHOULDER)	-0.36	-3.16
NOSHOULDER	-0.61	-2.06
ln(AATEMP)	-2.11	-2.84
MOUNTAIN	-0.38	-1.81
BRIDGE	-1.49	-2.68
MNCOLLCTR	-1.23	-1.73
DISTRICT2	0.66	2.93
DISTRICT11	0.60	2.85
F	8.63	
df	(11,995)	
R^2	0.09	
N	1007	

Note: Excludes sections with zero maintenance costs.

β = regression coefficient
t = t-statistics (critical value = 1.96 at α = 5%)
F = F-statistics (critical value = 1.80 at α = 5%)
df = degrees of freedom
R^2 = coefficient of determination
N = sample size

TABLE 5 MARGINAL INCREASE IN PAVEMENT MAINTENANCE COST DUE TO ADDITIONAL TRAFFIC

Heavy Truck		Passenger Car & Light Truck	
Increase in Traffic	Increase in Maintenance Cost	Increase in Traffic	Increase in Maintenance Cost
1	3.73	1	0.04
5	18.64	5	0.22
10	37.20	10	0.44
25	92.45	25	1.09
50	183.10	50	2.18
(Vehicles/day)	($/year/mi)	(vehicles/day)	($/year/mi)

Note: The marginal cost increases are evaluated for a roadway section which is not in the mountain climate, not a bridge section, not a minor collector, and is not in District 2 or 11. The sample average values are used for HT-AADT, P&LAADT, AGE, SHOULDER, and AATEMP (see Table 3 for the values used).

mile per year. The corresponding figure for each additional light truck or passenger car per day is only $0.04 per mile per year. When an increase of 50 vehicles per day is assumed, the costs due to the two types of traffic compare as $183.10 versus $2.18, with the marginal cost increase of the light truck or passenger car less than 1/90 that of the heavy truck.

Evaluation of Average Maintenance Cost of Heavy-Truck Traffic

The average cost of heavy-truck traffic can be evaluated as the increase in maintenance cost due to heavy-truck traffic divided by the heavy-truck traffic volume. Table 6 summarizes the calculation results carried out for the same hypothetical average highway section as that in Table 5. Table 6 confirms the result obtained in Table 5 using the concept of marginal maintenance cost that the impact on highway maintenance cost of a heavy truck is approximately 90 times as much as that of a passenger car. The study results thus establish the impact of heavy-truck traffic on pavement maintenance costs relative to that of light-truck or passenger-car traffic.

MAJOR CONCLUSIONS

The objective of this study has been to determine factors influencing pavement maintenance costs for California state

TABLE 6 AVERAGE MAINTENANCE COST PER VEHICLE

Heavy Truck Volume	Heavy Truck Cost/vehicle	Passenger Car & Light Truck Volume	Passenger Car & Light Truck Cost/Vehicle
250	20.44	5000	0.31
500	12.53	15000	0.12
987.5 *	7.67	23700 *	0.08
1000	7.60	25000	0.08
2000	4.57	50000	0.04
5000	2.31	100000	0.02
Vehicles/day	$/year/mile	Vehicles/day	$/year/mile

*Sample mean traffic volume.

NOTE: Maintenance costs are calculated assuming average roadway and climatic conditions (see the note in Table 5) using the following formula:

$$\text{Average Cost} = \frac{\text{Total Cost - Fixed Cost}}{\text{Traffic Volume}}$$

where the fixed cost is obtained assuming no traffic.

highways. A particular goal was to evaluate the impact of heavy-truck traffic on maintenance cost. To this end, more than 1,000 one mile sections of state highways were randomly sampled, and data from various sources were integrated for these sections to form as comprehensive a data set as possible. Variables included in the resulting data file represented traffic data, weather data, geometric data, and pavement maintenance cost data.

Following an extensive explorative analysis of the data, and after examining many alternative model formulations, a statistical model of pavement maintenance cost was formulated. The most important finding is that heavy-truck traffic has a much larger impact on pavement maintenance cost than does light-truck or passenger-car traffic. Our estimation results indicate that, on a typical roadway, the average maintenance cost per heavy truck (five or more axles) is $7.60 per mile per year, whereas the cost per passenger car is approximately $0.08 per mile per year. It was further shown that one additional heavy truck per day would cost annually an additional $3.73 for pavement maintenance per mile of roadway. An increase of 50 heavy trucks would cost an additional $183.10 per year per mile. The corresponding cost increases due to light-truck or passenger-car traffic are $0.04 and $2.18 per year per mile, respectively. This study thus establishes that one heavy truck is approximately equivalent to 90 light trucks or passenger cars in terms of its impact on pavement maintenance costs.

In addition, the model indicates that the effect of weather on pavement maintenance costs is relatively small, with maintenance cost decreasing with the average annual temperature. The model also indicates, other things being equal, that less funds are spent per mile on pavement maintenance in mountain areas.

As expected, maintenance cost increases with the age of the pavement. The study found, however, that this increase is small, presumably because routine pavement maintenance is performed at a certain rate regardless of the age of pavements. Substantial differences exist in per-mile maintenance costs across districts. District 2 is mostly rural, mountainous, and remote, whereas District 11 includes San Diego County plus low-elevation, hot, and remote desert. The uniqueness of these districts includes remoteness, mountains or desert, and Interstate highways. Perhaps these features combine to cause the significance for these district indicators. It was also found that less maintenance costs tend to be expended on minor collectors and bridge sections.

This study has shown that a statistical analysis of a carefully compiled data set is capable of providing useful information for pavement maintenance cost allocation. The robustness of the findings and the accuracy of the cost estimates will improve if the quality of the data can be improved. In particular, it is recommended that the definition of pavement age and the practice of cost proration be critically examined, and subgrade soil types and drainage conditions be introduced into the data base in the future.

MAJOR RECOMMENDATIONS

Extending the conclusions yields three major recommendations. First, the state of California should review its highway taxation policies. Second, effort should be directed to refine and improve this analysis and the results contained here. Finally, a national study should be undertaken to evaluate the applicability of this approach for other states.

Although this study suggested a pavement maintenance cost distribution between heavy trucks and light vehicles of the order of 100 times, the most recent California cost allocation effort used a ratio of approximately two to one (*8*). This information, of course, implies a need for the state of California to review and perhaps revise its current vehicle fee structure. This is a major policy issue separate from this research effort. The trucking industry provides benefits to the general economy that should be considered in deliberations regarding vehicle fees.

As this research project neared completion, several significant issues surfaced that were beyond the project's scope. An additional contract was recommended (and is now under way) to address the following concerns:

- Study variation in costs among districts,
- Perform additional analyses of environmental effects,
- Develop models with ESAL as an independent variable, and
- Develop separate models for rigid and flexible pavements.

The final major recommendation is for the development of a national research project to (a) apply this approach to other states and (b) prepare a supplement to the FHWA highway cost allocations guide dealing with pavement maintenance costs. The scope and development of such a project should include discussion with appropriate AASHTO and TRB representatives as well as with FHWA.

ACKNOWLEDGMENTS

The authors are grateful to a number of individuals in the Department of Transportation, State of California, for their assistance during the course of this project. In particular, Cindy Bartolomei, Niel Colley, Robert Copp, Jim Gardner, Joseph Hannon, and Emory Stoker aided the research team in collecting traffic, maintenance cost, and geometric data. Paul Benson and Bruce Gunderson offered valuable comments in an earlier draft of this report. A meeting held with Bruce Gunderson, William Nokes, and Rich Quinley provided guidelines for extending the study. John VanBerkel offered many insights and encouragements throughout the project.

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The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the state of California. This report does not constitute a standard, specification, or regulation.

Publication of this paper sponsored by Committee on Application of Economic Analysis to Transportation Problems.

Measuring Economic Development Benefits for Highway Decision Making in Wisconsin

GLEN E. WEISBROD AND JAMES BECKWITH

The Wisconsin Highway 29/45/10 study was a pioneering effort to conduct a comprehensive evaluation of potential economic development benefits associated with a proposed major regional highway project and apply those findings for cost-benefit analysis. A series of five alternative design levels, for each of two alternative highway routes, was evaluated. A set of interacting transportation and economic analysis models and techniques were used to evaluate the alternatives in terms of the potential for greater business expansion, new business attraction and tourism, and auto passenger-user benefits. A rigorous cost-benefit evaluation framework, designed to avoid double counting, was used to rank the alternatives for public policy decision making.

Issues involved in measuring and evaluating the economic development impacts of major highway investment and the application of those findings for investment decision making were examined. This paper focuses on a proposed highway construction project to create a 2,000 mile four-lane highway across north-central Wisconsin. This corridor would provide a major east-west link from Green Bay and Appleton on the east to Eau Claire and Chippewa Falls to the west. There the route intersects with I-94 and continues to Minnesota (see Figure 1).

A major motivation for considering the highway improvement was the belief, promoted by community and business leaders, that a high-quality four-lane highway connecting cities across the corridor would significantly enhance economic growth in the region. It was generally believed that unless highway improvements to the corridor were evaluated for long-range economic development potential, the benefits of the corridor improvement would be underestimated.

At the state level, there was also interest in using transportation investments to promote economic development objectives. The Wisconsin Department of Transportation was very interested in expanding its cost-benefit analysis to include not only benefits to the user, but also benefits to the economy. Accordingly, the department commissioned a study to assess the potential long-term economic development benefits of building a new major four-lane facility across the state (1).

The study evaluated five alternative levels of improvement for the Highway 29/45/10 Corridor, ranging from a two-lane arterial to a full freeway. The alternatives are described further in Figure 2.

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The most notable aspect of this study is its breadth. The analysis process included an integrated set of simulation and forecasting models of the economy and the transportation network to evaluate potential impacts of this major highway investment. In addition to projecting benefits to auto travellers, the study focused on estimating impacts on expansion of existing business, attraction of new business, and tourism growth. Specific attention focused on providing a rigorous framework for benefit assessment that avoids double-counting, a typical problem of economic impact assessment. In addition, attention was given to providing a methodology for estimating transportation and economic impacts that adequately recognizes implications of business efficiency benefits, a shortcoming of some prior economic assessment studies.

This article provides an overview of how economic impacts were measured, describes the analysis modeling techniques used, and shows how cost-benefit analysis was applied for highway investment decision making.

LITERATURE REVIEW

Before evaluating the economic impacts of proposed highway projects, it is important to understand the limitations of prior research on this topic. In fact, a major aspect of the economic impact literature is that the research has gone in several distinct directions, addressing different sets of issues. Overall, the studies provide only limited guidance for local economic development evaluations.

For instance, one set of studies has shown the relationship of national highway investments to reducing shipping costs and increasing business productivity (*2–5*). These studies generally find evidence, using national time series statistics, of increased business productivity over time associated with reduced shipping costs resulting from upgrading the national highway network. Such findings, however, are not transferable to the evaluation of individual highway improvements, where geographic differences in travel patterns and economic patterns become important considerations.

Another set of economic modeling studies has analyzed the relationship of highway locations to nearby business growth patterns (*6–10*). Other case studies have attempted to document the shifts in business growth patterns associated with specific new freeways (*11–13*). Most of these studies were conducted a decade ago and found mixed evidence concerning

FIGURE 1 Highway 29/45/10 Corridor.

whether there is statistical or causal relationship between regional economic growth and highway improvements. They generally conclude that many local factors other than highway improvements affect regional growth. Thus, one can only conclude from these studies that a new or substantially upgraded highway may or may not have economic impacts, depending on where it is located and the intercity connections it provides.

If, however, one moves beyond the numbers and talks to business executives who make location decisions, and economic development professionals involved in trying to attract businesses, the evidence shows that highway issues are prominent in the expansion and location decisions of many firms. Surveys of corporate executives by Dow Jones & Co. and by *Site Selection* magazine, for instance, have consistently found highway access to be among the top three locational considerations for corporate headquarters, regional offices, research and development facilities, manufacturing plants, and distribution centers. Overall, past research supports the assertion that major highway improvements can have significant economic development benefits, although the magnitude of those benefits will vary depending on the particular setting and types of highway improvements being considered.

MEASUREMENT OF ECONOMIC BENEFITS

Types of Economic Development Benefits

Whenever a section of highway is improved, individual auto and truck travellers benefit in terms of travel time, transportation cost, and accident reduction. These direct user benefits have been the traditional means of determining the benefits of a highway project. The direct user benefits for trucking can translate into real dollar savings for businesses that ship items by truck. However, highway improvements can significantly affect the corridor and state economies, over and above the direct user benefits. Specifically, by reducing truck shipping costs, a real efficiency benefit can accrue to the business shipping the product, and a potential cost savings can accrue to the business receiving the product. Cost savings can mean lower product costs, in turn making local area businesses more competitive compared with their outside competition, and better able to expand to new markets.

In addition to the business expansion benefit related to trucking cost savings, highway improvements can extend the market area that businesses can serve, as well as the areas

Two Route Alternatives

- "29/45 Upgrade Replacement" WIS 29 (Eau Clare to Green Bay) and U.S. 45 (E. of Wausau to Appleton) connecting to Highway 29.
- "29/10 Upgrade Replacement" WIS 29 (Eau Clare to Green Bay) and U.S. 10 (Stevens Point to Appleton) connecting to Highway 29 via U.S. 51 freeway.

Five Design Level Alternatives

- "Freeway" - A full four-lane, limited access divided highway, meeting interstate highway standards and therefore eligible for a 65 mph speed limit. Most of the freeway would be constructed on new alignment in order to bypass built-up areas around all communities.
- "Freeway/Expressway I" - About 35% of the finished highway would be constructed as 4-lane "freeway"; the rest would be constructed as "expressway." The major difference between expressway and freeway design is that an expressway allows some at-grade intersections rather than requiring that all access to the highway be through interchanges. (Later upgrading of the highway and intersections would be possible.) Under current law, the speed limit for a freeway/expressway combination would be 55 mph.
- "Freeway/Expressway II" - The primary design difference between this and the previous alternative is fewer interchanges and more at-grade intersections with other public highways. About 15% of the finished highway would be constructed as 4-lane freeway; the rest would be constructed as 4-lane "expressway". (Later upgrading of the highway and intersection would be possible.)
- "Base Case" - The base case parallels the Department's normal improvement schedule for the highways by proposing four-lane sections only warranted on strictly traffic capacity needs. Under this alternative, about 35% of the corridor highways would be four-lane by the year 2000.
- "No Build" - The No Build Alternative represents the point of reference against which to measure the additional costs and benefits of each of the four above alternatives. It represents maintenance of the highway segments at their current 2-lane design.

FIGURE 2 Design characteristics of highway alternatives.

from which they can access suppliers. They can extend the distance range accessible within a day's drive for truck deliveries or customer visits. They also can extend the distance range over which local businesses effectively compete with their out-of-state counterparts (and vice versa). The extent of such benefits depends critically on the relative locations of business buyers, suppliers, and competitors. These travel range impacts can provide opportunities for significant expansion and attraction of manufacturing and distribution industries. Consumer market areas for retail and service businesses are also affected by changes in effective trade areas, but those effects tend to be merely localized shifts in retail activity rather than true gains for the region and state as a whole.

There can be additional impacts on the attraction of new business. In the Wisconsin Highway Study, some types of businesses would find the corridor to be an attractive location if it were not for its lack of a four-lane, east-west highway. Some businesses not previously attracted to the area could also be attracted if they were to see the area upgraded to be fully served by four-lane freeway or expressway facilities, providing fast and reliable transportation links to the national highway network, regional population centers, and specific buyers or suppliers. Improvements to this corridor could also enhance the perception that north-central Wisconsin is an attractive place to live and locate a new business. These types of impacts of highway upgrading are over and above the incremental effects of travel time savings alone.

Some types of businesses could find the proposed highway improvements to be necessary, but not sufficient, to attract them to the area. Some businesses could be attracted to the area if the highway improvements were to be accompanied by other economic incentives and/or public improvements, as part of an effort to address what those businesses see as local or regional deficiencies in resources and services available. For this reason, the economic attraction benefits of each alternative must be viewed in the broader context of existing marketing and business development efforts at the local, regional, and state levels.

Tourism-related business is a special type of opportunity, where passenger travel benefits can lead to additional visitation to the state. For instance, given the location of Highway 29, four-lane improvements to it can provide a particular opportunity to make vacation and recreation areas along the Lake Michigan shore more accessible and attractive to Minnesota residents. The easier and more relaxed quality of the travel experience along a four-lane freeway or expressway, in addition to safety and travel time benefits, can affect these tourism and recreational travel patterns.

The economic development effects of highway improvements do not end with the direct effects on business expansion and attraction. There are also very significant spillover effects on the rest of the area economy. The direct effect on business expansion and attraction leads to such "indirect effects" as additional orders for materials and equipment from other businesses. For instance, expansion of the food processing industry would lead to increased orders for plastic packaging and cardboard boxes. In addition, "induced effects" result when new and expanding businesses hire more workers, who then spend money on consumer products and services.

While businesses within the highway corridor study area are the principal beneficiaries of the direct benefits, the spillover that indirect and induced business growth can provide is a very real benefit for the rest of the state.

Appropriate Measures of Benefits

Economic growth can be viewed as bringing more business sales, jobs, personal income, and population growth to the state. Such economic growth is publicly perceived as desirable insofar as it leads to increased employment opportunities, greater variety of shopping merchandise and cultural activity, higher income levels, a more vibrant atmosphere for private business investment, and greater public resources for investment in local infrastructure.

The impacts can be measured in terms of jobs, business sales, or personal income. For cost-benefit analysis of Wisconsin highway projects, the "disposable personal income" measure is the appropriate measure of benefit for Wisconsin residents. The business sales measure includes benefits that go to out-of-state residents. For instance, fuel sales include the cost of Middle Eastern and South American petroleum. "Personal income" includes only the additional income to Wisconsin residents involved in the local sales, distribution, or manufacturing of the product. "Disposable income" further deletes the portion of personal income paid in taxes, the majority of which goes to the federal government.

There are other financial impacts of economic growth in addition to those associated with job creation, business sales, and personal income. Economic growth can also lead to impacts on *investment* in industrial, commercial, and residential land development, and hence increase *property values*. It would also be expected to bring about changes in local *government revenues and expenses*. These types of impacts tend to vary considerably by locality. Major new highway facilities and changes in economic growth can also bring localized changes in environmental conditions and quality of life resulting from shifts in traffic patterns, shifts in shopping patterns, and shifts in land use and development patterns.

While highway projects can provide potential benefits for many different groups, and those benefits can be seen in many different ways, it is *not* appropriate to consider all these different forms of benefits in a cost-benefit analysis, because it would be *double counting* to add what are really the same benefits showing up several different ways. For instance, property value increases can be the direct result of business growth and the increasing demand for property. Business growth changes, in turn, may be partly the result of changes in relative business cost, which, in turn, may reflect changes in travel time and operating cost.

For this study, all user benefits associated with trucking travel time, cost, and safety improvements are incorporated in the measures of impacts on business expansion and attraction, and resulting disposable personal income benefits to state residents. The economic benefits are in fact larger when measured this way than when accounted for as simple user benefits. In the economic model, the additional income associated with business expansion is itself larger than the direct value a user benefits for existing truck travel. Similarly, the additional income associated with new business attraction is greater than the direct value of user benefits associated with the induced increment of truck travel.

To be complete in the cost-benefit analysis, all impacts related to value-of-time savings, out-of-pocket costs, and safety for auto travellers are also calculated, but no economic development benefits are calculated beyond the user benefits. All economic benefits in the cost-benefit analysis are presented in terms of the discounted present value of the stream of additional disposable income over the 1990–2020 period.

MODELS USED

Analysis Methods

The evaluation of economic development benefits involved the following analysis techniques:

- A computerized traffic simulation model of the entire state, sensitive to traffic distribution impacts and measurement of savings for area travelers;
- A detailed economic forecasting and simulation model of the study area and state economy, sensitive to business growth impacts of changes in transportation costs;
- An industry "screening" analysis process for identifying new business attraction impacts, sensitive to transportation impacts on interindustry sales and supply patterns;
- A tourism market forecasting process, sensitive to relative differences in travel time among competing areas.

The integrated design of the traffic and economic model systems used in this study is of particular note. A highway network model was used to estimate impacts on traffic, distribution, and travel times. These travel time changes were then input into the economic simulation model to estimate long-term impacts on population and employment growth. The forecast changes in population and employment were, in turn, used to estimate future changes in passenger and truck traffic for the highway model. This ability to interplay the traffic and economic models ensured consistency and recognized interrelationships between traffic and business growth impacts. The transportation and economic models are discussed below. The methodology for applying these models, and the analytic processes used for business attraction and tourism forecasts, are discussed later.

Transportation Model

"User benefits" refers to the savings in travel time and out-of-pocket cost and safety associated with highway improvements. User benefits traditionally have been calculated for both autos and trucks and then combined to provide a total measure of direct benefits. For this study, however, truck benefits were separated from auto benefits and included as a basis for the analysis of some economic development benefits, in the form of business expansion and new business development. Although trucking cost savings were initially estimated using the traffic model analysis of benefits, they were used as an input to the economic impact model, rather than directly used in the cost-benefit evaluation.

Estimation of user benefits for each of the highway alternatives was based on the output of a trip-generation and route-assignment travel model. The basis of the traffic forecasting was a UTPS network representation of the current and expected future statewide highway system. Using origin-destination studies and traffic counts, these models simulated current traffic volume and travel patterns. Population and employment projections were used to forecast trip patterns and future traffic, separate from any improvements to the corridor. Once "no build" conditions were estimated, the models simulated new traffic and travel patterns expected under each of the improvement alternatives. In addition to the increase in normal traffic growth (expected from changes in population, employment, and auto use), the models were used to estimate how the alternative highway improvements would attract trips from nearby routes, thus further increasing traffic volume.

The assignment of traffic to the most efficient route linking origins and destinations on the system produced a different distribution of trips for each alternative. With each successive level of improvement, the corridor was forecast to attract more traffic from other routes previously used by travelers. As Figure 3 indicates, each higher improvement level extends the area of influence (i.e., the area of origins and destinations it would serve) of the improved highway.

The end product of the simulation process of all highway

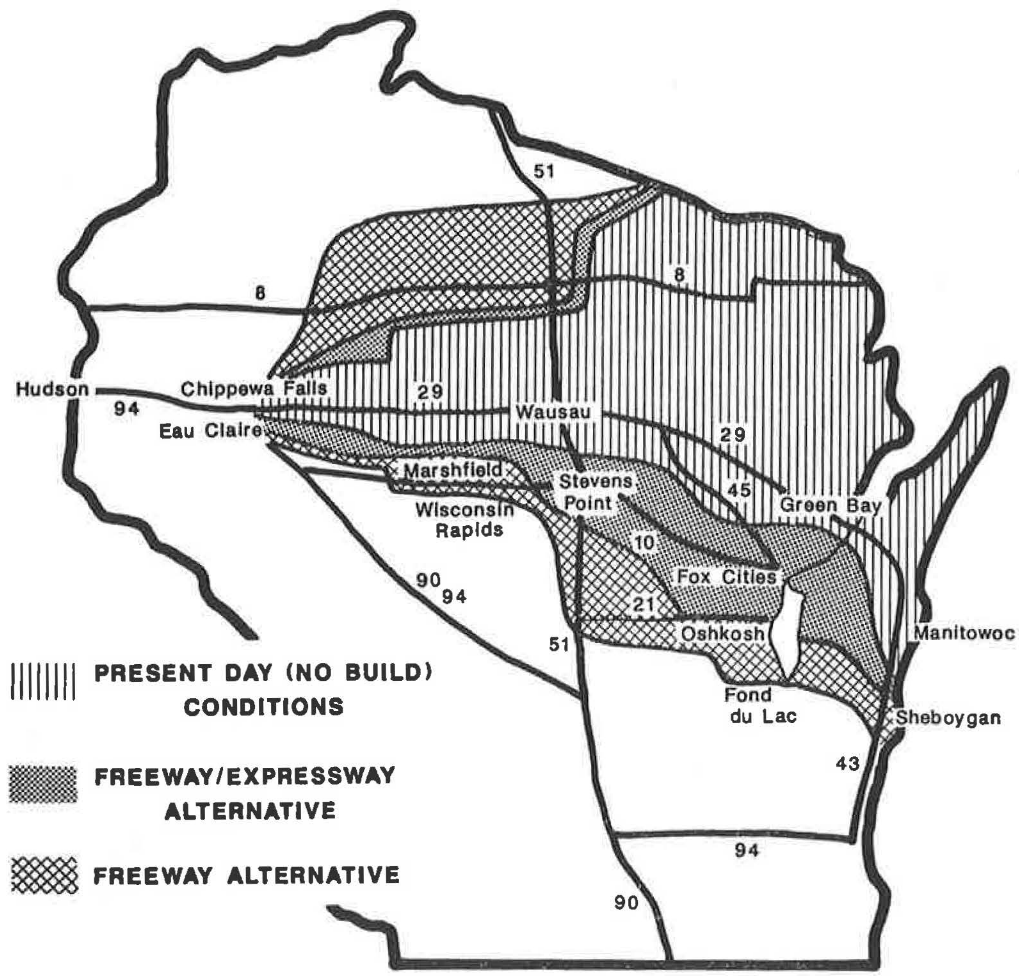

FIGURE 3 Highway 29/45 Corridor area of influence (travel to and from Twin Cities).

use was an accumulation of all highway use assigned to individual portions of the statewide highway network. Based on these assignments, miles traveled and hours spent were totaled for trips between all locations on the network. These miles and hours were related to safety, time, and operating costs and thus used to calculate auto and truck user benefits for each improvement alternative.

The automobile user benefits were calculated assuming a value of time of $7/hr, and a value of accident reduction based on "willingness to pay" studies sponsored by FHWA and conducted at the Urban Institute. Results of the auto user benefit analysis showed that a freeway produces the greatest absolute benefits, as time savings and accident reduction benefits more than offset the growing operating costs that result from higher freeway speeds.

Economic Model

The direct truck cost savings can lower such business costs as acquiring supplies and distributing products, thus making local businesses more cost competitive and better able to expand relative to out-of-state competition. This impact is estimated by examining the current relative cost of doing business in the study area compared to elsewhere (for each industry), and by considering how reductions in relative business costs lead to expansion in relative rates of business growth (for each industry).

Traditional economic analysis techniques fall short here. The traditional approach uses an input-output model to estimate the indirect and induced growth of the area economy, given a direct change in jobs and business sales that the highway creates. What it does not predict is how highway improvements will change the competitive position of different types of businesses, and how that competitive change will directly affect future business growth. To address such issues, the regional economic forecasting and simulation model (REMI) was created by Regional Economic Models, Inc.

The Wisconsin Forecasting and Simulation Model is a statewide REMI model used for the past several years by the Wisconsin Department of Development. A special multi-area version, specifically designed for counties within the study area, was applied for this study. Essentially, the model predicts, for each year in the future, the number and distribution of income, output, and employment in each substate area for each industry sector and each occupational category. The substate areas are defined as five subzones within the project study area, plus a sixth zone comprising the rest of the state. The REMI simulation model and conjoined input-output model provides information on business output and employment for 490 detailed industry sectors and 94 detailed occupational categories. The model process is shown in Figure 4. One basis for the REMI model was information on interindustry purchasing patterns for the specific industrial structure of the state. This is essentially the information that comes from input-output accounting tables tracing the extent to which each industry sector generates demand for inputs from other sectors. The REMI model, however, goes beyond simple input-output accounting by incorporating information on a large number of policy-sensitive economic factors and relationships—how they change the region's economic growth or

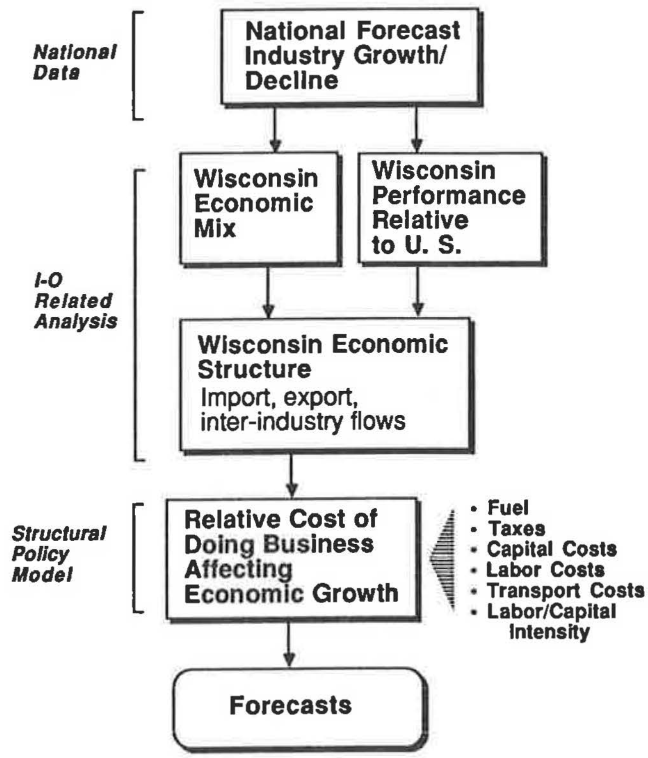

FIGURE 4 REMI Forecast.

decline by industry sector. They include the effects of transportation costs, as well as the costs of labor, equipment, materials, capital financing, and taxes.

In each case, the REMI model evaluates the cost of doing business for each industry sector, comparing costs for businesses within the study area with costs for similar businesses located elsewhere. The forecast of future business growth and decline in each area is then made based on the following: (a) national forecasts for change in each business sector and their technologies of production; (b) differences in relative costs of production in each business sector within the study area, compared with production costs elsewhere in the nation; (c) the expected change in transportation and production cost in each business sector resulting from the highway projects; and (d) the expected change in attracting business from out of state and tourists from out of state.

ANALYSIS METHODOLOGY AND FINDINGS

Future Economic Changes

It was recognized that the economic impacts of the highway improvements could be increased or lessened by future changes in the area's business mix, which will affect relative reliance on trucking. In addition, it was recognized that economic impacts could also be affected by future changes in technologies affecting interindustry shipping relationships.

For the study area, the REMI forecasts indicated that the output of three major industries—paper, food products, and health care—will grow in the future. Growth will proceed at a slower pace and employment will actually decline compared with the past decade. These patterns, which hold for both the study area and the rest of the state, are due in part to the expected slowdown in the growth rates of the state population and economy. They are also due to forecasts of continued technology change, raising the output per employee over the long term (1986–2020). In fact, both the paper and food industries are also undergoing significant changes in product mix. In the paper industry, production of converted paper products is forecast to increase, while production of paperboard containers is not forecast to increase. In the food industry, production of frozen foods is forecast to increase, while production of dairy products is not. These changes in industrial mix were forecast to have a bearing on highway impacts because surveys showed that each type of industry had a different shipping pattern.

Trucking Cost Impacts

In order to estimate the magnitude of trucking-related benefits to business, a three-step process was used. The first step was to conduct a series of surveys to profile truck shipping patterns and current truck reliance on Highways 29, 45, and 10. The next step was to estimate the business cost savings of proposed highway improvements, based on the truck shipping patterns and the cost structure of different types of businesses. The final step was to estimate the impacts of these cost savings on business expansion rates. This process made use of the REMI economic forecasting model relating changes in the business costs of truck shipments to the competitive cost of doing business, comparing businesses in the study area, rest of the state, adjoining states, and rest of the country.

A mail-back survey of area firms provided information on the overall pattern of truck trips originating in or destined for locations within the study region. The survey showed differences in industry supplier-buyer locations among types of businesses. These were reflected in their truck shipping patterns. These patterns of interstate travel are shown for four major industries in the study area, in Figure 5. The survey also showed systematic differences in truck shipping patterns among subzones of the study corridor (Figure 6).

The cost savings for truck movements was then calculated on the basis of changes in travel time and operating costs for current users, forecast new users, and diverted trips under each highway improvement alternative.

It was recognized that the effect of a truck shipment cost savings on the competitive position of businesses depends on the importance of truck costs as a component of the total cost of doing business. Many components constitute the overall business cost, including labor, capital equipment, utilities, depreciation, financing costs, and so on. Truck shipping costs include the costs of businesses purchasing services from the trucking industry and the costs of businesses doing their own shipping (including truck driver labor costs). The types of businesses found to be most sensitive to truck shipping costs are trucking firms, petroleum product firms, and paper manufacturers.

The overall economic impacts reflect the expansion of businesses benefitting from trucking cost savings (direct effects), plus the expansion of their business suppliers (indirect effects) and the expansion of other businesses receiving the additional worker spending (induced effects). While the directly-benefitting businesses are largely manufacturing, distribution, and trucking firms, the indirect and induced benefits involve retail, wholesale, and service businesses.

The analysis of truck travel concluded that total benefits to existing business are larger for the freeway and freeway/expressway alternatives than for the base case. However, improvements beyond freeway/expressway II yielded no further increase in truck cost savings, because the time savings from further speed increases were cancelled by the lower fuel economy and higher vehicle operating costs that occur when trucks travel faster than 55 miles per hour.

Business Attraction Impacts

While trucking cost savings can lead to business growth, there are other ways in which highway improvements can affect the attractiveness of the corridor as a place to do business. The area might become more attractive to new businesses because of the geographic position of the highway relative to the locations of particular population centers, suppliers, or buyers (both in state and out of state). The area thus might provide special opportunities for combinations of industries to better support each other and take advantage of emerging technologies or provide new products. Highway improvements can improve the perceived quality of life of the region served. These are business attraction impacts over and above the truck cost saving impacts.

Estimation of the impact on business attraction of the proposed improvements to Highway 29 and 45 required a three-phased methodology. First, a list was compiled of industries compatible with the corridor economy and resources available. Second, characteristics of those industries—and the comparative cost of business operations in Wisconsin and the corridor—were evaluated to determine whether these types of businesses would find the area cost competitive to be attracted to the region. Third, business attraction and job creation potentials were distinguished in terms of whether they required (a) only highway improvements to be made, (b) other economic development or business attraction factors aside from highway improvements, or (c) both highway improvements and attention to other economic development or business attraction factors.

As a first step in identifying industries that might be attracted to the study area as a result of the highway improvements, economic development agencies and chambers of commerce within the study area were contacted. These organizations were asked to list current business attraction targets and reasons for these targeting efforts. To further identify industries that might be attracted as a result of the highway improvements, the existing economic base and regional characteristics were examined to identify potential linkages between the existing industries, natural resources, universities and technical schools, labor force, and so on, and the industries not currently located in the study area. In addition, interviews were conducted with representatives of individual businesses and trade associations. Interviewees were asked to identify the most important locational characteristics considered when making facility location decisions. These industry specialists were further asked to evaluate the importance of highway

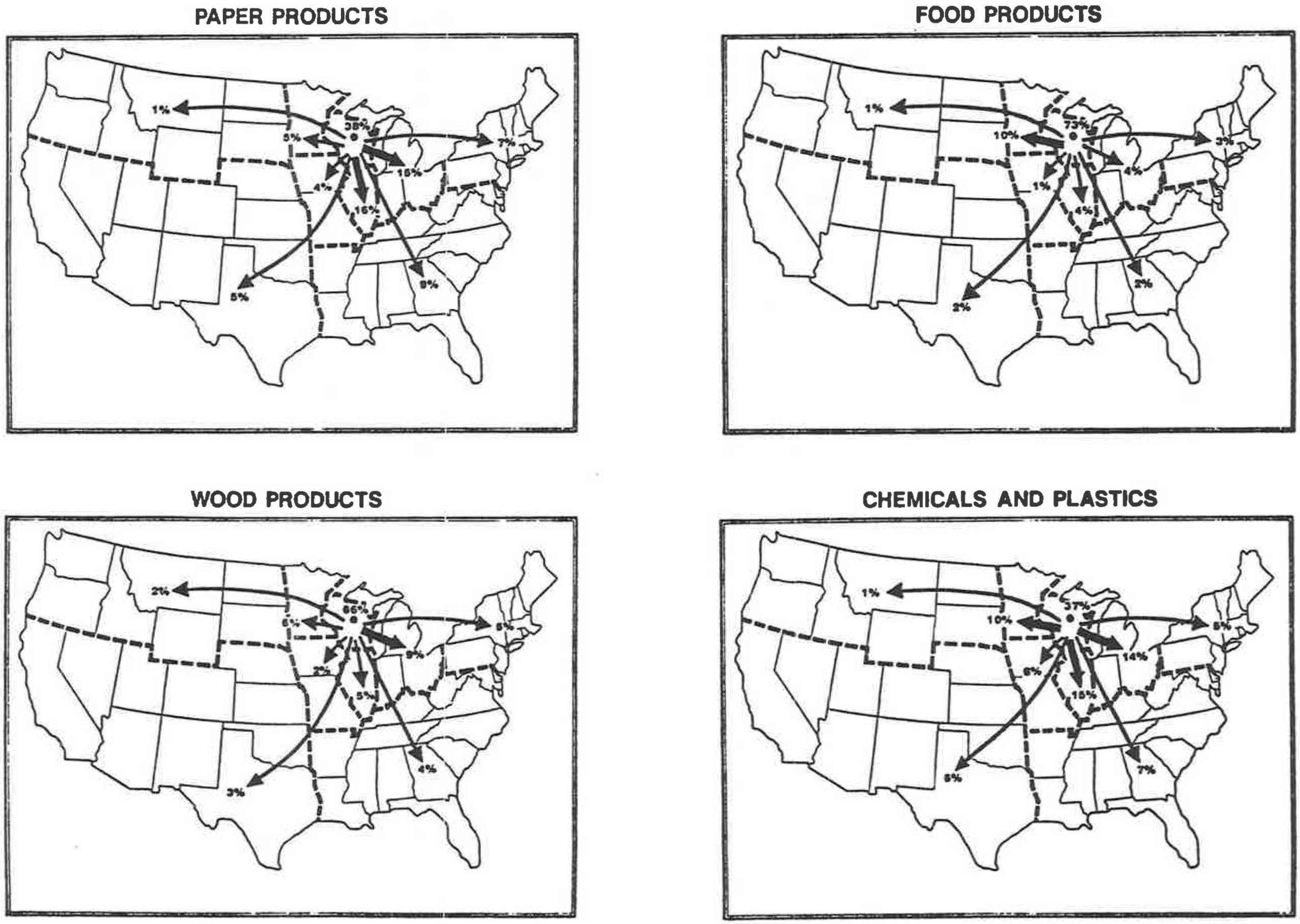

FIGURE 5 Interstate trucking patterns for selected industries (by zone of origin/destination).

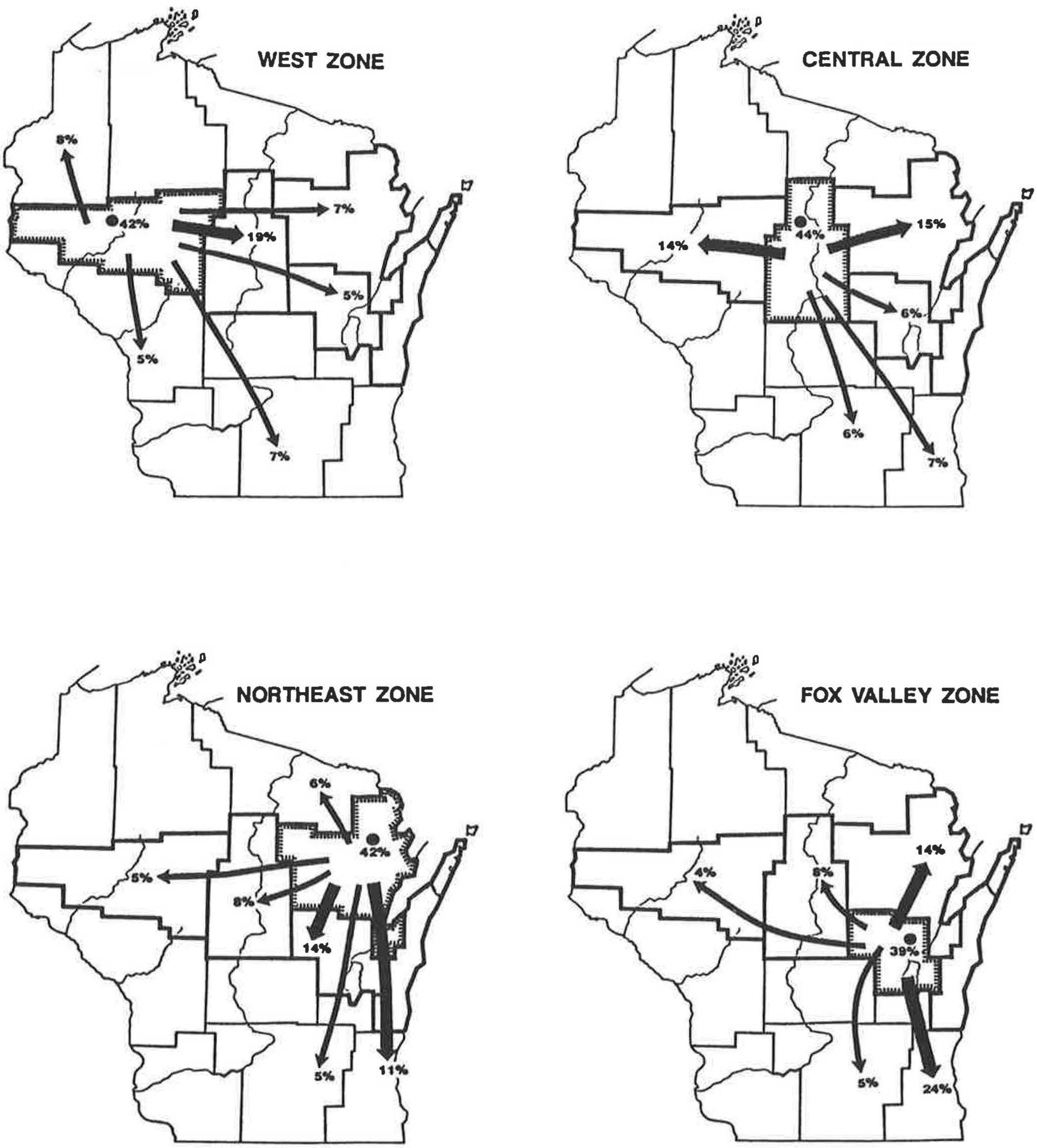

FIGURE 6 Intrastate trucking patterns—all industries (by zone of origin/destination).

access to their location decisions and the appeal of central Wisconsin locations.

The competitive position of the corridor study area for attracting the target industries was also evaluated in terms of relative costs for fuel, capital, and labor in the study area, compared with the same cost factors for the rest of Wisconsin, Minnesota, and the United States as a whole. The existing concentration of each industry in the study area was also compared with the concentrations in those comparison areas. This comparison was used to identify the types of businesses thriving nearby but currently underrepresented in the study area. Finally, because the highway improvements would improve accessibility through the region, the potential negative impacts of businesses attracted out of the region were also taken into account.

The analysis concluded that the greatest business attraction expected to occur as a direct result of the highway improvements was in the northeast area of the corridor, followed by the central and east (Fox Valley) areas. Essentially no further business attraction benefits were expected for the west or Lakeshore areas. The key beneficiary businesses were forecast to be specialized paper products, printing, food products, and wood products.

Compared to the full freeway, the two freeway/expressway alternatives and the base case were found to have a lesser benefit, because both have at-grade intersections, foregoing the "Interstate quality" freeway access that some businesses look for in their location decisions.

The business attraction analysis concluded that while highway improvements alone can enhance the region's ability to attract investment for business location and expansion, these positive impacts can be even larger if coupled with business marketing and economic development programs.

Tourism Benefits

The business impacts of the proposed highway improvements will extend beyond trucking firms and businesses that ship or receive goods by truck. In fact, one industry expected to be a major beneficiary of any of the proposed highway improvement alternatives is the tourism industry, which serves both business travel and recreational trips. Tourism benefits occur to the extent that highway improvements lessen travel time, reduce safety hazards, and make travel more enjoyable for trips to various tourist destinations and recreational attractions within Wisconsin. Tourism benefits occur principally because of increased visitation and spending by out-of-state visitors. Shifts among in-state visitor destinations are of no economic benefit to the state.

Deriving the impact of proposed highway improvements on tourism included two key steps. The initial part of the tourism impact analysis was to estimate baseline tourist and visitor activity in the area. The baseline data were then refined to estimate the number of visitors to each zone that used Highways 29, 45, and 10. Visitor spending for these highways was calculated based on prior surveys of typical spending levels by different types of visitors.

The second part of the analysis was to determine the potential impact on visitation patterns resulting from the proposed highway improvements. The findings drew heavily on responses to interviews with owners and managers of hospitality, tourism and recreation businesses, and promotional organizations within the study area. It drew upon their own evaluations of existing and potential market attraction characteristics, competitive position relative to competing attractions, travel distances, and spending patterns.

The assessment distinguished new tourist trips generated or attracted from out of state, and new tourist trips that are merely transfers of trip destinations from one part of Wisconsin to another. Overall, the study concluded that the Lakeshore and northeast areas would be expected to realize the greatest absolute increase in visitor days and dollars spent by tourists. The concentration of tourism impact on these two regions occurred because both have major regional and superregional tourist destinations with the potential to attract additional visitors from the Twin Cities and the rest of Minnesota.

OVERALL BENEFITS AND COSTS

Issues in Benefit-Cost Analysis

The cost-benefit evaluation is a comparison of benefits and costs associated with each of the four highway improvement alternatives, relative to the no build scenario. The comparison is made for net benefit (defined as benefits minus costs) and B/C ratio (defined as the ratio of benefits divided by costs).

The set of costs considered for each alternative includes estimates of all right-of-way acquisition and construction-related costs, plus all ongoing rehabilitation and maintenance costs. The set of benefits considered include user benefits to auto travellers plus estimates of long-run (after construction) economic development impacts, including those that result from the truck user benefits.

Construction period benefits are explicitly ignored for purposes of the cost-benefit analysis, due to the nature of the investment decision making. It is recognized that the highway construction expenditures associated with the project provide real benefits in terms of business sales, income, and jobs created. However, these dollars are assumed to be funds that would have been spent anyway by state government—if not on this project, then on other highway or public works investments with comparable capital expenditure benefits. For this reason, the short-term benefits associated with construction spending are not relevant as additional benefits for ranking the project alternatives.

The long-term transportation efficiency and economic development benefits associated with the project are measured by comparing statewide levels of income and jobs that would exist with and without each of the alternatives for proposed highway improvements. This is a clear, straightforward way of assessing project impacts on the state economy. The streams of benefits and costs over time are assessed by their present value, which discounts benefits and costs expected to occur in the future.

Yet another academic issue is whether funding the Highway 29/45/10 project actually causes other socially beneficial, but competing projects (or other public expenditures), to be foregone. If so, it could be argued that the potential benefits of those foregone projects represent an additional opportunity cost associated with the Highway 29/45/10 project. In fact, it is clearly premature and inappropriate to guess how the proposed project will be financed, whether it be federal grants, new taxes, or allocations from existing departmental budgets or other sources. Hypothetical competing alternatives need not be considered if the study objective is to evaluate highway improvement alternatives relative to each other, and not relative to all possible alternative expenditures.

Overall Project Benefits

Economic development benefits are classified in terms of business expansion induced by cost savings, additional business attraction, and increased tourism. User benefits for truck users are not counted in this benefit assessment because they are encompassed within the measure of business expansion benefits. Auto user benefits are estimated based on a valuation of travel time savings, operating cost changes, and accident rate reduction benefits.

The present value of all economic development and auto user benefits (compared with the do nothing alternative) is shown in Table 1. Among the several notable aspects of these data include the fact that economic development impacts account for roughly one-half the total benefits (varying from 42 percent to 52 percent with the highway improvement alternative.) This is particularly notable because trucks account for just 20 percent of the traffic on Highways 29, 45, and 10.

A second observation is that the spread in economic development benefits between the freeway and the base case alternatives is nearly twice as large as the corresponding spread in auto user benefits for the same alternatives. There are several reasons for this. One is that the computation of economic development benefits includes a large reduction in industry and tourism attraction for the base case alternative

TABLE 1 PRESENT VALUE OF COSTS AND BENEFITS OF HIGHWAY IMPROVEMENT ALTERNATIVES (PRESENT VALUE OF 1990–2020 DISPOSABLE INCOME BENEFITS IN MILLIONS OF 1987 DOLLARS, COMPARED TO THE NO BUILD ALTERNATIVE)

		Free-way	Free/ Exp I	Free/ Exp II	Base Case
Costs					
Present Value of Total Cost	29/45	$550	$447	$334	$225
(Compared to No Build)	29/10	564	415	337	250
Economic Development Benefits (disposable income)					
Expansion Due to Truck	29/45	164	164	164	131
Cost Savings	29/10	168	168	168	132
Additional Industry	29/45	218	164	153	55
Attraction	29/10	246	184	172	62
Increased Tourism	29/45	56	42	39	14
	29/10	55	41	39	14
Subtotal: Economic	29/45	$438	$370	$356	$200
Development Benefits	29/10	469	393	379	208
Auto User Benefits					
Value of Auto Travel	29/45	$385	$305	$296	$218
Time Savings	29/10	356	288	287	200
Change in Auto	29/45	-115	-46	-13	7
Operating Costs	29/10	-116	-39	-12	4
Value of Auto Accident	29/45	138	103	98	56
Reduction Benefits	29/10	146	123	107	67
Subtotal: Auto User	29/45	$408	$362	$281	$281
Benefits	29/10	386	372	382	271
Present Value of	29/45	$846	$447	$334	$225
Total Benefits	29/10	855	765	761	479

TABLE 2 COMPARISON OF BENEFITS AND COSTS (PRESENT VALUE OF 1990–2020 BENEFITS AND COSTS IN MILLIONS OF 1987 DOLLARS, COMPARED TO THE NO BUILD ALTERNATIVE)

		Free-way	Free/ Exp I	Free/ Exp II	Base Case
Present Value of Total Benefits	29/45	$846	$732	$737	$481
	29/10	$855	$765	$761	$479
Present Value of Total Costs	29/45	$550	$447	$334	$225
	29/10	$564	$415	$337	$250
Benefit/Cost Ratio	29/45	1.5	1.6	2.2	2.1
	29/10	1.5	1.8	2.3	1.9
Net Benefit (Benefit - Cost)	29/45	$296	$285	$403	$256
	29/10	$291	$350	$424	$229

where less than a fully four-lane expressway is provided. The other is that auto user benefits do not increase proportionally to speed increases and travel time savings for the higher level improvement alternatives, because of the offsetting impacts of increased fuel consumption and auto operating costs at higher speeds. In fact, the penalty of higher operating costs at higher speeds causes the freeway/expressway I alternative to have slightly lower auto user benefits than the lower speed freeway/expressway II alternative.

Project Costs

Costs associated with each highway improvement alternative include construction costs from 1989–1999, plus rehabilitation and general maintenance costs from 1989–2020. All costs are shown in excess of those for the no build alternative that includes pavement maintenance costs.

Benefit-Cost Comparison

Table 2 compares the benefits and costs of each of the four highway improvement alternatives for both the 29/10 route and the 29/45 route. The benefit-cost ratio measures the efficiency of spending in terms of return on investment. Highway 29/10 freeway/expressway II alternative provides the greatest benefit-cost ratio. It returns $2.30 of benefit for every dollar spent on the highway. Of course, not all these benefits represent dollars added to the economy. In fact, half the benefits from the Highway 29/10 freeway/expressway II alternative are in the form of auto user travel time and safety benefits.

Another measure is the net benefit, calculated as benefits minus costs. The Highway 29/10 freeway/expressway II alternative also provides the greatest net benefit, which has a present value benefit of $424 million over costs. Thus, the freeway/expressway II alternative for the Highway 29/10 route clearly emerges as the most beneficial, providing more benefits than that same alternative using the Highway 29/45 route.

CONCLUSIONS

The Wisconsin study demonstrates how the economic development benefits of highway projects can be estimated, and those estimates used for benefit-cost analysis to support policy decisionmaking. The State of Wisconsin has adopted and started to implement the highway alternative recommended by this study. However, this study also shows that a full evaluation of economic development benefits can be complicated, requiring separate analytic techniques for estimating the impacts on relative business costs, business attraction, and tourism, as well as modeling of travel patterns and regional economics.

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Publication of this paper sponsored by Committee on the Application of Economic Analysis to Transportation Problems.

Utilities Study for the Alabama Highway Department

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The state of Alabama Highway Department conducted a two-year project to revise its utilities policies and develop a state-of-the-art manual setting out these policies. The project was conducted by the University of Alabama. The university formed an advisory group of 41 representatives from utility companies, engineering consultants, construction companies, and utility regulatory organizations. Interviews conducted with the advisory group and with utilities-related managers from the department resulted in more than 300 suggestions for changes to utilities activities. These suggestions were condensed to 85 action items studied by the university and led to the adoption of a majority of these items in the department's revised utilities policies. The new utilities manual was prepared with a desktop publishing system, which allowed the manual's style and format to be customized to fit the department's requirements. Several drafts of the document were prepared, followed by intervening reviews by the advisory group and the department. After adoption of the updated policies and publication of the new manual, the department and university conducted nine training sessions throughout the state, which were attended by more than 1,200 department employees, local government employees, utility industry representatives, and consulting engineers.

The Alabama Highway Department conducted a 2-year program to analyze and revise its utilities policies and develop state-of-the-art documentation to guide the utilities program. To explain why and how the project was conducted, outline the work steps used in analyzing the department's utilities program, discuss some of the major changes developed during the study, and describe the features of the updated utilities manual is the purpose of this paper. Several innovative procedures, such as the use of an external advisory group and a survey of utilities manuals from other states, are also discussed.

Department managers found that they were spending approximately 15 percent of construction funds on relocation of utilities. The department hoped to reduce this substantial amount to a more acceptable level. The department relied upon two utilities documents to set out its policies and procedures, both of which were more than 10 years old and required updating to reflect technical changes in the utility industry and promulgation of new regulations by the Federal Highway Administration (FHWA) and the department.

In September 1987, the department awarded a contract to the University of Alabama to recommend revisions to utilities practices and prepare a single manual containing the revised policies and practices.

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PROJECT ORGANIZATION

The university proposed to accomplish the research in two phases. The initial phase would consist of problem identification and recommendations for improving utilities operations. The second phase would consist of preparing a comprehensive manual containing all utilities regulations, policies, and practices.

Phase I

Most of the effort in this phase was devoted to obtaining information pertinent to the project. For example, the research staff requested and obtained copies of all department utilities documents. A literature review identified other studies or articles reflecting upon the efficiency of utilities operations. The research staff then conducted a series of interviews with a large number of people. Four separate groups of department employees were interviewed. An external advisory group was formed (41 members from utility companies, contracting firms, and engineering organizations) and interviewed. Other state highway agencies were contacted through telephone conversations and visits. Copies of utilities manuals were obtained from more than 40 states.

As a result of these actions, an enormous amount of information was assembled regarding utilities practices. The university research team and the department's utilities managers categorized and condensed the information into a series of recommendations for improving utilities practices. The university prepared a Phase I report (*1*) containing these recommendations, and forwarded it to the Department for consideration.

Phase II

In the second phase of this research project, a comprehensive utilities manual was developed, including such work steps as comparing department written policies with practices occurring in the field. In several instances, department policies were revised to reflect field operations. As a second example, more than 150 suggestions from the utility industry and department employees were tabulated by category and condensed to 85 items for study as possible policy revisions. Within each category of possible action, the items were prioritized to guide the research staff.

The majority of effort during this part of the project focused on preparation of a revised utilities manual. The university developed an outline of the proposed manual and a major portion of one chapter to illustrate the format and quality of the proposed document. These were reviewed and approved by the department. The manual then was developed topic-by-topic and chapter-by-chapter, with each portion receiving preliminary review by the appropriate department management officials as each was completed.

The completed first-draft chapters were assembled and appendices added. This 350-page document was then reviewed by a number of organizations and individuals. Comments and suggestions were received and incorporated into a second draft that was similarly reviewed. The final draft was developed in desktop publishing format so it can be updated easily by the department as future changes occur. Finally, eight training sessions were conducted throughout the state to acquaint department employees and utilities industry representatives with provisions of the department's new utilities policies.

ORGANIZATION OF PAPER

The research project work steps are described in much greater detail in the remainder of this paper. Sections are devoted to interviews, information from other states, the external advisory group, recommended policy and procedure changes, use of a desktop publishing system, and production of the new utilities manual.

INTERVIEWS

The university research staff conducted a series of group and individual interviews to learn more about the department's utilities procedures. During group interviews conducted at the department's central offices in Montgomery, managers at several levels were asked about the strong and weak points of utilities operations, and about desired changes to utilities operations or documents.

Four interview sessions lasting from 2 hr to one-half day were conducted with department managers over 6 weeks. The research staff conducted these interviews with employees in groups sharing similar utilities responsibilities. For example, all district engineers were interviewed simultaneously. Because their utilities responsibilities (and problems) were all similar, this maximized the opportunity for discussion and interchange of ideas.

Bureau Chiefs and Division Engineers

The first group interview was conducted during the second month of the project. Participants were top-level department managers, bureau chiefs (managers of major branches of the central office), and division engineers (managers of the nine primary field offices). The meeting's purpose was to gather comments regarding desired changes to utilities procedures.

The approximately 35 suggestions gathered during this group interview concentrated on such topics as limiting liability, concentrating more control in field offices, increasing the utilities industry's speed in responding to department requests, and developing new legislation regarding utilities actions.

District Engineers

A group interview was conducted with all the department's district engineers. There are 41 district offices, with three to five districts grouped together to constitute a division. District engineers are responsible for maintenance activities. Their duties include inspecting all utilities work performed under permit and oversight of other utilities activities.

This group conducted a spirited discussion covering a wide range of topics. More than 30 suggestions were received on such areas as increasing the utility's responsibility for inspecting their work, requiring better traffic control plans, increasing coordination between utilities and district engineers, and requiring that utilities contractors maintain a copy of the approved permit and approved drawings at the construction site.

Division Utility Engineers

At each of the nine primary field offices, one employee, the division utilities engineer, has primary responsibility for utilities actions. These nine division utility engineers reviewed the comments collected in previous interviews, then developed 19 additional suggestions dealing primarily with increased coordination and communication between utilities and the department, changes to permit forms, and adding standard clauses to contracts.

Maintenance Bureau Managers

The department's maintenance engineer is the approval authority for permit applications, so a group interview was conducted with the maintenance engineer and his key utilities-related employees from the central office. This discussion included a review of the permitting process, a discussion of desired improvements to the process, and an examination of several policy letters developed and distributed by the bureau.

Interviews with Others

In addition to interviewing department managers, the research staff contacted many other interested parties to gather background information. Discussions were held with national experts, highway departments in other states, and a group of representatives from the utilities industry. These discussions are specified in other portions of this paper.

INFORMATION FROM OTHER STATES

A large amount of useful information was gathered through several techniques from individuals and organizations located in other states.

TRB Committee on Utilities

One of the first actions of the research staff was to contact knowledgeable utilities officials throughout the nation. The principal source of names for these contacts was the roster of the TRB Committee on Utilities. The research staff telephoned eight committee members and three committee participants. These correspondents identified six other individuals knowledgeable about utilities, who were then telephoned.

The purpose of the telephone calls was to identify states with good utilities practices, locate previous utilities studies, determine current national utilities issues, and find documents that might be pertinent to the Alabama project.

Utilities Engineers

The research staff contacted 10 state highway agencies to discuss utilities practices. Both telephone conversations and visits were used to obtain this information. Four states contiguous to Alabama and six additional states were contacted during this work step. The six additional states were those identified as having good utilities practices.

Conference telephone calls were conducted from the offices of the Alabama Highway Department. Typically, the researchers requested that other states provide their utilities engineer, design engineer, and the individuals who supervise permit processing and utilities field operations. Two or three representatives of the Alabama Highway Department and three university researchers also participated in the calls.

The calls usually consisted of introductions, an outline of the research project, and discussion of a previously selected list of topics related to policies the department was attempting to improve. As the telephone conversation progressed, questions were expanded and new topics included as needed to maximize the amount of useful information exchanged.

The initial telephone session lasted an entire day and resulted in extended conversations with six state utilities engineers. As a result of the discussions, the research staff concluded that virtually all states were dealing with the same group of basic utilities questions. Some states had solved these problems, whereas other states had only diverted the problems into other areas.

Several good ideas emerged from this work step. For example, one state was found to emphasize master utilities agreements that save time and minimize misunderstandings. Another state had found that utilities conflicts with highway construction projects could be minimized by providing an automatic 45-day grace period in their contracts. This same state took great pains to reimburse contractors very quickly and with no retention of progress payments. They believed that this made utilities work less expensive because contractors got their money sooner. They audited their invoices at the end of the project and made a final payment or billed the contractor for overpayment.

Another state had invested heavily in field inspection. All utilities approval occurred at the field level and was followed by a rigorous inspection program. This state had managed to minimize claims of delay by highway contractors by closely following a 2-year schedule for highway construction projects. This allowed plenty of planning time for utilities. Another state found that many of its utilities problems were generated by local-government water and sewer work. Frequently, small cities engaged consultants not knowledgeable about utilities processes. This problem was solved by adopting a preapproved list of consultant firms. A firm could be placed on the list by demonstrating utility expertise.

Topics in the preceding paragraphs are examples of the useful types of information gathered by the university research staff. States participating in the telephone calls were extremely helpful and gracious. Frequently, these states agreed to provide copies of legislation, special policies, or forms that would be useful in Alabama.

Visits to Other States

In addition to telephone calls, visits were made to two other states to obtain more details about utilities policies and conduct interviews with a wide range of utilities personnel. These useful visits helped the research staff identify local geographical, economic, and political constraints that influenced utilities policies in the individual states.

State Utilities Manuals

The Alabama Highway Department wrote to highway agencies in each state requesting copies of manuals or other documentation used in utilities activities to be sent to the university research team. Forty-one states complied. These manuals proved to be extremely useful in determining the national state of the art and in defining topics and supporting materials for inclusion in the proposed new Alabama manual.

Manuals from other states were used in several ways. First, they were reviewed by members of the project research staff. Novel or useful ideas were identified and categorized for future use. Next, all manuals were delivered to the department's utilities engineer. He and his staff reviewed them and identified materials thought to be useful in Alabama. These reviews consumed a great deal of time, but had a corresponding positive effect on the project.

Both the university and the department reviewed the manuals topically to determine the average or typical treatment for certain problems. Items such as clear zone treatments, encasement requirements, reimbursement procedures, and standard forms for permit actions were tabulated to determine the range of current procedures. Some of these tabulations resulted in position papers, publications, or presentations at national meetings (*2*). This review allowed the research staff to develop good background material and permitted the department to develop state-of-the-art policies.

The manuals also provided excellent source materials that the research staff used while writing the revised Alabama utilities manual. Wordings of difficult issues, figures, tables, and other materials were extracted (with permission) from other state manuals for adaptation to Alabama.

This work step was extremely costly in terms of the effort expended to review and analyze all the materials obtained; however, it was also extremely fruitful in helping to bring the research staff to the state of the art and providing example materials from which to prepare the Alabama manual.

EXTERNAL ADVISORY GROUP

The university wanted the advice and contributions of the utilities industry within the state. With the encouragement of the department, an external advisory group was organized consisting of representatives from several segments of the utilities industry. It included large utilities agencies, small or rural utilities companies, government and regulatory agencies, utilities contractors, general contractors, and consultant engineers.

The advisory group was called the Utilities Accommodation Advisory Committee (UAAC). Its structure and organization were defined through the joint efforts of the department and the research staff. The department then selected candidates for the UAAC, and the university contacted them to secure volunteers to help develop the new manual. Thirty-one organizations initially agreed to provide representatives.

As the project unfolded, additional firms and organizations became interested and requested to participate in the study. Eleven firms were added to the UAAC in this manner. By the time the initial draft of the revised utilities manual was ready for review, the UAAC consisted of 41 representatives (see Table 1).

TABLE 1 COMPOSITION OF EXTERNAL ADVISORY GROUP

I. LARGE UTILITY ORGANIZATIONS
- Alabama Gas Corporation
- Alabama Power Company, Distribution Division
- Alabama Power Company, Transmission Division*
- American Telephone & Telegraph Company
- BellSouth Services, Inc.*
- City of Mobile Water & Sewer Commissioners
- Jefferson County Sanitary Sewer Board
- South Central Bell, Inc.
- Transco Energy, Inc.*
- Transcontinental Gas Pipeline Corporation

II. SMALL OR RURAL UTILITY COMPANIES
- Alabama Rural Water Association
- Gulf Telephone Company*
- Pioneer Electric Cooperative
- Storer Cable T.V., Inc.

III. GOVERNMENT/REGULATORY AGENCIES
- Alabama League of Municipalities
- Alabama Public Service Commission
- Alabama Rural Electric Association
- Association of County Engineers of Alabama
- Federal Highway Administration
- Farmer's Home Administration
- Tennessee Valley Authority
- Tuscaloosa County Public Works Department*

IV. UTILITIES CONTRACTORS
- Boan Construction Company, Inc. (Greenville, Ala.)
- Buchanan Contracting Company, Inc. (Birmingham, Ala.)
- H & F Construction Company, Inc. (Birmingham, Ala.)
- Star Construction Company (Birmingham, Ala.)

V. GENERAL CONTRACTORS
- Alabama Roadbuilders Association*
- Associated General Contractors*
- Capitol City Asphalt (Montgomery, Ala.)
- McCartney Construction Company (Gadsden, Ala.)
- W. S. Newell Construction Company (Montgomery, Ala.)
- Rast Construction Company* (Birmingham, Ala.)

VI. CONSULTING ENGINEERS
- Almon & Associates (Tuscaloosa, Ala.)
- BCM - Converse, Inc. (Mobile, Ala.)
- R. W. Beck & Associates, Inc. (Nashville, Tenn.)
- Carter, Darnell & Grubbs, Engrs., Inc. (Andalusia, Ala.)
- Paul B. Krebs & Associates, Inc. (Birmingham, Ala.)
- Lucas Engineering*, (Birmingham, Ala.)
- McGiffert & Associates, Inc. (Tuscaloosa, Ala.)
- Moore Engineering Company*, (Fairhope, Ala.)
- Post, Buckley, Schuh & Jernigan, Inc.* (Columbia, S.C.)

*Added during the project

Activities

The UAAC held two formal meetings and conducted other business by mail or telephone. Several of these activities are outlined in the following discussion.

During the second month of the research project, the initial meeting of the UAAC was held at the Alabama Highway Department's central offices. UAAC members were introduced to each other and the university research staff presented an overview of the project. Department management officials stressed their strong desire for feedback from utilities representatives at the meeting. An open discussion followed in which the university research staff received more than 100 comments and suggestions regarding existing utilities procedures. Following the meeting, UAAC members continued to supply suggestions through correspondence, telephone calls, and visits.

The second meeting of the external advisory group, held 6 months into the research project, summarized the project's status and helped set directions for the remainder of the project.

A representative of the International Right of Way Association and the chairman of the TRB Committee on Utilities attended the meeting to give presentations on national utilities issues. Representatives of the university's research staff and the Alabama Highway Department summarized the current status of the research project. The university staff presented a tabulated copy of all suggestions and comments received during Phase I. The comments were categorized and UAAC members were asked to rank the suggestions by priority in each category. This meeting helped both the university and the UAAC to determine which actions were most important for revising department utilities procedures and policies.

During the preparation of the first draft of the revised utilities manual, UAAC members were frequently called upon to interpret technical materials and provide opinions about proposed policies. They were also occasionally asked to prepare written materials for inclusion in the manual.

The external advisory group was asked to review the draft manual and provide comments, corrections, and suggestions. About 40 members of the UAAC participated in this review and a majority of them supplied written comments to the department's utilities engineer.

Benefits

The UAAC enhanced the project in several ways. First, it provided an early indication to the utilities industry of the department's proposed future utilities policies and provided direct, immediate feedback. Second, it demonstrated to the utilities industry the department's good faith by including utilities representatives in the formulation of the policies and the revised manual. Third, the department was able to gather suggestions and make improvements upon the first draft of the manual using ideas contributed by industry representatives. Finally, both the utilities industry and the department will minimize future expenses through enhanced policies and improved communication.

RECOMMENDED CHANGES IN POLICY AND PROCEDURES

The majority of the first phase of the research project was spent gathering information about utilities practices. As a result of interviews with four different groups of department employees, interaction with an external advisory group, a literature review, and contacts with other state highway agencies, more than 300 ideas and suggestions were gathered for possible changes to department utilities policies and documents. These ideas were tabulated, sorted by category, and then evaluated by department managers and the external advisory group. As a result, the 300 suggestions were reduced to 85 topics for further study by the university researchers. These topics were ranked by priority in each category. The research staff then concentrated on the most important topics to determine the policy changes best suited to the utilities industry and the Alabama Highway Department. Several of the more prominent changes (or recommendations for changes) are outlined below.

Improved Communications

The most noticeable issue to the research staff was incomplete communication, as shown by statements that revealed a misunderstanding of policies or lack of comprehension of the total utilities-highway picture. Incomplete communications were noted by both highway employees and utilities industry representatives. One illustration may be taken from an interview session with the department's division engineers. These managers suggested a large number of changes to the department's policies. Eleven of the suggested changes had already been incorporated among existing policies, although the division engineers did not realize it. A second example is the suggestion made by a member of the external advisory committee who wanted the department to develop separate utilities manuals for each type of utility and for each size of utility company. This would have involved the production of at least 25 different utilities manuals, causing a hopeless morass of bureaucratic regulations. It would have been virtually impossible to determine which manual and which regulations applied to which utilities.

The university chose to attack the communications problem by gathering all existing policies, simplifying them, and setting them out in a carefully indexed manual. The final manual was large, but it was broken into clearly defined topics and subtopics with a uniquely numbered reference system. This allows readers to locate easily any topic of interest and quickly check the many cross references on the topic.

Engineering Consultants

The strongest concerns of engineering consulting firms were that they rarely had sufficient time to properly design a utilities relocation project, that it took too long for utilities to receive approval to hire consultants, and that they were not punctually paid for their services. The department was primarily concerned that engineering consultants sometimes did not appreciate the complexity of the utilities-highway relationship and did not always adequately inspect utilities construction projects.

The research staff recommended several changes to improve the situation. The use of continuing contracts between utilities and consulting engineers was urged, to allow more rapid approval of the consultant and provide a measure of assurance that the engineer understood the utilities design process. A second recommended change was that utilities relocation design be separated into three phases (Phase 1 = analysis and concept design; Phase 2 = plans, specifications, and estimate; Phase 3 = construction engineering). This would allow the department to pay for engineering work on any completed phase even if succeeding phases were never implemented. The department also agreed to set up project budgets for utilities engineering at a much earlier stage than previously considered. This also allowed faster, more complete reimbursement to utilities engineering consulting firms.

Relocation Design and Permit Processing

Concern was expressed by both highway and utilities representatives that the time span for utilities design was frequently too compressed on relocation projects. Lack of adequate time could contribute to inefficient or excessively expensive design. Lack of design time could also lead to construction delays and possible interference with the highway construction project.

The research team analyzed the department's Guide for Development of Construction Plans (GDCP), the formal, 65-step process used for designing highway plans. Several major changes were recommended, including earlier notice to utilities of the possible relocation of their facilities (moved from Step 40 to Step 19). In addition, arrangements were made for utilities companies to receive more rapid notification as changes occur during the highway design sequence.

The department's utilities functions are divided between two offices. The Maintenance Bureau oversees normal utilities accommodations, and the Utilities Section of the Design Bureau is involved in relocations and adjustments caused by highway construction projects. Utilities industry representatives did not always understand this distinction nor did they always comprehend the correct channels for submitting permits or asking questions. The research staff distinguished between the two processes (accommodation and relocation) by adopting different nomenclature. "Permits" will be used for accommodations, and the roadway is under the day-to-day control of maintenance employees. "Agreements" will be used for utilities relocations caused by highway construction projects and will be controlled by the Utilities Section. Application forms and procedures were redesigned to make the process simpler and clearer.

Several additional changes were recommended as a result of suggestions received during Phase I. Utilities industry representatives had requested removal of the 1-year limitation for completion of all work associated with an individual permit. This limit was extended to 2 years. Department field representatives requested that permit applications include the name of a utilities representative for 24-hr-per-day emergency response along with the name of the utilities-designated construction inspector.

Often in the past, utilities contractors applied for permits on behalf of utilities owners. This led to problems because there was no coordination between the utilities and the department during the design process, and the contractor had no knowledge of the intricacies of the design. The department decided to restrict future permits to utilities owners, not their contractors.

Required Notifications to the Department

The department had traditionally required utilities companies to supply notice for many of their actions, such as blasting and lane closure. These requirements had been developed in several forms over many years as rules of thumb, unwritten understandings, policy letters, and formal documents. The research staff identified and documented these requirements for notification and evaluated them for retention. Several were deleted; the others were tabulated, sorted, and clearly defined under the heading of "notifications to Department" in the new manual. For the first time, all these notifications were grouped in one location.

Guidelines and Practices

The researchers found many utility industry questions concerning the department's routine guidelines and policies in such areas as bonding, blasting, traffic control plans, herbicide applications, clear zone treatments, encasement, and similar issues. Answers to the questions could usually be found in the department's existing documentation such as the standard specifications, construction manual, and maintenance manual, but utilities firms did not always have these documents or know how to use them.

The university decided that the new utilities manual would contain outline-type summaries of the most pertinent guidelines. Information from the department's existing documents was supplemented with a survey of practices in other states, AASHTO documents, and other available information to develop these policy statements. For each issue, researchers attempted to develop a simply stated policy if none previously existed. Where such policies already existed, the new utilities manual would contain references to the appropriate department documents and briefly outline contents of these documents.

Summary of Changes

The preceding paragraphs illustrate just a few of the 85 topics addressed during the research project. Many of these changes were handled by simple revisions of the department's policies. Where one of the bureau managers could authorize the changes, they were made as the project progressed. In other cases, it was necessary to obtain a legal opinion or solicit the approval of a higher authority. The need for some of the changes could not be seen before the initial draft of the manual had been assembled.

The department did not choose to adopt all the changes recommended by the university. However, more than 90 percent of the suggested changes were adopted. In all cases, the utilities industry contributed to shaping these recommendations and was given the opportunity to influence Department managers who made the decisions regarding the adoption of changes.

DESKTOP PUBLISHING SYSTEM

The contract for this project called for the manual to be produced on a desktop publishing system. The university was to identify, purchase, and install a system for preparing the manual. This system would be turned over to the department when the project ended.

Desktop publishing involves the combination of a microcomputer, a laser printer, and comprehensive software that allows the user to prepare versatile documents of such high quality that they appear to have been typeset. The system may be used to create a document, reformat it easily, prepare graphics, merge them into the text, and customize the document with little effort.

Acquisition of System

Because the desktop publishing system was being purchased for the department, it had to be compatible with the department's other computing equipment. The researchers interviewed the department's data automation manager to define the most probable future hardware configuration and also attended desktop publishing training courses to gather information for purchasing the system. In addition, telephone interviews were conducted with organizations actively using such systems.

After assembling much background information, the researchers designed a configuration that matched the department's future needs and was compatible with a proposed department microcomputer network. The system included a high-speed microcomputer with a 386 processor, large amounts of memory, excellent graphics capabilities, menu-driven software, and user-friendly features. Commercial software widely used by industry was purchased, because of its proven track record and excellent documentation. These features would help department employees learn to use the system and maintain and update the manual.

Capabilities of the System

Software used in preparing the manual allowed rapid format changes and provided for certain automatic features highly desirable in producing the manual. The software, for example, provided automatic tabulation of the table of contents, automatic indexing, automatic numbering of pages, and other features that simplified the production of a comprehensive, high-quality manual. These same characteristics will simplify future revisions and updates of the manual.

Pictures and logos were scanned to convert them into digital images and data from these images were stored on floppy disks. Desktop publishing allowed the scanned information to be merged into the text at any location on a page. The Highway Department's logo, for example, was scanned and used in the manual, as were maps of the state and other information to customize the document to the user audience.

To assist the department in choosing the style and type of text for the new manual, researchers prepared sample paragraphs in the form of a booklet (*3*). Line spacing, character size, type face, referencing systems, and manual styles were all varied in the sample text. Department managers reviewed the samples to select the printing parameters that would produce the most readable format for the proposed manual. The research staff recommended that the department adhere to certain characteristics to emphasize the clear labeling of topics and subtopics in a style recognized by accepted literature references.

Transfer to the Department

At the conclusion of the project, researchers transferred the system to the offices of the utilities engineer of the department. Training was supplied for the secretarial staff to ensure that they could operate the system and handle future revisions to the manual. An internal cataloging system was established to preserve the names and addresses of owners of the utilities manual so that future revisions could be mailed to them with minimal effort.

PREPARATION OF THE MANUAL

Organization

To make information in the manual easier to assimilate, it was organized by topics, with most chapters restricted to a single major topic such as design or construction. The majority of the department's operational policies affecting utilities were gathered into one major chapter to make them easy to find. Rather than searching through the entire manual, the reader can scan the chapter on policies and guidelines and locate (alphabetically) the policy in question. The manual is composed of the following chapters:

1. Introduction,
2. General Guidelines and Policies,
3. Legal Basis,
4. Permits and Agreements,
5. Design,
6. Construction,
7. Reimbursement, and
8. Appendices.

Writing the Manual

The contract for this research had established a well-defined procedure for preparing the manual. The university was to develop an outline of the document, then provide a draft manual and a revised draft manual before producing the final manuscript. This procedure allowed maximum review and produced a manual attuned to the needs of the department and utilities industries within the state.

Development of Individual Chapters

Preparation of the manual was an arduous process, with the first draft taking 8 months to complete. Researchers typically assembled all available information for a chapter in the manual, visited the department and discussed the chapter, and then began preparing a draft. As questions arose, representatives of the department or members of the external advisory committee were telephoned for suggestions or to resolve discrepancies. The utilities manuals of other state highway agencies, AASHTO publications, and existing department documents were consulted frequently. As the draft of each chapter was completed, it was forwarded to the department for a cursory review. This review allowed department managers to provide direct, immediate feedback during preparation of the manual.

The most difficult material to prepare was the chapter on general guidelines and procedures, because an extremely large amount of material had to be compressed into succinct, separate policy statements. Many of these policies were extracted from other publications. The manual contains references to these publications to encourage users to obtain first-hand knowledge of the full primary reference.

Initial Review

In February 1989, approximately 50 copies of the first draft were distributed to the UAAC for initial review, and the department furnished additional copies to its employees. The university requested that the review be completed within 1 month; however, it took almost 3 months. At the conclusion of the review period, the university met with department utilities representatives for a half day to receive comments and discuss various portions of the manual. Comments of the UAAC also were covered during this meeting.

Second, Third, and Fourth Drafts

The second draft of the manual was completed in two additional months. The research staff provided copies of the manual to the department, marked to indicate all changes since the initial draft. The markings facilitated review of the manual by department and FHWA representatives.

The second-round review lasted less than a month. The resulting remarks and suggestions were received by the university and incorporated into the manual to produce the third draft. After another review, the manuscript and all graphics (including plates for multicolor production of some figures) were delivered to the department in early August 1989.

Appendices

The appendices introduced utilities-related forms, offered background information, and provided access to documents normally used in utilities actions (see Table 2).

TRAINING COURSE

As the project unfolded, it became apparent that the policy and procedure revisions would be much more substantial than initially envisioned. Likewise, the new manual would be much

TABLE 2 APPENDIX ITEMS FOR UTILITIES MANUAL

A	Index
B	Glossary
C	Acronyms and Abbreviations
D	Field Office Map with Phone and Address Information
E	Standard Legend for Utilities
F	AASHTO Publication Order Form
G	Form BM-174, Construction Bond Form
H	Forms, Occupancy and Use Permit
	MB-01 Standard Permit Form
	MB-02 Permit for Non-Public Utility
	MB-03 Permit for Non-Public Utility, Utility Pays Department
I	Forms, Standard Agreements
	SAHD No. 1 Non-Reimbursable Agreement
	SAHD No. 2 Reimbursable Agreement
	SAHD No. 3 Reimbursable Agreement, Work by State Contractor
	SAHD No. 4 Non-Reimbursable Agreement, Work by State Contractor
	SAHD No. 5 Retention of Existing Facilities
	SAHD No. 6 Supplemental Agreement
	SAHD No. 12 Agreement to Negate a Reimbursable Agreement
J	Forms, Inspection Reports
	SP-1 Daily Inspection Report
	SP-3 Utilities Relocation Progress Report
K	Form, Utility-Engineer Consultant Agreement
L	Form, U-10, Cost Estimate
M	Drawing U-1, Bridge Attachments
N	Invoice Check Sheet
O	Samples of Completed Invoices
P	Guide for Developing Construction Plans (GDCP)
Q	Federal-Aid Highway Program Manual
R	Registration Form

different and much more comprehensive than the department's previous utilities documents. These changes required training both departmental employees and utility industry representatives.

Discussions were conducted between the researchers and the department's utilities engineer to design the training course. Eight one-day sessions were planned at four locations throughout the state. At each location, the first day's training was to be departmental employees. The second day's training was to be open to cities, counties, utility representatives, and others interested in the utility process.

The goal was to hold the training after the manual had been distributed but before the January 1, 1990, target date for implementing the new policies. The training dates were scheduled as follows:

Date	*Day*	*Location*
October 30	Monday	Mobile
October 31	Tuesday	Bay Minette
November 1	Wednesday	Montgomery
November 2	Thursday	Montgomery
November 6	Monday	Decatur
November 7	Tuesday	Huntsville
November 8	Wednesday	Birmingham
November 9	Thursday	Birmingham

Invitations to attend the training were to be distributed by the division utilities engineers, who were notified in late September 1989 to prepare to distribute the announcements.

The university researchers were asked to prepare a letter announcing the conference. A draft letter was prepared for the utilities engineer's signature, along with a registration form and an announcement brochure.

As the course was conducted, department utility representatives and university researchers provided 6 hr of training on the changes in utility processes and the contents of the new manual. Typically, the day started with introduction of the instructors and a quick overview of the manual. The manual's contents were then discussed by the instructors on a chapter-by-chapter basis. Overhead transparencies were used to illustrate major points in each chapter. Questions were taken from the audience because attendees needed additional information.

Demand for the training course exceeded all expectations. A ninth training session was scheduled especially for the Annual Meeting of the Alabama Rural Water Association (ARWA). About 150 people attended this 4-hr session conducted November 14, 1989, in Montgomery.

The training sessions were extremely well attended. Overall, 256 department employees, 74 city representatives, 54 county representatives, 504 utility employees, 100 consulting engineers, 150 ARWA members, and 27 others were trained. As a result, approximately 1,200 persons became familiar with the new policies and new manual.

SUMMARY

A 2-year research project was conducted by the University of Alabama for the state of Alabama Highway Department to identify problems with utilities procedures and documentation and prepare a new utilities manual. More than 300 suggestions for changes were received from department employees and an external advisory group. These suggestions were condensed into 85 topics studied by the university to provide recommendations for changes to department utilities procedures.

At the project's conclusion, more than 2,000 copies of a 324-page manual were published. Nine training sessions were held to introduce more than 1,200 persons to the new policies and the new utilities documentation.

ACKNOWLEDGMENTS

Funding for this project was supplied by the state of Alabama Highway Department. The authors gratefully acknowledge and appreciate the cooperation and participation of the many department employees and representatives of the utilities industry, without whom this project would not have been possible. Technical and administrative assistance was supplied by employees of the Civil Engineering Department of the University of Alabama, including Teresa Sikes, Judi Williams, and Nell Vice.

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Publication of this paper sponsored by Committee on Utilities.

Review of the HDM-III User Cost Model for Suitability to Canadian Heavy Vehicles

PETER BEIN

Operating expenses of the Canadian heavy-vehicle fleet exceed several times the expenditures on the public road system, but sound aids that recognize the importance of user costs in road investment decisions are lacking. A state-of-the-art model of user costs was developed after a study in Brazil by the World Bank. The current version of the Highway Design and Maintenance Standards Model, HDM-III, is evaluated for relevance to the Canadian heavy-vehicle operating conditions, and the results of preliminary calibrations for five typical vehicles are presented. The model is relevant to studying road infrastructure issues. It is also easy to operate and calibrate, but the cost-roughness slope and the effect of road texture, a roadworks decision variable in Canada, remain to be validated. The model will become more useful once the effects of congested traffic conditions on operating speeds are incorporated. Maintenance and depreciation costs need closer examination because they are interrelated and complicated by the inclusion of factory warranty costs in the purchase price. Maintenance cost formulas themselves need reevaluation because they were developed for a low labor-cost environment. If the present HDM-III "adjusted utilization method" is retained, it should be modified to account for the fact that time savings on a haul do not necessarily translate into additional trips. Relationships for cargo delay and damage due to road conditions also need improvement.

Trucking makes a major contribution to the economy. Not counting the smaller operations, Canadian for-hire and private carriers spend well over $20 billion annually in operating costs and engage more than 120,000 straight trucks, 49,000 tractors, and 110,000 trailers (*1*). Trucks move about two-thirds of the commerce between Canada and the United States at a cost of $2.5 to $3 billion, an amount that could double in less than 10 years with free trade. Deregulation will have growth effects similar to those observed between 1978 and 1987 in the United States (*2*).

Most of the heavy vehicle travel takes place on paved surfaces that account for 40 percent of the total 840 000 km of road in Canada. Robust economic arguments are needed to support increased road agency funding levels and proposed changes in heavy vehicle size and weight regulation. An accurate assessment of trucking costs is important because they have significant multiplier effects in the national economy. Canadian road users' contribution to the economy is an order of magnitude higher than the present public spending on construction, maintenance, and reconstruction of all rural and urban roads (*3*).

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Highway user cost and benefit analyses in Canada rely on outdated data. There is a recognized need to establish user cost parameters for the Canadian vehicle fleet and develop a methodology for road deterioration relationships (*3*). Trucking industry models, such as those of Trimac (*4*) or IBI Group (*5*), are unable to relate the costs to road surface condition or geometry and are less useful for studying road infrastructure issues. The applicability of the HDM-III model of road user costs to Canadian heavy vehicles is discussed in this paper.

HDM-III MODEL

Following a large-scale study in Brazil in 1975 to 1981, the World Bank developed the Highway Design and Maintenance Standards Model. The present version of the model, HDM-III, can aid feasibility studies of individual projects as well as policy studies for highway networks (*6*). The model is generic and can be calibrated to suit local conditions if they differ from those covered by the model's data base. The research represents the largest effort to date to develop a model capturing the relationships between costs of construction, maintenance, and utilization of roads. The model is based on the following premises deduced from earlier studies:

- User costs are related to highway construction and maintenance standards through the effect of road geometry and pavement surface condition.
- Pavement deterioration depends on the original construction, maintenance, and reconstruction, as well as traffic loading and uncontrollable environmental effects.
- Surface roughness is the principal road-related factor affecting user costs in free-flow traffic that can be related to all major pavement performance variables.
- Interrelationships are structured to describe known mechanistic and economic phenomena and can be suitably calibrated using the observed data.

User Cost Components

User costs depend on a region's economy, vehicle technology, driver behavior, and fleet-operating decisions. In order to facilitate future calibrations of the model to different local conditions, the World Bank's goal was to employ generic principles. The goal was reached for vehicle speed and fuel consumption models. Tire consumption and vehicle maintenance modeling experienced difficulties in gathering controlled experimental data. Generic economic causes of interactions between vehicle maintenance, depreciation, and interest costs were fully appreciated only after HDM-III was examined for conditions different than in the Brazilian study.

Operating cost relationships were developed for automobiles, light vehicles, two- and three-axle trucks, an articulated truck, and a bus. Vehicle speed, fuel, and tire consumption models were derived from a force-balance equation. The other user cost components are: oil; maintenance parts and labor; depreciation as the loss of vehicle market value; interest on undepreciated capital tied up in the vehicle assets; and driver, occupant, and cargo delay costs. Administration overhead costs can be calculated either as a lump sum per vehicle prorated over the annual distance travelled or as a percentage of running costs. This cost category could include other fixed costs such as terminal, registration, insurance, and license costs.

A sum of the vehicle operating costs (VOC) and delay costs weighted by each vehicle percentage in the traffic mix is the total cost on a road section or network link. This total cost is used in the HDM-III highway investment model and in the evaluation of alternative individual projects.

A stand-alone VOC prediction model is available for an IBM PC or compatible microcomputer running on an MS-DOS 2.0 or higher version. The program fits a curve to the total user cost expressed as an exponential function of surface roughness. Road geometry features are fixed parameters in the program.

Assumptions and Limitations

The HDM-III user cost submodel assumes that roads consist of homogeneous sections of sufficient length for a vehicle to attain a steady-state speed for a given road geometry and surface condition. The speed is a function of engine power, road gradient, horizontal curvature, surface roughness, and driver behavior.

The submodel in its original form cannot include the costs resulting from congested traffic conditions and start-stop operations. Until a suitable revision is made, these costs can be included in the HDM-III highway investment model by a generalized procedure. Other user costs such as construction-related traffic delays, accidents, and environmental pollution can also be entered from separate estimates.

A significant amount of work will be required to adapt and calibrate the HDM-III user cost submodel so as to accurately reflect the heavy-vehicle conditions in all Canadian provinces. Preliminary calibrations have already been accomplished within two Canadian projects (*3,7*). The assumptions and limitations of HDM-III user cost model will now be discussed from the point of view of application to heavy vehicles in Canada.

COMPARISON OF BRAZIL STUDY AND CANADIAN HEAVY-VEHICLE OPERATING CONDITIONS

Vehicle Technology

The Brazilian vehicle fleet was supplied by the domestic automotive industry, ranked among the world's top ten. Brazilian truck designs in the 1970s featured engine efficiency and body design for payload maximization within gross vehicle weight and axle load limits, but were not as efficient as their European counterparts. By 1980, a range of engines was available that could run on a variety of gasoline, gasohol, and diesel fuels. Vehicle owners could match truck specifications to the type of service they wished to provide.

Data for typical Canadian and Brazilian heavy vehicles are compared in Table 1. The most widely used interurban truck in Brazil was a three-axle rigid vehicle with a nondriven trailing axle, grossing between 18 to 22 tonnes and powered by a 147-hp (SAE) engine. This should be compared with a 1986 five-axle unit grossing 37.5 (Saskatchewan) to 49 tonnes (Quebec) and equipped with a 300- to 350-hp engine. The new Canadian heavy-vehicle weight regulations allow a gross combination weight (GCW) of 46.5 tonnes for five-axle combinations and 63.5 tonnes for Roads and Transportation Association of Canada (RTAC) B-trains that are eight-axle configurations. Canadian two- and three-axle trucks are used mainly in urban service. The three-axle tractor body design in Brazil was cab-over-engine, but conventional design was favored in North America for some time because of its lower maintenance cost and better fuel economy. Five-axle combinations were lighter and not as numerous as in Canada, and larger combinations were unusual. Intercity buses were also lighter in Brazil.

An extensive use of lighter materials in the body and mechanical components of both the truck and trailers has led to increased payload capacity per axle. In a quest for lighter equipment, North American truck operators have considered sacrificing vehicle durability and truck life. Advances in truck combinations technology have produced units of seven and more axles that did not exist in Brazil. Recent regulatory changes allowing higher gross vehicle weights are certain to increase truck productivity.

Modern tractors are powered by energy-efficient power plants with semiautomatic transmissions. Aerodynamic design is considered an important feature of equipment operated on long hauls. The vehicles are increasingly being equipped with radial tires that augment fuel efficiency by up to 30 percent compared with bias-ply tires. "Electronic" engines that can be programmed for a specified horsepower, torque, and speed for a given haul are already available.

The bus supply in Brazil ranged from integral and platform, rear-engine vehicles with air suspension and air-conditioning for long-distance operations on paved roads to traditional front-engine, ladder-type chassis versions for use on unpaved routes. All buses crossing state boundaries or traveling routes longer than 300 km within a state had to be fitted with a tachograph. Rules governing speed limits and driving hours were strictly enforced for both buses and trucks.

Fleet Operation

Computer applications in trucking management have created an unprecedented potential for productivity improvements that were technically impossible for operators participating in the Brazilian study. Computerized dispatching and routing systems can help the dispatcher's judgment in optimizing the company's pick up and delivery operations. Maintenance, parts inventory, fuel, and tire control software, when used intelligently, reduce fleet operating costs and increase service reli-

TABLE 1 DIFFERENCES IN VEHICLE TYPE AND UTILIZATION

VEHICLE	CANADIAN PRAIRIE PROVINCES, 1986	BRAZIL, 1976
2-Axle Truck(1)	International(2)	Mercedes Benz 1113
GVW, kg	14,600	15,000
Curb weight, kg	5,700	5,400
Max. rated engine power, hp (SAE)	166	147
Max. rated engine speed, rpm	2,400	2,800
Typical annual km	32,000(3)/5,000(4)	101,000
Typical annual hours driven	1,000/200	2,040
Type of service	Urban/Farms	Intercity
3-Axle Truck(1)	International(2)	Mercedes Benz 1133
GVW, kg	21,500	18,500
Curb weight, kg	11,000	6,600
Max. rated engine power, hp (SAE)	180	147
Max. rated engine speed, rpm	2,700	2,800
Typical annual km	32,000	101,000
Typical annual hours driven	1,000	2,040
Type of service	Urban	Intercity
5-Axle Truck(1)	Kenworth W900(2)	Scania 110/39
GVW, kg	37,500	22,000
Curb weight, kg	14,500	14,700
Max. rated engine power, hp (SAE)	350	285
Max. rated engine speed, rpm	2,150	2,200
Typical annual km	140,000(4)	?
Typical annual hours driven	1,600(4)	?
Type of service	Intercity	Intercity
7-Axle Combination(1)	Western Star(2)	(6)
GVW, kg	53,500	
Curb weight, kg	16,000	
Max. rated engine power, hp (SAE)	400	
Max. rated engine speed, rpm	2,100	
Typical annual km	140,000(4)	
Typical annual hours driven	1,600(4)	
Type of service	Intercity	
Bus	M.C.I.(7)	Mercedes Benz 0362(8)
GVW, kg	17,200	11,500
Curb weight, kg	12,900	8,100
Max. rated engine power, hp (SAE)	300	149
Max. rated engine speed, rpm	2,100	2,800
Typical annual km	> 100,000?	?
Typical annual hours driven	1,600?	2,400
Type of service	Intercity	Intercity

NOTES: Brazil data from *reference (8)*
(1) Trimac (1986) data for general merchandise cargo;
(2) Vehicle dealer automotive data on most popular makes;
(3) Estimate using 33 km/h average running speed in urban service;
(4) Lea Associates 1987 survey and "1985 Travel on Saskatchewan Highways";
(5) Trimac (1986) data for bulk cargo;
(6) Equivalents to 7-axle combinations did not exist in the Brazil study;
(7) Motor Coach Industries (M.C.I.), 3-axle bus;
(8) 2-axle bus.

ability. Less-than-truckload freight can be consolidated and empty truck runs eliminated by using computerized matching service for the interchange of information between shippers and carriers.

Electronic data interchange between shippers, carriers, and consignees eliminates paperwork, speeds up deliveries, and enables manufacturers and distributors to synchronize the flow of goods. This is possible owing to high-technology developments such as on-board computers in trucks, driver-dispatcher communication systems, and satellite tracking of vehicles. These systems are now becoming a reality among larger motor carriers, who will be able to fill the transport function in the just-in-time, cost-reducing method of materials and goods management in manufacture and distribution.

Rolling Resistance

The largest contribution to vehicle rolling resistance arises from the hysteresis of tire materials caused by deflection on road surface macrotexture. In the Brazilian study, rolling resistance was regressed through controlled experiments on longitudinal road roughness, which was considered the primary variable. Surface texture, tire, and suspension characteristics were ignored. Road-surface texture characteristics are definitely a location-specific variable, depending on materials, methods of construction, and the weathering effects of climate (*9*). Tire properties have changed considerably relative to the bias-ply technology prevailing in Brazil.

Neither load conditions nor pavement texture was found to be a significant determinant of test truck rolling resistance, but tire pressure was found to be highly significant (*10*). Between a flush seal, hot mixes, and a chip seal, the macrotexture varies by almost eight times, whereas microtexture varies by almost two times (*11*). Rolling resistance is 25 percent higher on deeply textured asphalt than on medium texture asphalt, and almost 70 percent higher than on smooth concrete (*12*).

The HDM-III relationships relating to rolling resistance would need revision in Canada. Coast-down experiments are recommended using vehicles of contemporary suspension and tire designs on a range of typical Canadian road surfaces in order to verify the Brazilian rolling resistance relationships. This verification is important, considering that the force-balance equation underlies fuel and tire consumption and time-related user cost estimation. It is also important to quantify the effect of the pavement deflection bowl. It has been observed in Canada that loaded trucks need to gear down in order to climb a gradient created in front of the wheels on thin pavements.

Vehicle Speeds

The HDM-III VOC model has been developed for steady-state speeds encountered under free-flow traffic conditions. Speed change and stop-and-go cycles along the roadway are not modeled in the present version, but at least one compatible model for these traffic conditions exists (*12*) and could be included in a future version of HDM. The new version would be much more useful in Canada for both highways and urban roads.

In the Brazilian study, vehicle loads were estimated visually and payloads recorded in broad weight classes. Truck payload has an important influence on speeds, and visual observations are not accurate estimates of loads carried. One study (*7*) encountered some complications in calibrating the speed relationships, possibly for this reason.

For lack of other measures, the HDM-III roughness-related speed function was adopted from the standard Mays-meter-equipped Chevrolet Opala car. Its average rectified velocity of suspension motion was used as a surrogate for that of the heavier vehicles. This assumption may not be suitable for trucks, especially those hauling high-value cargo susceptible to damage by vibrations and shocks.

Fuel Consumption

The Brazilian study found that fuel consumption could be predicted by using a constant nominal engine speed rather than the actual one. Adjustment factors have been introduced to allow corrections for changes in vehicle technology and for experimental driving conditions. The HDM-III default factors are specific to the Brazilian study. They were obtained by correlating experimental data with actual road-user fuel consumption. Specific vehicle and engine technology imposed by the trucks in Brazil does not permit extrapolation to modern Canadian trucks, and corrections will be required.

HDM-III fuel consumption relationships are based on an inadequate approach to representing pavement texture in the rolling resistance equations. Pavement texture causes energy losses in the tires that are responsible for an additional resistance compared with driving on a surface without texture. A Swedish model (*13*) predicts a 40 percent increase in fuel consumption for heavy vehicles traveling on deeply textured surfaces compared with smooth roads. For free-flow traffic, an Australian model (*12*) found a reasonable agreement with HDM-III fuel consumption predictions for straight trucks and combinations. A Canadian study (*7*) found calibration of HDM-III fuel consumption to be one of the easiest adaptation tasks.

The omission of texture, an important decision variable in highway management in developed countries, has caused some controversy. Zaniewski (*14*) could not find any dependence of fuel consumption on road roughness, possibly because the Serviceability Index does not capture pavement texture characteristics, according to Claffey (*15*). The other factor important in increasing fuel consumption is a higher wheel slippage in Canada because of the presence of slush, snow, and ice on road surfaces in winter. Winter fuels were not used in the Brazil tests.

The Scania test tractor in Brazil had a high fuel consumption when running loaded on grades compared with a similar European version. Investigations have revealed that the vehicle was fitted with a low-speed differential that may be partly responsible for the differences. This was not realized when the fuel data were collected and analyzed. The fuel study results for this vehicle type should be used with caution (T. Watanatada, World Bank, unpublished data, 1987).

Tires

Tire data are difficult to collect because tires are moved between vehicles and axles. Tire life varies even under identical operating conditions according to load carried, position on the vehicle, speed of operation, and driver behavior. Tire utilization also depends on a company's standards of maintenance for tires and vehicles, and on recapping policy.

Tire technology and manufacture continue to change rapidly. Research into tire costs for road vehicles is required to measure the benefits of new tread and carcass materials, recapping techniques, new tire types, and central tire inflation equipment on large articulated vehicles. Steel-braced radial tires were not available in Brazil during the periods in which user surveys were performed, and these tend to give different tire costs per kilometer.

The limitation of the rolling resistance coefficient with regard to capturing pavement texture properties also applies to the tire consumption relationships. A survey of bus companies has found that angular stones in the pavement caused accelerated tire wear (*10*). The HDM-III relationship for tire consumption of trucks and buses is intended for use with roads of moderate horizontal alignment and a well-designed superelevation. These conditions are met on Canadian arterials and collectors, where most of the truck transportation takes place.

Maintenance Costs

HDM-III maintenance cost relationships will most likely be difficult to transfer to Canada. Maintenance expenditures are sensitive to price and wage levels and the trade-offs of depreciation and interest charges, all of which are linked to the size, strength, and structure of the local economy and to the type of transport service offered by the operator. For example, an operator providing service of high reliability at peak periods in a competitive economy will set high levels of inspection and conduct preventive maintenance. These costs will be balanced by keeping reserve vehicles to a minimum.

Despite these transferability problems, close agreement was found between the cost-roughness slope in Brazilian and South African data on bus parts consumption (*10*). Maintenance parts and labor costs, and their trade-off with depreciation and interest charges, are likely to prove highly resistant to a mechanistic approach. Economics, not technology, is the key factor in predicting these components. Calibration of the maintenance cost relationships of HDM-III for Saskatchewan (*7*) met some difficulty because of their mathematical structure.

Depreciation and Interest

In the Brazilian study, no data were collected to estimate the relationships between depreciation and interest costs and road characteristics. HDM-III considers speed, utilization, and service life to be interdependent. A number of relationships are provided for calculating utilization and service life, but only "the adjusted utilization method" is recommended for Canada. It assumes that each vehicle operates on a fixed route throughout a given year and that the annual hours available for driving are constant and independent of vehicle speed and route characteristics. Vehicle operators maximize vehicle productivity by making as many trips as possible within the availability constraints.

HDM-III has two methods for calculating the average annual depreciation and interest. The constant-vehicle-life method uses a straight-line depreciation for a specified vehicle life, which is assumed to be a constant regardless of any calculated vehicle speed. The average annual interest is calculated on the average vehicle price over its lifetime. In the varying-vehicle-life method, vehicle life decreases (or increases) somewhat as vehicle speed increases (or decreases). This means that the service life, lifetime kilometerage, and depreciation charges change less proportionately than speed. This method was found unsuitable for low vehicle utilization levels in New Zealand (*16*).

Occupant and Cargo Delay Costs

In the HDM model, the cost of crew labor and cargo-holding cost are considered to be variable rather than fixed costs. This means that the time spent on loading, unloading, and layovers is not charged against this cost category.

The cargo-holding cost per 1,000 vehicle-km is defined as the product of vehicle hours spent by cargo in transit and the user-specified cargo-holding cost per vehicle-hour delayed. In general, the cargo-holding cost is small, but for cargo of high value the cost will be significant. For example, a $1 million cargo delayed 2.5 hr because of a reduction of truck running speed from 100 km/hr to 80 km/hr will give rise to a delay cost of 2.9 cents/km.

CALIBRATION OF HDM-III FOR CANADIAN HEAVY VEHICLES

Uncalibrated HDM-III

Trimac Consulting Services Ltd. carries out a survey of Canadian truck operating costs every 2 years (*4*). Trimac's assumptions on truck characteristics and unit costs are representative of the industry, and were fed into the Highway User Benefit Assessment Model (HUBAM) used by Transport Canada and into the uncalibrated HDM-III. Figure 1 compares the results of Trimac, HUBAM, and uncalibrated HDM-III analyses for three trucks. HUBAM does not analyze vehicles larger than five axles.

Costs are fairly close for the two-axle truck, provided that driver costs are adjusted and interest charges in HUBAM are taken into account. Trimac's driver cost is high because it reflects an urban pick-up and delivery service at an average 32 km/hr, whereas HDM-III and HUBAM assume intercity haul at free-flow speeds. Fuel and oil costs in HUBAM are overestimated, as is maintenance cost in HDM-III.

Total costs for a five-axle Trimac truck are similar to HUBAM, but HDM-III is much too high because maintenance and tire costs are about four times higher than the corresponding figures. The HDM-III results for a seven-axle truck suffer from a similar deficiency, although the other cost components seem comparable to Trimac's industry rates.

Figure 2 compares the VOC changes on rougher roads relative to a smooth road with a Riding Comfort Index (RCI) value of 8. HDM-III provides much larger benefits than HUBAM for any improvement project, particularly for trucks. This must result from the overprediction of truck maintenance costs and the strong influence of road roughness on these costs. RTAC and Saskatchewan data shown in Figure 2 indicate disagreement in Canada on this crucial relationship underlying all highway feasibility, maintenance, and rehabilitation decisions. The most likely relationships would be between the HDM-III and HUBAM curves.

Figure 3 emphasizes the need for an accurate calibration of vehicle speed in HDM-III. The HUBAM speeds are highest because HDM-III speeds are determined by an 80-km/hr limit in force during the study in Brazil. Neither model is realistic about the gap between automobile and truck free-flow speeds on present highways. Trimac speeds of five- and seven-axle trucks are not comparable because they are trip averages including stops and urban driving at each end of an intercity haul.

Calibrated Relationships

Typical Canadian trucks and a bus operating in the prairie provinces were chosen for trial calibrations of the HDM-III model. Vehicle operating characteristics, utilization, auto-

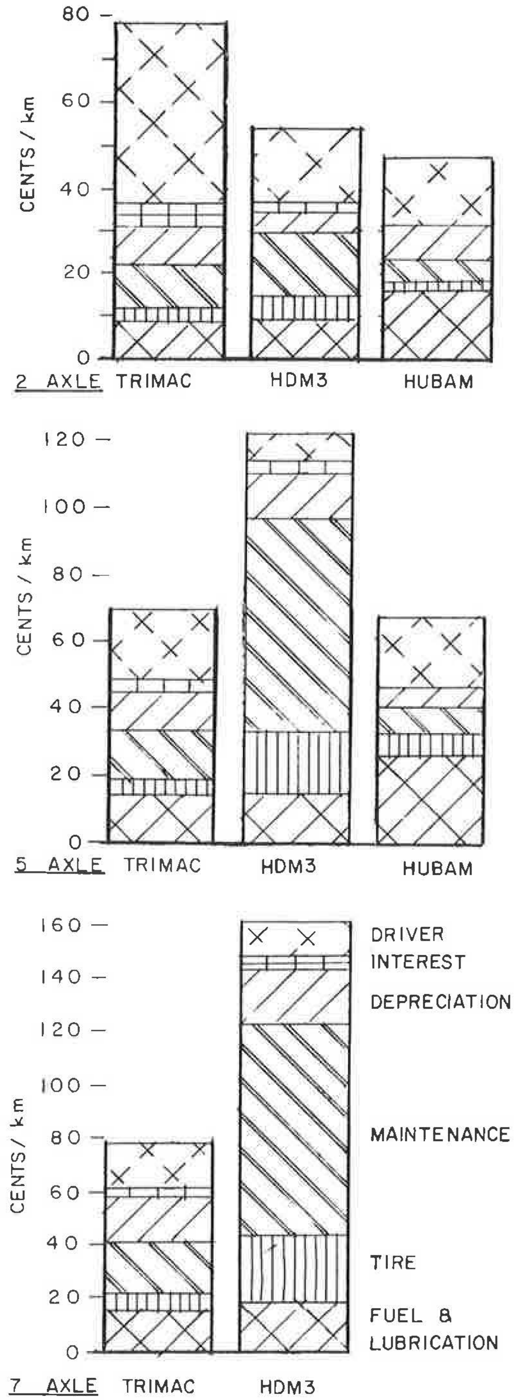

FIGURE 1 Comparison of Trimac's VOC data with predictions by uncalibrated HDM-III and HUBAM.

motive data, and unit costs were obtained in surveys and interviews of the trucking industry, vehicle dealers, and manufacturers. Trimac data (*4*), found reliable compared with the survey data, were used as the benchmark to calibrate HDM-III for smoother road conditions. For rougher roads, data are not readily available and the slope of the VOC-roughness relationship was adopted from the Brazilian study.

Figure 4 shows the total VOC in cents per kilometer as a function of roughness expressed in RCI units. The seven-axle truck has the steepest slope and the three-axle bus the gentlest slope. The two-axle truck has the lowest VOC and the seven-axle truck the highest VOC, but the three-axle truck is more expensive to operate in cents/km than the five-axle.

The breakdown into VOC components is shown in Figure 5 for the seven-axle truck. Crew cost is significant, but depreciation and interest are greater. The largest cost increase with roughness occurs in the maintenance and depreciation components, while fuel cost does not change much with roughness. Fuel cost drops at lower RCI values because of reduced speeds on rough roads, but crew time increases then.

For a three-axle bus, tires cost less because there are fewer of them and the load is lighter. Maintenance is also less because there are fewer components to break down compared to a seven-axle truck.

Figure 6 summarizes the change in total VOC when roughness decreases from RCI 8 to 4. This type of data can be used in road investment decisions to estimate extra user costs due to road deterioration or determine user cost savings from road improvements. The two-axle truck experiences the highest, and the bus the lowest, marginal rates of increase with RCI. When a delay of 20 passengers is added, the marginal rate of the bus halves, indicating a high sensitivity to the number of passengers.

Sensitivity Analyses

The VOC of trucks is about three times more sensitive to rolling resistance than the VOC of cars, regardless of roughness. Cost increments due to deep-textured versus medium-textured asphalt surface would be similar to increments resulting from an RCI drop from 8 to 6.5. A 20 percent decrease in truck utilization leads to a comparable effect. A 10 percent increase in payloads from better productivity, or from higher truck GVW or volume, can lead to 7 to 9 percent reductions in unit trucking costs.

CONCLUSIONS

The HDM-III user cost model is a robust tool for road transportation decisions based on economics, road engineering, and vehicle operation and management principles. Adaptations will be required to make the model an accurate simulator of heavy-vehicle operations because they were not represented in the HDM-III database. The model is relatively easy to adapt, owing to the mechanistic form of most of the relationships, and it will become more useful once the ongoing research into modeling congested traffic flows is incorporated.

Maintenance and depreciation costs need closer examination because they are interrelated and were developed for a low labor cost environment. If retained, the "adjusted utilization method" should be modified to reflect the fact that time savings on a haul do not necessarily translate into additional trips. Relationships for cargo delay and damage due to road conditions need improvement because these costs are more important in developed countries than developing ones, for which HDM was conceived.

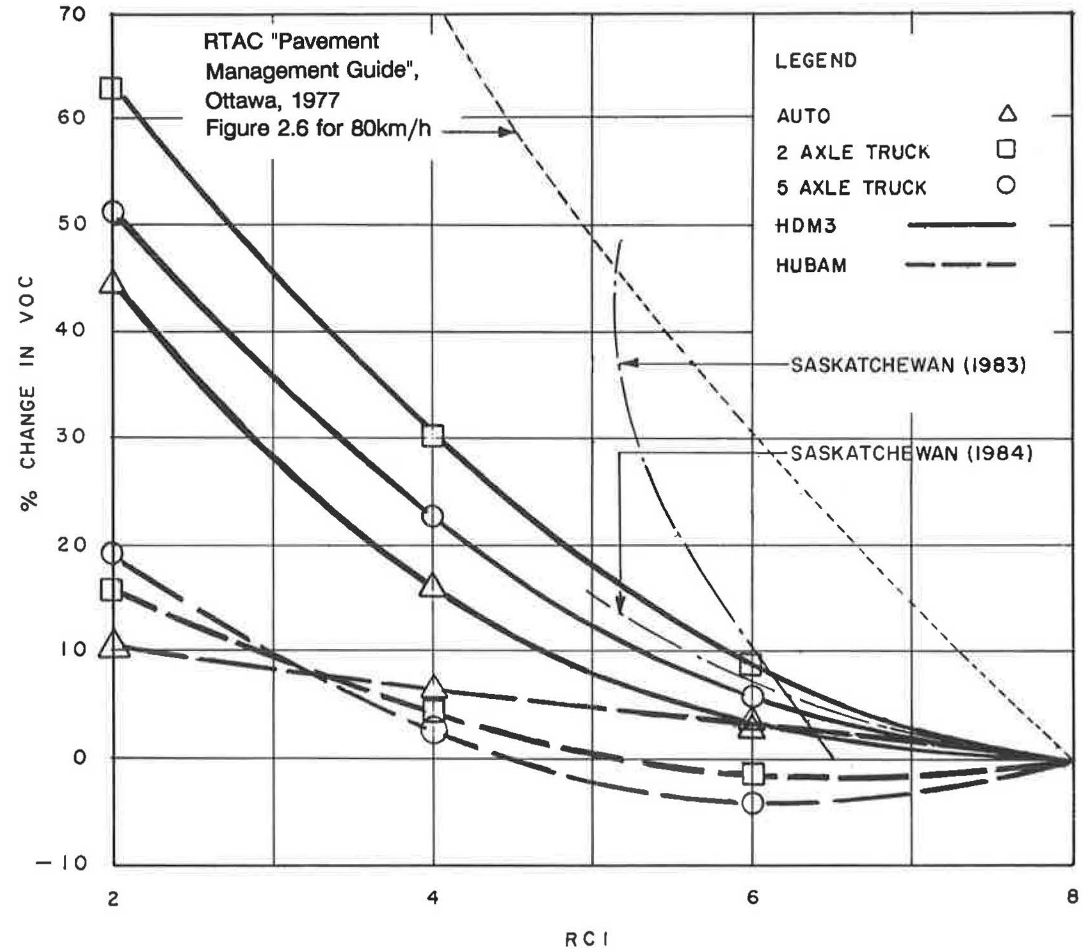

FIGURE 2 Percent change in VOC relative to RCI = 8.

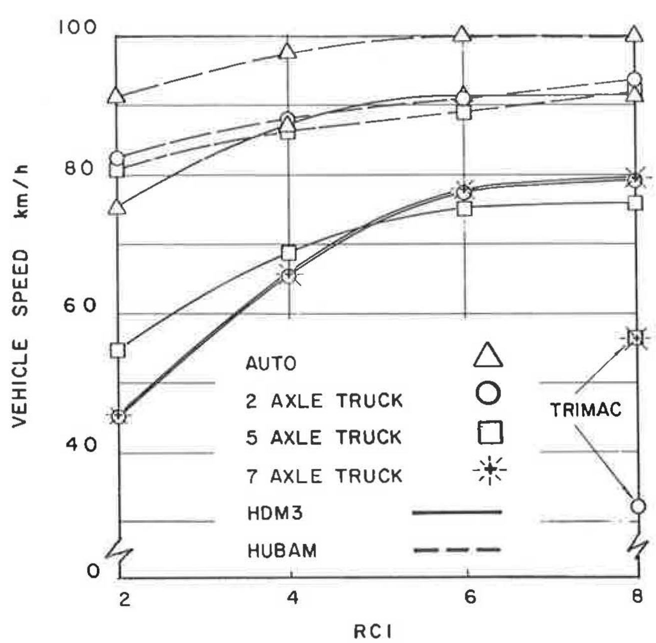

FIGURE 3 Predicted vehicle speeds for free flow conditions.

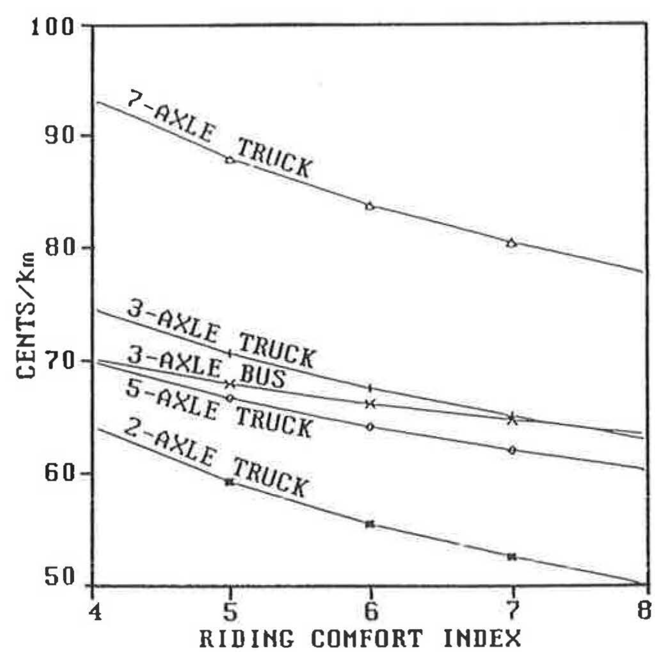

FIGURE 4 Total VOC of heavy vehicles.

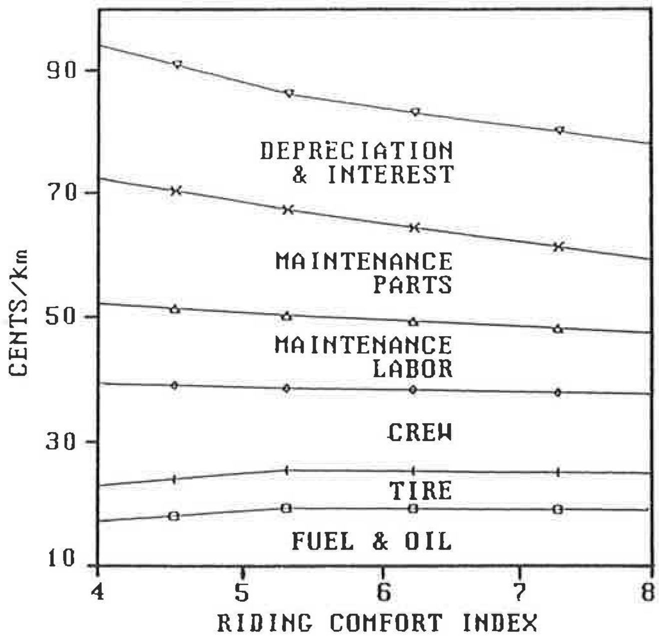

FIGURE 5 Seven-axle truck VOC components.

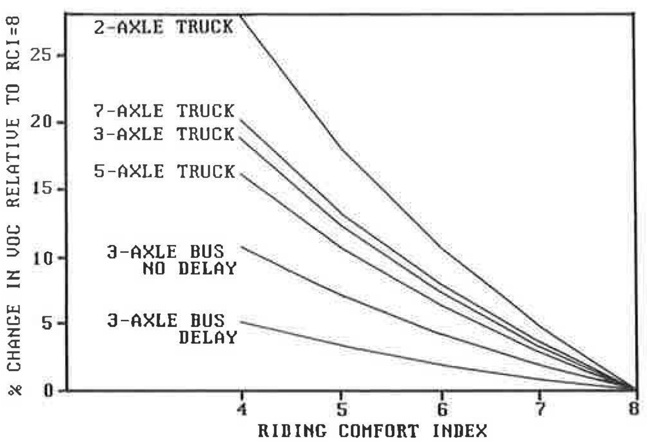

FIGURE 6 Relative change in VOC of heavy vehicles.

Trucking cost data from rough routes are urgently needed for planning. This data would enable verification of the slope of the cost-roughness functions critical in planning and programming road maintenance and rehabilitation. The HDM-III assumptions on road surface texture should also be checked in full-scale experiments using representative trucks and tires, so that the rolling resistance base of speed, fuel, tire, and time-related trucking costs in HDM-III can be regarded with confidence. A similar conclusion has been reached by an independent, in-depth research (*12*). A concerted effort would be desirable among the Canadian road infrastructure administrators, the trucking industry, and the research community to carry out the adaptations and calibrations.

ACKNOWLEDGMENT

This research was sponsored by the Roads and Transportation Association of Canada and the Saskatchewan Highways and Transportation while the author worked for N. D. Lea International Ltd. Valuable insights from John B. Cox, Norman D. Lea, and Merv F. Clark are gratefully acknowledged.

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Publication of this paper sponsored by Committee on Application of Economic Analysis to Transportation Problems.

Cost-Effectiveness for Circulation-Distribution Systems

JAMES H. HERENDEEN, JR., AND JAMES MORENO

The Environmental Impact Statement for the Omni and Brickell legs of the Miami Metromover required a cost-effectiveness analysis. As the analysis was undertaken, it became evident that the cost-effectiveness procedures usually used to analyze major regional transit improvements were not appropriate for circulation-distribution systems. One of the primary functions of circulation-distribution systems is to change trip-making patterns usually resulting in longer trips and sometimes in increased travel times. No provision in current cost-effectiveness procedures measures this travel impact. The methodology also fails to consider farebox revenue and local subsidies as offsets to either local or federal "costs." These issues, encountered during the cost-effectiveness analysis phase of the study, are described and suggestions made for modifying the procedures, so that the results of circulation-distribution system analyses are meaningful. A comparison of the values computed using different procedures for the analysis of the Omni and Brickell legs is also presented.

The transit system in Miami consists of three major components: Metrorail, Metrobus, and Metromover. Metrorail is the regional rapid rail component extending from Dadeland in the south through downtown Miami to Hialeah in the northwest. Metrobus provides regional and local bus service throughout the remainder of the region. Metromover, an Automated Guideway Transit (AGT) system, is the downtown component of the system designed to provide for the distribution of transit travelers within the downtown and improve circulation among the Omni area to the north, the Downtown, and the Brickell area to the south across the Miami River.

The first phase of the Metromover component, a 1.9-mi double-loop system, opened for service in 1986. Design work has begun on the Omni and Brickell legs that were the object of this study. Although the specific debate about the Miami Metromover is moot, the issues raised during this analysis are relevant to future studies of major transit investment alternatives.

INTRODUCTION

The primary purpose of a circulation-distribution (C/D) system is to improve accessibility to and mobility within a densely developed area. Improvements in accessibility and mobility, in turn, are expected to increase the amount and density of economic activity in the developed area where other infrastructure needs can be provided effectively and efficiently. Because it is difficult to quantify the impacts of transportation system improvements on promoting development and structuring future growth, the effectiveness of such improvements is usually measured in terms of accessibility and mobility changes as they affect travel characteristics and transportation system use. Changes in the number of trips made, travel time, and the distance traveled within the downtown area are valuable measures of the effectiveness of C/D systems.

As part of the studies conducted for the Environmental Impact Statement for the Omni and Brickell legs of the Miami Metromover system (*1*), it was necessary to conduct a cost-effectiveness analysis. Costs for building the legs were estimated to be $240 million ($96 million per mile) in 1986 dollars based on preliminary engineering studies. Operating and maintenance costs were estimated to be $2.5 million more for the build alternative compared with the no-build alternative in 1986 dollars considering both the increases in Metromover costs and decreases in bus operating costs. Operating revenues were estimated to be $0.7 million more for the build alternative. The task was to determine whether the expenditure necessary to build the Omni and Brickell legs was cost-effective.

It became evident that the procedures currently used to measure the cost-effectiveness of transit improvements do not adequately measure the effectiveness of C/D systems. In particular, the cost-effectiveness indices used by the Urban Mass Transportation Administration (UMTA) to analyze transit investment options nationwide (*2*) assume that introduction of a new transit system has no effect on the generation or distribution of trips, nor do they consider the diversion of walk trips to transit within the downtown area if the travelers arrive in the downtown by regional transit. Changes in travel patterns and the distribution of regional transit trips throughout the downtown are two of the primary functions of C/D systems.

The purpose of this paper is to describe the findings of the cost-effectiveness analysis conducted for the Omni and Brickell legs of Metromover by Metro-Dade County and suggest new procedures for evaluating future C/D systems. Of particular interest is the rationale and method for measuring the value of increased trip lengths induced by the legs.

BACKGROUND

Cost-effectiveness has evolved over the last 15 years or so as a method for evaluating alternative investment strategies that

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lack a common basis for comparison. Alternative transportation investment strategies frequently have vastly different initial costs, annual operating and maintenance costs, and life expectancies, and usually do not achieve the same performance level. Cost-effectiveness provides a mechanism for evaluating the performance level of alternatives for achieving some stated objective, or group of objectives, with respect to costs.

The concept of cost-effectiveness, as applied to transportation projects, was fostered by UMTA and has been applied to the decision-making process for all major transit system investments since the mid 1970s. UMTA was searching for an alternative to single-valued indices such as benefit/cost ratios and internal rates-of-return to evaluate project performance. Single-valued techniques require the conversion of all project costs, benefits, and disbenefits to their dollar values. Numerous assumptions are required regarding the dollar value of travel time saved, the dollar value of accidents foregone, and so on. These assumptions, and the often complex calculations involved in applying them, tend to mask the performance and impact differences among alternatives.

Cost-effectiveness provides the opportunity to examine a project from many different perspectives. The effectiveness of a transportation system improvement can be measured in terms of the number of trips it serves, the different travel markets accommodated, or its economic impacts. Using cost in the numerator of the cost-effectiveness measure scales the performance by the project's cost.

Cost-effectiveness has its roots in economics. Like many economic analysis techniques (e.g., equivalent uniform annual cost, rate-of-return, benefit/cost ratio), initial costs for construction, vehicle procurement, and rights-of-way (i.e., the capital costs) are annualized and added to annual operating and maintenance costs, or the actual costs by year are converted to their present worth. In some applications, benefits that accrue to transit system users are converted to dollar values and subtracted from the costs. The costs are then divided by a measure of effectiveness.

One difficulty in applying this concept to the Omni and Brickell legs of the Metromover system was the absence of a frame of reference to guide in determining if the cost-effectiveness values computed indicated good, average, or poor performance. This project had been restricted by the federal legislation mandating the study of the build and the no-build alternatives. There was, therefore, no separate Transportation System Management (TSM) or other build options to use for comparison. (The no-build alternative and the TSM alternative were considered to be the same for the purpose of this study.) Without some frame of reference, the cost-effectiveness indices would be of little value in the decision-making process.

UMTA has adopted a cost-effectiveness index used throughout the country to determine whether a project is eligible for funding. The measure of effectiveness is the change in regional (linked) transit trips. (A trip from primary origin to primary destination is a single-linked trip, regardless of the number of separate conveyances used.) The index can be calculated to represent the total project cost-effectiveness (the total index), the cost-effectiveness with respect to the local share of the project cost (the local index), or the cost-effectiveness with respect to the federal share (the federal index) of the project cost. Using the UMTA index would allow comparisons of the results of the "cost per additional transit rider" for the Omni and Brickell legs against other projects and against UMTA criteria.

The single-valued cost-effectiveness index described above has the same flaws as a benefit/cost ratio, an internal rate of return, or a uniform annual cost. There are assumptions regarding the benefits of the project to transit users (computed as travel time savings), and the difference in operating and maintenance costs are added to annual costs regardless of who pays. The application of the guidelines for computing the index (*2*) does not differentiate between the functions and impacts of C/D systems and regional transit systems improvements. Despite these difficulties, it was decided to apply the concept to the analysis of the Omni and Brickell legs of Metromover. Revisions in the methods of calculating costs, benefits, and the measures of effectiveness adopted for this analysis are presented.

DEFINITION OF THE COST-EFFECTIVENESS INDEX

The incremental annual cost per incremental annual rider, that is, the total index used by UMTA, is further described as follows:

$$\text{Index} = \frac{\Delta\$\text{CAP} + \Delta\$\text{O\&M} + \Delta\$\text{TT}}{\Delta\text{RIDERS}}$$

where

- Δ = change between the alternative being considered and the base case,
- \$CAP = total capital cost annualized over the life of the project,
- \$O&M = total annual operating and maintenance cost,
- \$TT = annual value of travel time by existing transit users, and
- RIDERS = annual transit ridership measured in "linked" trips, that is, not counting transfers among transit modes.

The index is often referred to as the cost per additional transit rider.

The federal index is computed by substituting the federal capital cost contribution in place of \$CAP. Note that the federal cost-effectiveness index includes all the annual O&M costs, regardless of who pays. Because they are paid largely by revenues and local subsidies, it would appear that they should not be included in the federal index. The local index is computed also by substituting the local capital cost contribution in place of \$CAP.

COST CALCULATIONS

The capital cost used in the numerator of the UMTA index is the total base-year capital cost, annualized assuming a 10 percent net discount rate, representing the time value of money. The life of the project is assumed to be 100 years for rights-of-way, 30 years for guideway facilities, 25 years for rail vehicles, and 12 years for buses. Operating and maintenance costs are computed for a transit operating plan developed for the project horizon year (usually 15 to 20 years into the future) and stated in base-year dollars. This technique essentially implies that the horizon year represents the operating characteristics throughout the project's life.

Farebox revenues are not considered in the UMTA index despite the fact that they are used to offset, and perhaps cover, increases in operating and maintenance costs. C/D systems are generally considered to be more efficient in terms of their ability to cover operating and maintenance costs from farebox revenues than more traditional regional transit systems because they require fewer operating personnel. This characteristic is lost in the UMTA index, which does not include the revenue generated by the system as an offset to operating costs.

BENEFIT CALCULATIONS

The UMTA index includes a measure of user benefits subtracted from the costs. Benefits are computed for the travel time savings that accrue to base system transit users with improved services. The procedure assumes that transit users are making the same trip, that is, the same origin and destination, with or without the C/D system. The value of time is specified to be $4 per hour for work trips and $2 per hour for nonwork trips in 1984 dollars.

The benefit calculations for base system transit users with a C/D system do not account for the redistribution of trips that occurs with improved service. People take longer trips that may increase their travel time. Despite the increased travel time, this must represent a benefit to users or they would not choose a longer trip. Failure of the UMTA index to consider this benefit is a significant deficiency in the use of the index to evaluate C/D systems.

One way to measure the value of longer trips to the user is to assume that the additional time spent traveling times the dollar value of time is a measure of the benefit. This procedure appears to be consistent with assigning a value to the travel time saved when a person makes the same trip as before, and it is compatible with information available from the travel demand and simulation models. Total travel time savings would consist of the time people would save if they were making the same trip with the C/D system as with the base system. The additional travel time they incur to make a longer trip with the C/D system represents the benefit of the longer trip. The travel time saving would be added to the additional travel time incurred to make a longer trip and then multiplied by the appropriate value of time ($4 per hour for work trips, $2 per hour for nonwork trips) for that trip purpose to estimate the value of the travel benefits.

MEASURES OF EFFECTIVENESS

The primary transportation function of a C/D system is to increase mobility within the downtown area, thus increasing accessibility and encouraging increases in the level of economic activity and the density of development. The measure of effectiveness, therefore, should be the number of new transit trips made within the downtown, regardless of the mode of arrival. The UMTA index uses the change in regional transit trips (linked trips) as the measure of effectiveness. Although this is an important consideration in evaluating a C/D system, it does not capture the contribution of the C/D system to downtown mobility.

CALCULATIONS OF THE INDEX

Estimates of ridership, travel time, and capital and operating costs documented in the draft EIS for the Omni and Brickell legs of the Metromover system (*1*) have been used in calculating the cost-effectiveness indices. All costs are in 1986 dollars.

- The annualized capital cost difference (Δ$CAP) between the build and no-build alternatives was estimated at $20 million (Table 1).
- The difference in annual operating and maintenance costs (Δ$O&M) between the build and no-build alternatives is $2.5 million ($149.0 − $146.5 million) (Table 2).
- The difference in net operating and maintenance cost (Δ$O&M minus the difference in operating revenue) is $1.8 million.

TABLE 1 ANNUALIZED CAPITAL COST (SAVINGS) SUMMARY (1986 COSTS TIMES THE CAPITAL RECOVERY FACTOR FOR THE APPROPRIATE LIFETIME OF THE COMPONENTS AT A 10 PERCENT DISCOUNT RATE)

	NO-BUILD	BUILD
METROMOVER	0	20.3
METRORAIL	0	0
METROBUS	0.3[a]	0

[a]16 more buses are required to operate the No-Build Alternative. Buses bought by MDTA in 1986 cost $145,000 each.

TABLE 2 OPERATING AND MAINTENANCE COST (SAVINGS) SUMMARY (ALL COSTS IN 1986 DOLLARS × $1 MILLION)

	NO-BUILD	BUILD
METROMOVER	4.03	8.26
METRORAIL	52.72	52.72
METROBUS[a]	89.73	88.00
TOTAL	146.48	148.96

[a]SOURCE: "Methodology for Calculating Operating and Maintenance Costs and Revenues for the MDTA Regional Transit System in the Year 2000," Feb. 27, 1987. Gannett Fleming.

The Metromover's transportation function is both to distribute trips arriving and leaving the CBD, and to circulate trips within the CBD.

- It is estimated that 23,602 daily Metrorail users will save an average of 2.79 min per trip, and Metrobus users will lose an average of 0.61 min per trip. This translates to 43,389 min saved per day, or 217,000 hr per year (Table 3).
- Assuming that two-thirds of the trips are work trips and one-third are nonwork trips, and the value of time in 1986 dollars is $4.41 per hour and $2.21 per hour for work and nonwork trips, respectively, the travel time savings (Δ$TT) is estimated to be $0.80 million for these users.

Other transit users who will benefit from the proposed build alternative improvements are internal travelers. This includes only person trips within the downtown made by Metrorail, Metromover, Metrobus, and walking.

- There will be 369,995 daily internal workplace-based trips and 154,075 daily non-workplace-based trips made within the expanded CBD with the no-build alternative in the year 2000 (Table 4).
- If the Omni and Brickell legs were built, the average travel time savings would be 0.46 min for the workplace-based trips and 0.41 min for non-workplace-based trips. Using $4.41 per hour for workplace-based trips and $2.21 per hour for non-workplace-based trips, the value of time saved is $4.45 million per year.
- The average trip length for Metromover trips for the no-build alternative is 0.61 mi and that for the build alternative is 1.16 mi. For the 15,700 Metromover users on the no-build alternative, the additional 0.55 mi at 11 mph average speed represents a travel time of 47,100 min per day or 235,500 hr per year. (It is recognized that this is an approximation of the additional travel time incurred; however, it was the best approximation available at the time the analysis was conducted. Reconstruction of the travel demand and network simulation model output would have been necessary to provide better estimates.)
- Assuming that two-thirds of the trips are work trips and one-third are nonwork trips, and the value of time is $4.41 and $2.21 for work and nonwork trips, respectively, the difference in travel time savings (Δ$TT) is estimated to be $0.87 million per year for this market segment.

TABLE 3 EXTERNAL/INTERNAL DAILY TRANSIT TRIPS AND AVERAGE TRAVEL TIME SAVINGS (LOSSES) IN MINUTES PER TRIP

	NUMBER OF TRIPS	SAVINGS (LOSSES)
METRORAIL USER	23,602	2.79
METROBUS USER	36,820	(0.61)

TABLE 4 INTERNAL DAILY TRANSIT TRIPS[a] AND AVERAGE TRAVEL TIME SAVINGS (LOSSES) IN MINUTES PER TRIP

	NUMBER OF TRIPS	SAVINGS (LOSSES)
WORKPLACE BASED	369,995	0.46
NONWORKPLACE BASED	154,075	0.41

[a] Walk trips are included.

The difference in the number of transit trips (riders) within the downtown is 8,681 per day (Table 5). Using a multiplier of 300 average days per year, the annual difference in transit riders is 2.6 million. If, however, the difference in the number of linked trips is used, the number of new transit users is 5,197 per day or 1.6 million per year. Applying these costs, benefits, and measures of effectiveness yields the results presented in Table 6.

CONCLUSIONS

Table 6 shows the results of adopting different assumptions to the calculation of cost-effectiveness for the Omni and Brickell legs of the Miami Metromover system. It is obvious that the assumption regarding the appropriate method for measuring

TABLE 5 DAILY TRANSIT TRIP SUMMARY (YEAR 2000)

		NO-BUILD	BUILD	DIFFERENCE
EXTERNAL/ INTERNAL MARKET	PARKING LOTS	593	1,167	574
	METRORAIL	10,001	15,349	5,348
	METROBUS	36,820	36,419	-401
INTERNAL MARKET	WORKPLACE	6,105	7,939	1,834
	NONWORKPLACE	2,408	3,734	1,326
TOTAL		55,927	64,608	8,681

TABLE 6 IMPACT OF DIFFERENT ASSUMPTIONS ON THE COST-EFFECTIVENESS RESULTS FOR THE OMNI AND BRICKELL LEGS OF METROMOVER (DOLLARS PER ADDITIONAL TRANSIT RIDER)

	TOTAL INDEX	FEDERAL INDEX	LOCAL INDEX
UMTA GUIDELINES	$10.78	$7.66	$1.40
USING THE INCREASE IN DOWNTOWN TRANSIT TRIPS	$ 8.63	$4.71	$0.86
ADJUSTING FOR LONGER TRIPS	$ 6.30	$4.37	$0.53
ADJUSTING FOR FAREBOX REVENUES	$ 6.03	$4.10	$0.26

effectiveness has the most significant impact on the values of the indices. The impacts of adjustments for the benefits of longer trips and for the consideration of changes in farebox revenues are smaller, but not insignificant.

The method of estimating the value of increased trip lengths is a new concept that deserves further consideration. The procedure adopted here equated the value of increased trip lengths to the value of the increase in travel time spent to make the longer trip. That is, had the person decided to make the same trip after the C/D system was introduced, the trip would have taken less time. The value of that decrease in travel time would have been measured by multiplying the value of time by the time saved. Because the person chose a longer trip, he or she has chosen to incur additional travel time. It seems reasonable that the value of the longer trip is at least equal to the value of the additional travel time he or she chose to incur. Although there may be other methods of estimating the value of longer trips, this method is compatible with the information available from current travel demand and network simulation models and consistent with concepts of applying values to travel time savings.

The results of this analysis indicate that any technique for evaluating alternative investment strategies, be it cost-effectiveness, benefit/cost ratios, internal rates of return, or equivalent annual cost, must be applied with a great deal of judgment and care. These techniques can help decision makers make judicious decisions if they are consistently applied to all options being considered. In the case of the Omni and Brickell legs of Metromover, only one build alternative was being evaluated. It was difficult to make judgments regarding the absolute value of the cost-effectiveness index in the absence of other alternatives. The primary value came from comparing the index with those computed for transit improvements in other cities and with UMTA criteria. These comparisons indicated that the Omni and Brickell legs were reasonable investments based on transportation performance.

Cost-effectiveness indices are not, however, the only relevant considerations. Land use and economic development impacts; infrastructure costs; and the vitality of social, recreational, and cultural activities should also be considered in selecting downtown circulation/distribution system investment strategies for major metropolitan areas. There is a need to refine procedures and techniques for evaluating cost-effectiveness and to develop a more comprehensive structure to provide decision makers with better, more useful information on the consequences of alternative transportation system investment strategies.

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Publication of this paper sponsored by Committee on Transportation and Land Development.

Computer Transportation Models for Land Use Regulation and Master Planning in Montgomery County, Maryland

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The evolution of computer transportation modeling in Montgomery County, Maryland, over the past 15 years, is described in this paper along with the ways in which transportation models have been used for planning and growth management. Transportation models have been used to link land development regulation decisions with the budget process for transportation infrastructure provision under the county's Adequate Public Facility Ordinance, with level of service standards for acceptable traffic congestion levels used to set limits on new subdivision activity in parts of the county. Transportation models have been used to evaluate the long-range balance between current zoning and infrastructure projected under the master plan of highways. Build-out of current zoning with planned infrastructure leads to intolerable traffic congestion. By reducing the ratio between jobs and households, clustering employment, and providing a new light rail system connecting major centers of the emerging polycentric metropolitan region, with infrastructure to make the centers bicycle- and pedestrian-friendly, acceptable levels of traffic congestion could be achieved at much higher levels of urbanization. The development of transportation models to support these planning efforts, including calibration of a peak-hour factor model, a nested logit mode choice model sensitive to the quality of pedestrian access to public transportation, and subarea master planning model systems are discussed in this paper. It describes preliminary work in combining Geographic Information Systems (GIS) technology with conventional regional transportation models. It describes how GIS may be the best tool for dealing with transportation behavior variables where the variance in the data within zones exceeds the variance between zones.

Montgomery County, Maryland, is a large, affluent municipality immediately north of Washington, D.C. Until recently, the county was composed largely of bedroom suburban communities, self-sufficient towns, and fertile agricultural areas. In the past several decades, the county has witnessed rapid growth in both employment and housing as the Washington area has developed a more multinucleated metropolitan form. Montgomery County's economic base is focused on biotechnology, information and communications technologies, and activities of the United States government. The county now encompasses 350,000 jobs and 700,000 people in 270,000 households with growth clustered in several urbanized inner-ring satellite cities and spread across the sprawling I-270 growth corridor. Six out of 10 county residents work in the county, while one-fourth work in the District of Columbia.

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In the past several years, traffic congestion and growth policy have become central political issues in many rapidly urbanizing suburban growth areas of America, such as Montgomery County. As the organization responsible for developing master plans and regulating the subdivision of land in Montgomery County, the Maryland National Capital Park and Planning Commission (M-NCPPC) has played an important role in shaping and staging growth in the area.

Since passage of an Adequate Public Facilities Ordinance (APFO) in the mid-1970s, the county has sought to keep growth from outpacing the provision of infrastructure, such as roads, sewers, and schools. This has sometimes led to a moratorium on subdivision approvals for housing or commercial development in selected planning areas across the county and helped stimulate increased investments in infrastructure to support development.

Computer transportation models have been used for nearly a decade as tools to help assess the maximum levels of household and employment growth desirable within different subareas of the county, given programmed transportation improvements. The county has recently been extending the utility of these computer models to assess master plan development issues, staging of capital improvements, long-range regional planning issues, and other matters. This paper reviews the evolution of computer modeling techniques and applications for land use and transport planning in Montgomery County.

EVOLUTION OF COMPUTER TRANSPORT MODELING SYSTEMS IN MONTGOMERY COUNTY

TRIMS

The M-NCPPC began using computer transportation models in 1977 by borrowing, with consultant assistance, the travel demand models and TRIMS modeling software developed by the Washington Metropolitan Council of Governments (COG). This conventional four-step transportation model, similar to UTPS, was run on a remote time-share IBM mainframe computer. A transportation engineer, with support from a computer programmer, maintained the road network and average daily traffic count data base and the land use inputs used by the model. The primary use of the model was to help evaluate how much new growth should be permitted in the subdivision review process in different policy areas of the county based on new roads programmed in the four- to six-year county and state captal budgets, working on an annual regulatory analysis cycle.

In the early 1980s, a citizens advisory committee evaluated the process used to establish growth policy under the APFO and recommended making a number of improvements in the modeling techniques. New staff was brought in to oversee the operation and enhancement of the model system in 1983.

Growth in the county reached unprecedented rates for a prolonged period following the 1982–1983 recession. In the meantime, road construction schedules slipped from those expressed in the capital budgets that had been used to estimate infrastructure available to support new development approvals. This led to noticeable increases in traffic congestion, public outcry against growth, numerous political initiatives to better manage growth and traffic, and strong pressures on the growth management system, computer data bases, and systems used to assess growth and traffic congestion.

Additional resources were made available for computer modeling and data collection, but with unrealistic expectation that near-immediate results could be forthcoming. Long-term system enhancement efforts took back seat to then current applications of the existing computer transportation model, which were handicapped by an obsolete and increasingly dysfunctional mainframe-based data base management system that handled model inputs and outputs.

EMME/2

In 1985, the M-NCPPC purchased the EMME/2 transportation modeling software to obtain its equilibrium assignment techniques, strong transit modeling capabilities, impressive computer graphics display and interactive graphic network editing capabilities, and a flexible framework for model development and calibration. The availability of this more robust and powerful software led to the abandonment of an in-house effort to transfer the TRIMS software and a newly developed data base management system to an HP-3000 owned by the M-NCPPC.

This change enhanced M-NCPPC's in-house capabilities for data management, transportation model development, and the creation of post-processing evaluation programs using programming tools available within the UNIX operating system. It offered the benefits of operating on a user-controlled microcomputer—an HP-9000—rather than on a remote mainframe. It also provided the context for beginning a gradual adaptation, enhancement, and replacement of COG travel demand models with models more sensitive to the policy analysis needs of Montgomery County planners and decision makers.

Over the years, the M-NCPPC has adapted zone and network systems to a variety of scales for different types of transportation model applications. The first step was in converting the COG 1246-zone traffic model to a county-focused system in which 246 zones represented Montgomery County and only 90 zones represented the rest of the Washington region. In recent years, this has been further focused within the county on smaller areas master planning models to obtain a level of detail more desirable for subarea master planning, assessment of new development proposals, and evaluation of community level strategies for transportation system management. These are all areas of extensive M-NCPPC regulatory and planning activity.

These more detailed subarea models retain the 90-zone coarse detail for the region outside Montgomery County, a moderate level of detail (about 200 to 230 zones) within Montgomery County outside the subarea, and great detail (70 to 200 zones) within the selected subareas of the county. Each subarea model data base is coded to operate with EMME/2 computer transportation modeling software, using the M-NCPPC's evolving set of transportation supply and demand models, coded as EMME/2 macros.

With increasingly sophisticated models and a rapid growth in model applications for short- and long-range planning on a subarea, county, and regional level of analysis, there has been a need to expand both staff and computer resources. Today M-NCPPC's Transportation/Land Use Modeling section employs one-half dozen transportation engineers, several planning technicians and interns, and an HP-9000/835 computer supported by 3000 MB of hard disk capacity, plotters, and graphics terminals. At any one time, 30 or more EMME/2 data bases for different model applications are typically in current use status on the system.

SPANS

In late 1988, the M-NCPPC acquired the SPANS Geographic Information System (GIS) to better estimate model inputs from large disaggregate datasets and better display model inputs and outputs. Eventually, the M-NCPPC hopes to develop new hybrid land-use and transportation-planning models that will combine the powerful disaggregate point and vector data manipulation of GIS technology with the network analysis and multidimensional matrix handling capabilities of conventional zone-based transportation models, such as EMME/2.

CALIBRATION OF AN AM PEAK HOUR TRAFFIC MODEL

The initial area for model enhancement when the EMME/2 software was acquired by the M-NCPPC was to calibrate an AM peak hour traffic model. Previously, a daily traffic model with link-specific composite peak-hour factors had been used for most traffic modeling in the Washington, D.C. region. Having a real peak-hour model, as opposed to a composite AM/PM peak-hour model, meant that directional capacity of roads with reversible lanes and uneven directional capacities could be directly represented. The capacity utilization by direction could be measured for more sensitivity to policy choices related to this. Changes in peaking behavior over time due to both urbanization and congestion could be more readily captured.

Moreover, the result of assignments would be traffic loads closely representative of what people encounter going to work, rather than a more abstract composite of both AM and PM peak congestion. Pure AM or PM peak hour assignments exhibit the true directionality of traffic flows typical of many communities. Daily assignments factored to represent composite peak period conditions with balanced directional flows had masked errors in network coding and trip table characteristics due to their ambiguous nature.

The object of the M-NCPPC modeling was the estimation of peak-hour congestion and the adequacy of traffic conditions given certain assumed land-use and network characteristics. With the daily traffic forecasts of the previous TRIMS system, it had been necessary to convert daily volumes to peak-hour volumes or to convert hourly capacities to daily capacities to estimate relative congestion levels.

The solution to this problem had been to assume that for certain road types, some fixed percentage of the total daily traffic would occur in the peak hour or to assume a fixed link-specific factor for the inefficiency of capacity utilization, recognizing that traffic flows demonstrate major peak demands usually twice a day with very low flows late at night. The data on which to determine these factors were very limited, so default factors had been used, that could not readily reflect gradual changes over time in the peaking characteristics of traffic.

Common sense suggests that two key factors influence the peaking characteristics of traffic: (a) the land use density and mix and associated demographic character of an area; and (b) the amount of peak hour congestion in the transportation system.

Small towns, sprawling bedroom communities, and isolated industrial or office parks typically display higher peak-hour factors—that is, a greater portion of the total daily trips are made in the AM and PM peak hours of traffic—than do heterogeneous, high-density, cosmopolitan urban centers. Homogeneous land use areas, whether office centers or residential communities, where the "sidewalks roll up at 6 o'clock," as the saying goes, attract or generate far more of their daily trips in the peak hours than do places that attract human activity both day and night, regardless of the levels of traffic congestion.

Travel corridors and areas with severe peak hour traffic congestion—the famous freeways of Los Angeles, where "rush hour" starts at 5:30 a.m. and ends at 8 p.m., with a slight dip in mid-morning and mid-afternoon, come to mind—also experience fairly flat distributions of daily travel demand, with low peak-hour factors, because the peak periods become very long. In response to increased peak-hour congestion, people with some flexibility start to alter their travel times to avoid the worst traffic conditions. Obviously, there are social, political, and ultimately theoretical limits to the degree of trip-time flexibility and congestion-induced peak-hour spreading.

Conventional approaches that use fixed factors to account for peaking characteristics of traffic obviously cannot hope to deal with either of these two conditions that lead to a lowering of peak-hour factors over time as areas urbanize and congestion increases. The limits of fixed factors became apparent to M-NCPPC staff trying to evaluate peak-hour congestion trends using average daily traffic count data. With the fixed factors, congestion levels of several times the assumed daily capacity were found on more than a few links in rapidly urbanizing formerly rural areas of Montgomery County.

Upon closer analysis, it became clear that the link peak-hour capacity factors needed to be altered to reflect urbanization and corridor congestion. However, with thousands of links in the model, a systematic and automated approach to establish new factors would be needed. An examination of the available traffic count data base yielded more evidence that change was needed but gaps and inaccuracies in the data provided no easy means for reliable calibration of a new link-based model. Indeed, the COG had recently undertaken its own assessment of new link-based peak factors for another jurisdiction with results that looked not too promising.

With installation of the new M-NCPPC EMME/2 model system, an opportunity arose to develop a new approach. The alternate and more direct way to get at the question of peaking of demand was to take daily trip tables and split them to a peak-hour trip-table for assignment.

A large data base of AM and PM peak period turning-movement traffic counts at intersections by half-hour interval was available for a large portion of Montgomery County from the early 1970s to the present, but this data had not been computerized. A half-dozen interns were put to work for some months to code and clean traffic-count data. Rather than seeking traffic counts for a particular hour of the day, it was decided to calibrate the model to the AM peak hour for each intersection, whenever it occurred.

It would have been desirable to develop a PM peak-hour model, as traffic congestion problems are somewhat more severe in the PM than in the AM. However, the majority of trips on the road at that time of day are non-work trips, for which there was little recent data to calibrate models. Because survey data suggested that home-based work trips constituted nearly 80 percent of trips on the road in the AM peak hour, M-NCPPC staff decided to tackle the easier problem first, relying on the 1980 Census trip-table data to help estimate a refined work trip model. A 1980 COG auto use survey of more than 600 households in the Washington region provided data on the percent of automobile trips by purpose by hour of day to help derive trip-table splitting factors.

Rough initial factors for splitting daily trip tables were estimated from the COG survey data: 19 percent of home-based work trips, 3.2 percent of home-based other trips, 1 percent of home-based shop trips, and 3 percent of non-home-based trips were to be assigned to the AM peak-hour highway network. The input trip tables were the observed work trip table from the 1980 Census and simulated non-work tables based on the COG models.

The results were disappointing at first, with substantial oversimulation of vehicle-miles of travel (VMT) in the core areas of the region and substantial undersimulation of VMT in the fringe suburban and rural areas. Then the experimentation began, first with area-based factors, then with density-based factors that adjusted these initial trip-table splitting factors upward and downward.

After several tests of alternate model forms, a simple density-based model was found that produced very close agreement between simulated and observed VMT for both 1980 and 1984. It adjusted the initial regional trip-table splitting factors from the COG auto use survey upward or downward by up to 20 percent at the origin and destination trip ends, based on household density at the origin end and employment density at the destination end. As expected, the lowest trip-table splitting factors were applicable to high-density, mixed land-use areas and the highest splitting factors to low-density, homogeneous areas. The final model is shown in Figure 1.

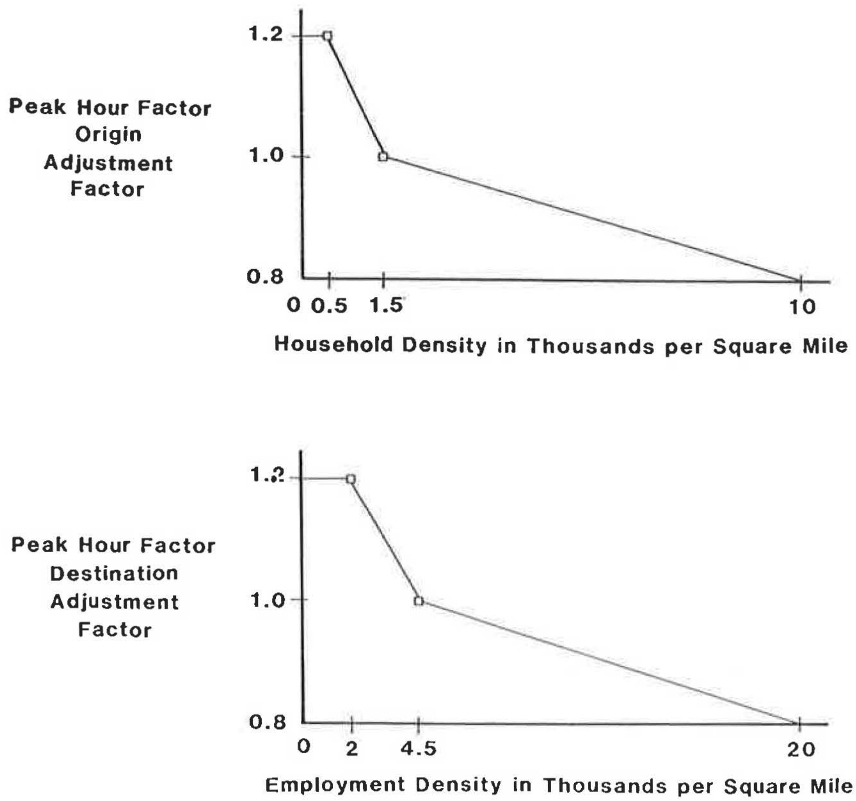

FIGURE 1 AM peak-hour trip-table splitting using density-based adjustment factors to account for effects of sprawl-clustering on peaking of trips.

The resulting AM peak hour model matched within 5 percent VMT and V/C ratio estimates produced from traffic counts for the 20 policy areas of Montgomery County. The model also matched major jurisdiction level VMT quite closely in the Washington region, with network assignments producing a root mean square error (RMSE) of about 26 percent against observed traffic counts (*1*).

Adjustments were made to the model structure to compensate for the relatively large zone size coded in some parts of the Washington region outside of Montgomery County that affected the computed densities. Another refinement was later made to discount home-based work trips in the AM peak hour related to retail employment in those zones with very large amounts of retail employment, in particular the regional shopping malls, where stores typically open at 10 a.m.

This model corroborates the findings of the costs of sprawl studies (*2*) done in the mid-1970s, suggesting that more transportation infrastructure per unit of development is needed when the development is put into low-density areas than if it goes into already built-up areas. It also corresponds to the common sense notion that small-scale, heterogeneous land use, which permits more travel demand to be met by nonmotorized means, similarly requires less transportation infrastructure per unit of development.

This peak-hour trip-table splitting model provides a means of formally accounting for changes in peak-hour factors in response to urbanization over time. Further research with additional data sources is needed to identify the extent to which this empirical model reflects peak spreading due to demographic changes versus the traffic congestion that typically comes with urbanization.

It should be noted that this density-based peak-hour trip-table splitting model does not explicitly account for the impact of congestion on peak spreading. It also has the weakness of introducing distortions in the relative trip distribution of the final peak-hour trip tables.

Because traffic conditions in 1980 in the Washington, D.C. area were not as bad as many other large metropolitan areas, it is presumed that much of the peak spreading simulated by the model is due to urbanization itself. A fruitful research project might be to test elasticities of peak spreading against various cross-classified corridor congestion levels and land use density/heterogeneity conditions in different cities.

Research is being carried out by the M-NCPPC in 1990 with data from a larger and more recent travel survey, with hopes to replace this simple density-based peak-hour factor model with a more refined approach.

CALIBRATION OF A NESTED LOGIT MODE CHOICE MODEL

With the TRIMS model system, the M-NCPPC was forced to use a very crude non-network-based approach to estimate transit mode shares for work trips. Non-work trips were generated as vehicle trips, so no mode share estimation was required to derive vehicle trip tables for highway assignment. When the EMME/2-based AM peak-hour highway model was developed, M-NCPPC staff concurrently developed a data base descriptive of AM peak hour transit services in the Washington, D.C. region and did a quick, crude calibration against 1980 census journey-to-work data of a simple stratified regression work trip transit mode share model with a form borrowed from COG. An extremely simplistic non-network-based cross-classification auto occupancy model used in TRIMS was transferred intact into the EMME/2 framework.

These tools provided temporary support for the growing workload of transportation modeling applications demanded by the M-NCPPC work program, but failed to provide sensitivity to a wide range of alternative public policies that might reduce dependency on the single passenger automobile.

To respond to these policy analysis needs, a new nested logit mode choice model for work trips was calibrated in late 1988 by M-NCPPC with assistance from Comsis Corporation, using 1987–1988 regional travel survey data. The model forecasts the probabilities of using an automobile by auto occupancy class, transit by walking, or automobile access. In addition to the usual model inputs related to travel time and cost by mode, this model is sensitive to transit serviceability factors—the availability of sidewalks and bicycle paths, the degree of heterogeneity of land use at a small scale, building setbacks, and availability of bus stop shelters. These factors have been crudely estimated at the zone level by use of a composite weighted index—the Transit Serviceability Index. For each transportation zone, assess and add the following:

- Sidewalks
  - .00 None
  - .05 Discontinuous and narrow
  - .15 Narrow but along all major streets
  - .25 Adequate width along all major streets
  - .35 Everywhere, augmented with traffic calming or pedestrian streets and shortcuts
  - .45 Full area-wide pedestrian district with restraints on automobile use
- Land use mix
  - .00 Homogeneous within walking distance
  - .10 Some mix of uses within walking distance
  - .20 Moderate density fully mixed use
  - .25 High density fully mixed use
- Building set backs
  - .00 Large (mostly sprawled campus style)
  - .10 Small (mostly abutting street & bus stops)
- Transit stop conditions
  - .00 No bus stop shelters
  - .10 Widely available bus stop shelters
- Bicycle conditions
  - .00 Little or none
  - .05 Some cycle paths and special facilities
  - .10 Network of cycle paths and lanes with good conditions for cyclists to reach centers

Sum total ranges between 0 and 1.0 and comprises the Transit Serviceability Index, or indicator of pedestrian and bicycle friendliness.

This new logit model was developed to better simulate current suburban transit use and improve sensitivity to factors that influence this. Comsis had previously analyzed the performance of a new mode choice model calibrated on 1980 census data for the COG. While the COG model performed well at the regional level and in forecasting transit trips destined to downtown Washington, D.C., it substantially overestimated transit trips to suburban activity centers, even with area-based adjustment factors. For example, the equivalent of 60 minutes of in-vehicle transit time had to be added to trips destined to the North Bethesda area of Montgomery County, an automobile-oriented, high-technology employment center, to match the observed propensity for transit use.

The COG model is typical of mode choice models used in the United States today, being based primarily on in- and out-of-vehicle travel times and travel cost, with some area-to-area adjustment factors. The quality of the transit access and egress system, a very disaggregate fine-grained element of the transportation system, broadly described as transit serviceability, is not a factor of the model. Indeed, the modeler must prespecify the share of access trips for each zone that will walk or drive to transit. M-NCPPC staff believed that inclusion of transit serviceability factors might account for much of the variance in mode choice behavior that remained unexplained by the COG model, especially when comparing automobile-oriented suburban activity centers with more traditional downtowns. Moreover, use of such variables might make it possible for the model to estimate mode of access to transit directly.

Model calibration bore out this hypothesis. Transit serviceability factors at both origin and destination ends of trips statistically proved to be highly explanatory variables, both for propensity to use transit and for means of access to transit (*3*).

In 1990, M-NCPPC staff is importing existing computerized data files on Montgomery County sidewalks, street medians, bus stops, and other factors influencing transit serviceability into SPANS GIS software for more precise quantification of these factors. SPANS or other software will also be used with parcel file, subdivision file, zone and subzone boundary files, and a file showing transit stop locations to calculate, rather than guess at, average weighted walking access distances from zones to transit stops, that can be assigned to walk-centroid connectors used in transit assignments. As data inputs are refined, the logit model will be reestimated using these additional disaggregate variables.

TRANSPORT MODEL STRUCTURE AND COMPUTER TECHNOLOGY

Across the United States, a conventional four-step transportation modeling process (trip generation/trip distribution/mode choice/network assignment) has been used with aggregate zone-based data input for transportation planning since the early 1960s. Montgomery County has been no different.

Zonal aggregation has been the product of practical and cost limits on computer memory and speed that have forced planners to simplify highly complex non-linear disaggregate systems into far simpler and more linear aggregate systems for analysis. With the advances in computer technology over the past decade, however, many of the original reasons for purely aggregate analysis have disappeared. Disaggregate data analysis and modeling is becoming more cost effective as data acquisition, management, analysis, storage, and computing technologies have improved and become less expensive. By making regional transportation models more disaggregate and reflective of the rich spatial variation that exists in living communities, some of the major limitations of classic four-step aggregate zone-based regional transportation models can likely be overcome.

The conventional four-step aggregate zone-based models have demonstrated their utility to simulate traffic flows on major roads in the short term, with some limitations. In general, the finer grained the data one attempts to measure in these systems, the less the reliability in the simulation, which is quite reasonable, given the probabilistic and nonlinear nature of human travel behavior and network flow. The farther out into the future these models forecast, the less likely it is that the actual future system inputs will correspond to the forecast system inputs or that assumed underlying relationships between the factors in the model system will remain stable.

A major limitation of most zone-based regional transportation models is their ignorance of fine-grained spatial variations in the built environment and in urban populations. Hundreds or thousands of households exhibiting and experiencing huge variations in the attributes shaping travel behavior are usually reduced to single zone values representing average characteristics. Often, variance of key attributes within zones exceeds the variance between zones, leading model builders to draw false conclusions from overly aggregated data. For such attributes, GIS technology offers great potential for improving the explanatory power of conventional transportation modeling techniques.

For example, within the confines of a limited number of often large transportation analysis zones, conventional aggregate models usually do a poor job of reflecting true transit access travel times and conditions. Is there a sidewalk people can use to get to a transit stop or are they forced to walk in the street as in so many American suburbs and cities? To get from the bus stop to the workplace door, must the transit passenger walk across a huge parking lot while dodging cars, as in so many campus-style office parks, or is the workplace entrance located near the bus stop with a sidewalk for access, as in a more pedestrian-friendly downtown? For how many households or employees is transit service within 5 minutes, 10 minutes, 15 minutes, or more by foot? Conventional model data structures are usually unsuited to determining even weighted averages of such parameters and if such parameters are used, they depend on the crude guesswork of semi-skilled planning technicians and interns who do much of the laborious network coding.

Fine-grained networks of footpaths, sidewalks, bikeways, alleys, and neighborhood streets are found in virtually all human-scale livable cities of the world and are essential for the transportation, community access, and connectivity functions they perform, but these are usually neglected in conventional aggregate zone-based transportation model systems. Until recently, the costs of collecting, coding, storing, and using such data within regional computer transportation models have been excessive. Roads and bus and rail lines are the sole representative elements of transportation capacity in most conventional zone-based regional transportation models.

The overuse of such transportation models to set priorities for transportation capital investment and operations planning in the United States, despite their inability to simulate short trips, non-motorized trips by foot or bicycle, and access trips to and from public transportation, has led to neglect of these elements of the mobility system. This practice has shaped the design of modern automobile-dominated American suburbs. Aggregate models have been used to justify creation of a built environment that encourages all who can to maintain a fleet of several cars per household to avoid immobility.

There has been an overreliance on area-specific calibration factors in conventional regional transportation models in the United States and in Montgomery County, Maryland, which has relied mostly on models developed by COG for the region. These factors have allowed models to calibrate to observed data without attaining sensitivity to key factors that account for differences in travel behavior, such as the quality of the pedestrian environment or the age and density of the neighborhood.

As communities mature from new neighborhoods to older neighborhoods, they frequently become far more demographically diverse. The degree of diversity shapes key elements of travel behavior, especially in the diurnal distribution of trips. Yet area-based factors in models mask these differences and rule out forecasting possibilities for change in the orientation of mobility systems in newer communities. With such factors, models become almost circular in their logic and make it nearly impossible to simulate the future as anything other than an intensified image of the present.

This is often reinforced by the tendency of conventional models to deal with households and employment in isolation as unitary input quantities. The models do not ask how these jobs and households are mixed at a small scale. Are there apartments over stores in the fashion of Europe, Japan, and America before the automobile age or are all the uses segregated in mid- and late-twentieth century fashion? The models usually do not ask how expensive are the dwellings and how much do the jobs pay? Can all the people who work in the jobs afford to live nearby? At what stage in their life-cycle are the households in each neighborhood? These questions lie at the current frontiers of computer transportation modeling, which must begin to incorporate activity analysis principles and textural variables into model structures to improve model stability and explanatory power over longer time frames.

The M-NCPPC hopes to use GIS technology and improved data acquisition and management systems to begin to get cost-effective quantitative answers to such questions so that computer transportation models can reflect more of the richness of the reality that shapes traveler behavior, mode choice, and community structure. GIS software can manage and manipulate spatially detailed data structures useful for describing trip origin or destination characteristics as thousands of points rather than as hundreds of zones, and may find an important role in trip generation and mode choice modeling. Conventional zone-based transportation models, however, retain their strength in the manipulation of two and three dimensional matrix data, such as trip distribution and trip-table development, and in network assignment and analysis.

Montgomery County planners are just beginning to explore these opportunities. Work is getting underway in 1990 to recalibrate the M-NCPPC travel demand models with the objective of eliminating as much as possible the use of area-specific model coefficients.

USE OF GIS SOFTWARE WITH TRANSPORTATION MODELS

Like a number of other planning agencies in fast-growing areas of the developed world, the M-NCPPC is exploring linkages of GIS to transportation and other modeling. The first M-NCPPC Montgomery County Transportation Division use of GIS software is for acquisition of more refined land use and demographic data at traffic zone and subzone levels from county tax assessor parcel file records, household and employment surveys, and other sources. The GIS should provide better data for transportation model input and calibration and aid the display of zone and network data inputs and outputs related to the model system.

The use of parcel file records to allocate zone level land use data to subzones for input to fine-grained model systems will be tested in early 1990. This application may allow substantial improvement in the productivity of planners producing land use data inputs for these subarea master planning models. Other applications are expected in the near future. The combination of SPANS and EMME/2 may allow greater sensitivity of the models to transit serviceability and other small scale factors in the built environment that affect travel behavior. SPANS may aid refined spatial analysis of travel survey data and, as a GIS data base integrator, it may aid low-cost data acquisition for developing a superregional Baltimore-Washington transportation model focused on Montgomery County, which sits between these two major cities.

Eventually, combining GIS technology with conventional transportation models may make it possible to overcome many problems inherent in aggregate zone-based model structures where the variance in data within zones exceeds the variance between zones. Highly disaggregate analysis of origin and destination characteristics related to trip generation and mode choice can be accomplished in the GIS environment, using point-based data, that can then be summarized or stratified for use in conventional zone-based software, such as EMME/2. Zone-based software has great strengths in manipulation of full matrix and network-related data.

One of the challenges of developing subarea models is to generate input—land use forecast data for small subzones. The M-NCPPC participates in the COG cooperative forecast process and develops forecasts of housing and employment by type for each of the 246 traffic zones used by the M-NCPPC regional model, for each 5-year interval out to the year 2010. These forecasts, while far from perfect, serve as reasonable indicators of possible future development patterns, given current market trends, zoning, and demographics. Until now, however, the only way that land use could be developed for subzones was by tedious hand mapping and calculation by a small team of community planners who would draw upon a number of data sources to "add up" the elements contributing to growth within each subzone.

Now with a GIS, these planners are poised to gain more freedom to think more about what direction they might like to push the zoning and development of the areas they are master planning with less time required for the mechanics of the process. The GIS can add up the elements desired by the planners through simple map overlays and the generation of unique condition reports for each subzone, zone, or geographic entity of interest. The procedure developed enables the direct calculation of subzone level totals from a disaggregate map layer or the allocation of zone-level forecast data to subzones on the basis of weights developed as a function of other map levels, with various boundary and control conditions on the allocation to ensure consistency and common sense. Typical input data include:

- The 255,000-record tax assessor parcel file containing data on all registered land parcels in the county, including acreage, zoning category, land use codes, assessed value of land and buildings, and numerous geographic tags, such as traffic zone number and census tract and block.
- A data attribute file concerning all approved subdivisions in the county, including information on size of approved subdivisions.
- Vector line graph files of parcel boundaries for approved subdivisions that can be polygonized.
- Vector line graph files of zone and subzone boundaries that can be polygonized.
- Attribute files of any type for policy areas, zones, subzones, parcels, or other areas that can be defined as polygons, such as areas within one-half mile radius of transit stations.

Numerous decision rules can be developed and applied within this general methodology. Currently the process requires a number of manual steps by someone skilled at using GIS software and some relatively simple custom software for processing the data base after using the GIS. Development of more automated procedures for accomplishing this methodology is underway.

GROWTH MANAGEMENT APPLICATIONS OF THE MONTGOMERY COUNTY MODEL

Annual Growth Policy

The M-NCPPC AM peak-hour model was first used in late 1987 to evaluate the annual growth policy limits on subdivision approvals. The new model, as one might expect, showed that traffic congestion would be worse in the low-density, sprawled new suburban growth areas than previously thought and somewhat better than previously thought in the higher-density inner-ring suburban centers.

Montgomery County's growth policy controls how many houses and jobs can be approved as new subdivisions of land in about 20 policy areas of the county. Because it takes some years to build these subdivisions, there has been much debate about what programmed road capacity should be considered available to support these subdivision approvals. Currently roads must be 100 percent funded within the next four years to be counted as available for the growth policy analysis.

Staff and M-NCPPC planning board recommendations of growth policy limits and administrative procedures are reviewed, guided, and adopted by the Montgomery County Council. Growth policy limits in Montgomery County are set by evaluating anticipated future traffic congestion levels against level of service standards describing acceptable traffic congestion levels for each policy area. More congestion is deemed acceptable in areas that have greater transit availability and where people thus have greater choice about how they can travel to work (*4*).

The growth policy limits are set through a judgmental evaluation of model outputs, not by any automatic process. Under- and oversimulation, observed differences between AM and PM peak hour conditions, and other technical adjustments must be made to interpret model outputs recognizing the weaknesses of the modeling system. To take back already approved subdivisions is almost impossible. Generally, county planners have made adjustments to job or housing growth limits only in those policy areas where new transportation capacity has come on line in a new budget, although periodic adjustments to account for trip distribution changes and improvements in the measurement and simulation of traffic levels of service are now being considered.

Thus, the result of changes from a daily to AM peak-hour model has only slowly taken effect in growth policy administration, as changes in transportation capacity, policy area boundaries, level of service standards, and other factors make it possible to alter growth limits established within a complex growth policy system.

In the coming months, the staff hopes to use GIS software to analyze proposed new policy area boundary definitions and use the logit model and transit network descriptions to devise improved measures of transit availability related to setting acceptable traffic congestion level of service standards for policy areas.

General Plan Assessment Study

In 1987, the M-NCPPC used the EMME/2 model system for the first time for long-range planning in a sketch planning exercise that evaluated the Montgomery County general plan (5). At the time, the new M-NCPPC logit model had not yet been developed, so default mode shares from some long-range modeling done by the Council of Governments, at times modified judgmentally using various techniques, were used to convert person-work trips to auto driver-work trips.

In an initial scenario, it was assumed that the entire zoning capacity of the county was built out along with the entire master plan of highways and transportation. This initial scenario produced extremely high levels of road congestion everywhere in the county, even with some increase assumed in transit mode share, and led to the conclusion that the county was overzoned for employment relative to housing.

Another scenario was developed in which the number of jobs was reduced by one-half. Without major changes in work trip mode shares, however, it was clear that even this would produce excessive traffic congestion.

This scenario was then modified further by assuming a regional network of light rail lines, amounting to 65 miles (100 km) in Montgomery County alone, that would connect all major activity centers in the polycentric Washington, D.C., region to each other and to the region's 103 mile (163 km) Metro system. It was also assumed that other public policies supportive of walking, bicycling, and public transport would be adopted. This scenario included a circumferential light rail network around the region roughly paralleling the Capital Beltway to help alleviate traffic pressures on that road, measures to slow and calm traffic in major growth centers to improve pedestrian and cyclist conditions, and major investment in sidewalks and bicycle paths.

EMME/2's matrix calculator was used to perform a thoughtful, largely judgmental manipulation of COG forecast mode shares on a zone pair specific basis to reflect these assumptions. This led to a reduction in anticipated county-wide origin automobile driver mode shares for work trips from 78 percent in 1987 to an assumed 50 percent. This "fewer jobs, enhanced transit" scenarios showed promise of achieving traffic congestion levels close to the standards set under the county's Adequate Public Facilities Ordinance.

This analysis was presented to the County Council in early 1988 and influenced a major zoning text amendment that had the effect of reducing employment zoning capacity in the county by roughly one-third in early 1989. The council also provided the M-NCPPC with $250,000 for further work, titled the Comprehensive Growth Policy Study (CGPS) (6).

Comprehensive Growth Policy Study

The CGPS, released in July 1989, looked 30 years into the future at the tough choices the county might face in balancing job and housing growth with attendant demands for transportation and schools, focusing particularly on fiscal and traffic congestion impacts. The study developed and evaluated land use and mobility patterns with appropriate bundles of supporting public policies consistent with each scenario.

Four major land use scenarios were devised with different levels of housing and jobs—FAST but balanced growth, SLOW but balanced growth, JOBS favoring employment growth, and HOUSING favoring housing growth. These were tested against several mobility patterns—AUTO continuing current policies and building out the master plan of highways, VAN adding to this a network of high occupancy vehicle lanes, and RAIL adding to AUTO a light rail network similar to the one described for the General Plan Assessment Study. For the RAIL pattern, most new housing and job growth above current levels of approved development were clustered at higher densities near rail stations. For the VAN pattern, the clustered employment pattern developed for the RAIL pattern was retained but the more sprawled housing of the AUTO pattern based on current zoning was used.

Major advances were made in techniques to develop alternative zone-level land use scenarios, working from the bottom-up to take account of community design principles, from the top-down to take account of knowledge gained through annual growth policy model analyses, and using in-house computer software to all-the-while observe a host of complex decision rules to ensure that the resulting land use allocations respected various boundary conditions at zone and county-wide levels. For the analysis, the county's 246 zones were split to 285 to allow greater detail in the areas with potential to become higher-density, new town centers.

In addition, the RAIL pattern assumed that:

- Major investments would be made to make all major activity centers very pedestrian- and bicycle-friendly, with measures taken to slow and calm automobile traffic in these centers,
- Transit-serviceable site planning would be adopted countywide, moving away from sprawled campus-style office development and homogeneous development,

- Parking charges would be much higher than today in all employment areas and parking supply would be capped in central business districts,
- An ordinance would be passed to require equalization of commuter subsidies, reducing user-perceived public transport fares, and
- Gasoline taxes and registration fees or road pricing would effectively double the cost of automobile operation.

The VAN pattern assumed a more modest package of supportive public policies. Figure 2 shows the mode shares obtained using the M-NCPPC nested logit mode choice model with these assumptions.

This model analysis used somewhat more sophisticated models and more refined input data, but was fundamentally consistent with the earlier sketch-level analysis in its conclusions. Figure 3 shows one of the major summaries of the study, comparing the auto driver-work trip mode share with the average traffic congestion level, countywide.

It is clear that the AUTO pattern—continued dependency on the automobile as the prime element for mobility—does not work from a transportation (or environmental) standpoint, regardless of the land use assumed. The VAN pattern fares considerably better, and reduces the congestion level closer to the countywide standard, but still fails for the FAST quantity of jobs and households. It might work for lower levels that were not tested due to time constraints. The RAIL pattern allows the county to closely approach or meet its traffic congestion standards, depending on the land use balance between housing and jobs.

If all else is held constant in the RAIL FAST scenario, but more housing is clustered in the inner ring and core of the region along the Metro lines, in a scenario variant called RECENTRALIZATION, traffic congestion levels in Montgomery County fall significantly. This scenario would tend to have the lowest per capita energy use, air pollution, and infrastructure costs as well, but is politically problematic for a variety of reasons. However, it points up the benefits of containing sprawl, developing real town centers and more affordable housing near jobs, with housing and jobs clustered near good public transportation in pedestrian- and bicycle-friendly areas, and encouraging reinvestment in housing in and near the central city.

The findings of the CGPS have added to the pressure for significant changes in the direction of master plan development, growth management, and the update of the county

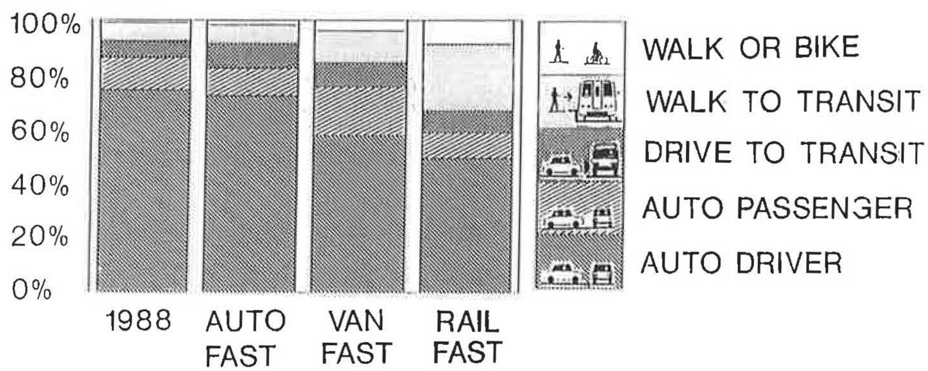

FIGURE 2 Montgomery County origin model share for home to work trips.

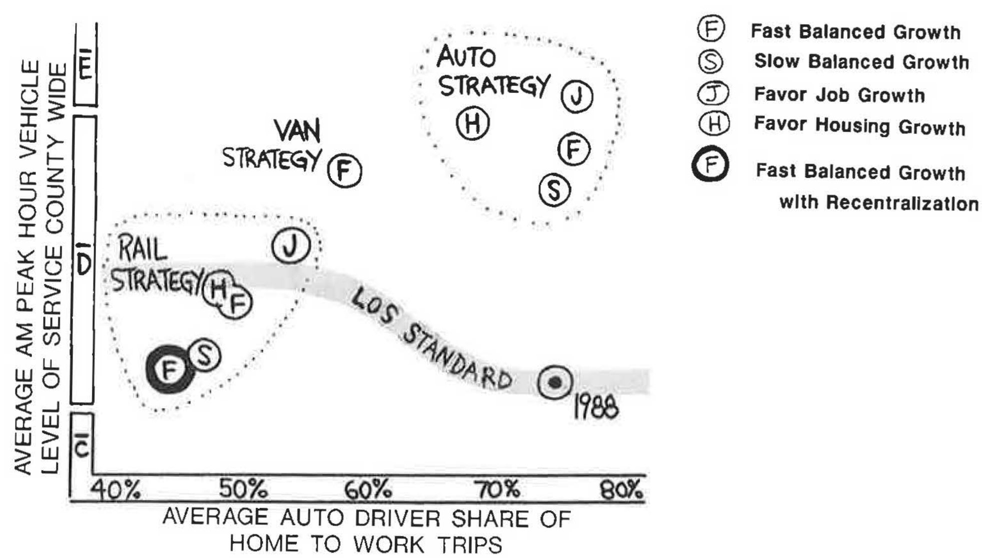

FIGURE 3 Comprehensive growth policy study effects of alternative scenarios.

master plan of transportation. It remains to be seen with what speed these reforms will take root, as they challenge many standard practices and vested interests. However, as the county faces a growing fiscal crisis, increased traffic problems, an affordable housing and labor shortage, and growing environmental problems, the CGPS suggests ways of making growth both economically and environmentally sustainable. The CGPS is expected to form a foundation for much planning in the county in coming décades.

CONCLUSIONS

It has become essential for United States local governments to develop new ways of evaluating transport and land use public policy options and alternatives to the single passenger automobile. These evaluation systems must be capable of testing the impacts of moving towards more clustered mixed-use development patterns and significant mode shifts away from the automobile, if growth is to be made economically and environmentally sustainable. Computer transportation models, GIS, and data management systems are all important tools for such work. Local governments must move quickly to adopt these tools and to train and retain qualified staff to manage them if they hope to manage growth effectively.

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Publication of this paper sponsored by Committee on Transportation and Land Development.

Dual Equilibrium Model of Urban Commercial Activity and Travel

NORBERT OPPENHEIM

A retail activity allocation/shopping trip assignment model is developed, in which the zonal retail price as well as the travel times are in equilibrium. The model is based on two main assumptions. First, in each zone, retailers maximize their profits from retail sales. Second, prospective shoppers in each residential zone select their shopping destination so as to minimize the cost of shopping and the cost of traveling. Use of the model to simulate the behavior of the commercial activity and travel system is illustrated.

In a previous Transportation Research Record paper (*1*), the author developed a model for retail activity allocation and travel that assumed there is only one link/itinerary from a given place of residence to a given place of shopping. This simplification, although assuming the transportation network was congestible, obviated the need to assign the shopping trips to the network. In other words, the model did not allow for predicting the routes that shoppers would follow to their chosen shopping areas.

This may be of obvious interest, not only to transportation planners, but also to retailers. The purpose of this paper is thus to extend the previous formulation to include a full transportation network. Specifically, there will now be several possible routes between any origin/destination pair, so that a complete description of the retail activity and travel system may be possible.

EQUILIBRIUM FORMULATIONS OF ACTIVITY ALLOCATION AND TRAVEL

The starting point is the standard network equilibrium model of urban location and travel (*2*). Specifically, given the numbers of trips O_i made for the purpose of some activity that originates in a given origin zone i, the link congestion functions $g_a(.)$, and a measure of attractiveness R_j for each of the potential locations j for the conduct of the activity, the number of interzonal trips Y_{ij} and the link volumes x_a may be determined as the solution of the standard combined distribution/assignment problem (*3*):

$$\underset{(Y_{ij},\, x_a)}{\text{Min O}} = \sum_a \int_0^{x_a} g_a(x)dx - \sum_j \sum_i R_j Y_{ij} \qquad (1)$$

such that

$$\sum_j Y_{ij} = O_i \qquad j = 1,2, \ldots, n \qquad (2)$$

$$\sum_r F_{ij}^r = Y_{ij} \qquad i,j = 1,2, \ldots, n \qquad (3)$$

$$X_a = \sum_i \sum_j \sum_r F_{ij}^r \delta_{a,r}^{i,j} \qquad i,j = 1,2, \ldots, n \qquad (4)$$

where F_{ij}^r is the flow on route r connecting i and j, and δ_{ar}^{ij} is equal to 1 if link a is part of route r between i and j, and zero otherwise.

From the Y_{ij}'s, the numbers of trip ends, Y_j, which measure the activity level in the zone, may then be determined.

In this formulation, however, the attractiveness of a given zone as a place to conduct the activity—shopping—is assumed given. This may not always be realistic because the attractiveness may be a function of the activity level in the zone. For instance, congestion at the destination zone (e.g., due to limited parking) may be a factor in the choice of destination, in the same manner that congestion on the network's links is assumed to be a factor in the choice of route. In general, from an economic standpoint, the cost, or price of the activity, will depend on the level of activity, in the same manner as the price of a commodity depends on the demand for it.

Thus, the destination attractiveness terms R_j should be endogenous variables, as are the link travel costs. This necessitates the incorporation of two additional relationships in the model above. The first is a "destination cost function" specifying the value of R_j as a function of Y_j to play a role similar to the "link cost function." The second is the statement of an equilibrium principle for activity levels, in addition to the "user equilibrium" principle for link volumes.

This paper presents the development of a retail activity allocation/shopping trip assignment model based on this approach.

FORMULATING THE MODEL

Because the purpose of travel is shopping, and in keeping with the previous version of the model (*1*), we may equate the destination's attractiveness R_j to the unit retail price of a basket of commodities. The demand and supply functions for the activity in each zone must then be specified. The demand function most often used in activity allocation models, and

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which in fact was used in the previous version of the model (*1*), is the logit function

$$Y_{ij} = O_i \frac{\exp(\beta M_{ij})}{\sum_j \exp(\beta M_{ij})} \quad \text{for } i,j = 1,2, \ldots, n \tag{5}$$

The assumption underlying the choice of this function is that residents choose their destination so as to minimize the (perceived) total cost (dis)utility M_{ij} of traveling from i to j and shopping in j.

The supply function will be determined in the standard fashion from maximizing the supplier's (retailer) revenues. The cost C_j of operating shopping facilities is assumed to be a power function of the level of activity (sales)

$$C_j = kY_j^{\omega}; \qquad \text{for} \quad j = 1, 2, \ldots, n \tag{6}$$

k has the dimension of a unit cost per sale. The value of parameter ω translates the magnitude of (dis)economies of scale in store operation. Because the revenues are equal to Y_jR_j, the level of supply Y_j is such that it maximizes the profit

$$p_j = Y_jR_j - kY_j^{\omega}$$

thus:

$$\frac{\partial P_j}{\partial Y_j} = R_j - \omega k Y_j^{\omega-1} = 0 \rightarrow R_j = \omega k Y_j^{\omega-1} \tag{7}$$

[It may be of interest to note that in the previous version of the model, zonal price was equal to

$$R_j = KY_j^{\omega-1}$$

This translated the assumption that in each zone/store, revenues were in balance with operational costs. By rewriting R_j as

$$R_j = (K/\omega)\omega Y_j^{\omega-1} = k'\omega Y_j^{\omega-1}$$

it may be seen that these two assumptions are equivalent when the cost function is a power function of the activity level.]

In keeping with Equations 1–4, a non-linear program may be developed, the solution to which provides a retail activity allocation and trip assignment model conforming to the principles described in the introduction, as well as to the functional requirements (Equation 5 and Equation 7).

The new program's objective is:

$$\underset{(Y_{ij}, X_a)}{\text{Min O}} = \tau \sum_a \int_0^{X_a} g_a(x)dx + \frac{1}{\beta}\sum_i\sum_j Y_{ij}(\log Y_{ij} - 1) + \sum_j \int_0^{\Sigma_i Y_{ij}} z(x)dx \tag{8}$$

in which the functions $z(.)$ and $g_a(.)$ are respectively defined as

$$Z(x) = k\omega x^{\omega-1} \tag{9a}$$

and

$$g_a(x) = C_a^0 [1 + 0.15(x_a/K_a)^4]$$
$$a = 1, 2, \ldots, A \tag{9b}$$

$g(.)$ is the standard "B.P.R." link cost function, where K_a is the link's "practical capacity" and C_a^0 is the "free flow travel time" (*4*).

The constraints are the same as in the program above, i.e. Equations 2–4, and all variables are again non-negative. The signs of the parameters are $\beta \geq 0$, $\omega > 0$, $k > 0$, and $\tau \geq 0$. The meaning of the parameters β and τ will become apparent during the ensuing derivations.

It may be shown that the solution to program Equations 8, 9, 2–4 has the following characteristics. First, the interzonal flows are equal to

$$Y_{ij} = \frac{O_i\, e^{-\beta(R_j + \tau t_{ij})}}{\sum_j e^{-\beta(R_j + \tau t_{ij})}} \tag{10}$$

Thus, shopping trips originating in zone i are distributed to shopping zones according to a logit function as was required in Equation 5. Its argument is the sum of the minimum travel cost from i to j plus the zonal unit price of goods R_j in the zone. Thus Equation 10 states that shoppers choose their shopping zone so as to minimize the perceived total cost of shopping and traveling. Furthermore, since R_j is given by Equation 7, the assumption that retailers maximize their revenues is represented as well. (The role of parameter β is to set the spatial dispersion of commercial activity across zones. A value of zero implies that cost is not a factor of destination choice, since the resulting distribution of shopping demands from a given origin is uniform. Conversely, an infinite value results in an "all-or-nothing" distribution in which the trip ends are concentrated in a single zone, that with the lowest cost from the given origin.) In addition, the solution to the program above is such that the loadings on the network's links conform to a "user equilibrium," that is, reflect the minimization of travel time by shoppers. (Trip volumes for purposes other than shopping are included, but must be given externally to the model.)

Finally, it may also be shown (*5*) that such a solution to the problem above will always exist and always be unique for all values of the parameters.

SIMULATING THE RETAIL ACTIVITY AND TRAVEL SYSTEM

To illustrate its uses for policy analysis and decision-making purposes, the model developed above was applied to the simulation of a hypothetical urban retail activity and travel system, under various circumstances. A prototype configuration of nine zones and 25 links was used, as represented in Figure 1.

Zone numbers are represented in Figure 1 in shadowed script, and link numbers in italics, including intra-zonal links. Bold numbers represent the link capacities, while plain numbers represent the "free flow" travel times C_0. Each (repre-

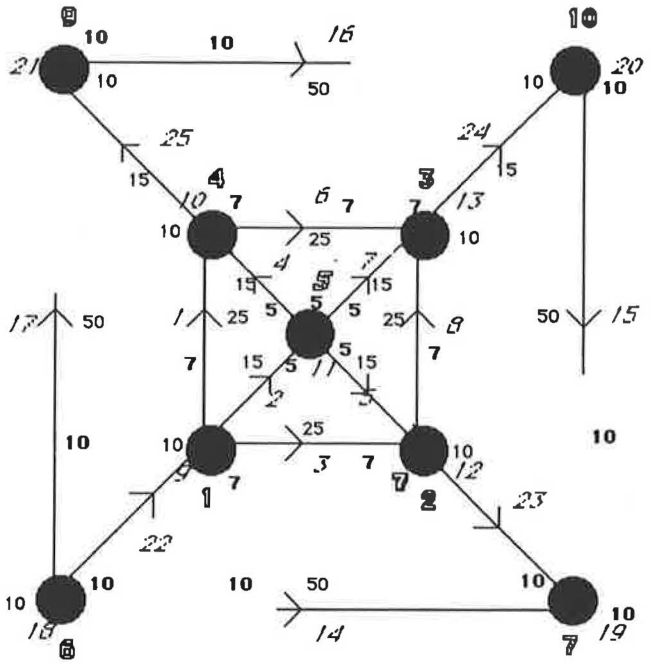

FIGURE 1 Simple hypothetical spatial system.

sented) directional link has an unrepresented counterpart in the opposite direction, with the same characteristics. Its number is equal to the link's number plus 25. The number of paths between two given zones is either one or three, depending on whether there is a direct, one-link connection or not. The total number of routes between all zones is 112. Also, the residential population levels were assumed to be highest in the central zone with the intermediate ring zones each at 60 percent of the central level, and the outer ring zones each at 20 percent.

The solution of program (Equations 8, 9, 2–4) provides the values of the interzonal flows Y_{ij}, the link flows x_a, the path flows F^r_{ij}, the zonal commodity prices R_j, the zonal levels of shopping activity Y_j, and the minimum cost routes from a given residential zone i to a given shopping zone j

In order to illustrate the model's application to the assessment of the sensitivity of the retail activity and travel system to changes in the prevailing conditions, the value of parameter τ, measuring the importance of travel time relative to that of the unit retail price, was varied, as represented as follows:

1. Travel time's importance is equal to that of the retail price ($t = 1$).
2. Travel time's importance is five times higher than that of the retail price ($t = 5$).

Parameter ω was set at 0.8, representing medium economies of scale. The value of β was set at 0.2, resulting in a ratio between lowest and highest activity levels of about 7. (The commodity prices and travel costs were between 1 and 10.) The value of k was set at 0.1, resulting in comparable magnitudes for the average (i.e., typical) unit retail price and the average interzonal travel time.

The results, represented in Figures 2–4, illustrate the complex interactions between the various system variables.

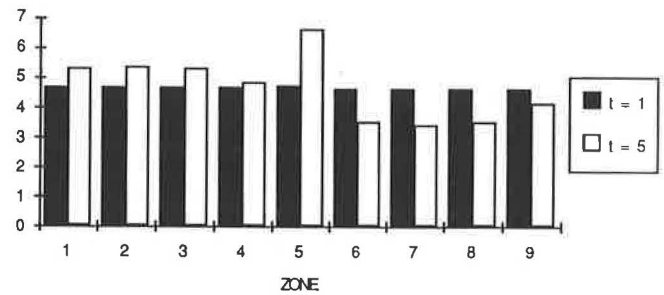

FIGURE 2 Shopping trip ends.

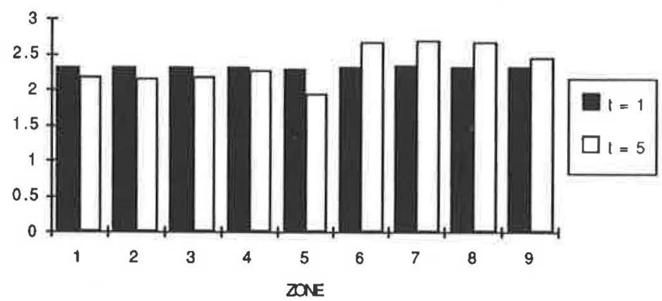

FIGURE 3 Retail prices.

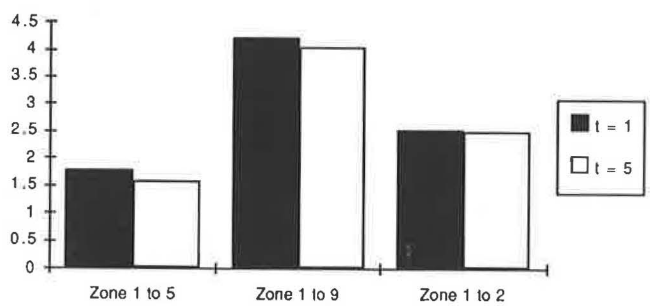

FIGURE 4 Interzonal travel time.

For instance, it may be seen that when the importance of travel time is equal to that of the unit cost of goods, the distribution of shopping trip ends (e.g., retail activity levels) is nearly uniform. (This does not imply that travel cost has no influence on the choice of shopping area, as the distribution of population is not uniform.) However, when travel time becomes much more (i.e., five times) important than shopping costs (corresponding, for example, to a change in shopping for high cost items to low cost items), the outlying zones (Numbers 6–9), those the farthest away from the center of gravity of the residential distribution, experience a decrease of about 30 percent in their level of retail activity. On the other hand, the level of activity in the central zone, Number 5, goes up by about 40 percent, while the middle ring zones (Numbers 1–4) see theirs increase by about 15 percent.

Concurrently, the effects on the levels of zonal retail prices reflect the inverse relationship between activity and prices. That is, as may be seen in Figure 3, prices in the outlying zones go up by about 15 percent, while the price in the central zone goes down by about 15 percent, and about 10 percent in the middle ring zones.

Finally, Figure 4 illustrates the effects of the change above on the travel time from Zone 1 to Zones 5, 9, and 2, respectively. It may be seen that the changes observed above on the zonal distributions of retail activity (trip ends) and the corresponding zonal distribution of unit retail prices (zonal destination attractivity) are translated into changes on the link travel times through network equilibrium loading and consequently on the interzonal travel times.

This brief application of the model assessing the impacts of changes in the prevailing conditions on the state of the retail activity system, is but an example of the large variety of other scenarios that may be similarly analysed through changes in the various parameters of the model.

SUMMARY AND FUTURE EXTENSIONS

The model of retail activity and travel presented above possesses the following features. First, retailers set the levels of sales of retail goods in each zone such that they maximize their profits. The resulting levels of zonal retail activity supply are in equilibrium with the zonal demand for shopping. This is the first equilibrium. Second, shoppers in each zone of residence choose a shopping zone, together with an itinerary to it, such that they minimize their traveling and shopping costs. The resulting congestion-related link travel costs are such that they correspond to the travel costs that give rise to the choices of shopping zone as demonstrated above.

From a practical standpoint, the model's inputs are relatively few. They include the spending budgets in each of the residential zones, the capacities and free-flow travel times of each of the links, and the cost functions for each of the retail facilities. The model's output includes the interzonal shopping flows, the volumes of shopping trips on each of the links and each of the routes on the network, the zonal retail prices R_j, the zonal levels of retail sales, and the minimum cost routes from a given residential zone i to a given shopping zone j. Many derived zonal measures of system performance may be evaluated from these variables, including the revenues to retailers, and spending by residents.

The model, however, does not represent the interactions between a retailer and his suppliers. This is important because such interactions have implications for land use, specifically, the allocation of wholesale activity. They also have implications for transportation, specifically, the assignment of goods movements/truck trips to the same network. The fact that wholesale activity will now compete with retail activity for the use of land, and delivery trucks will compete with shoppers' cars for the use of the transportation network will change the configuration of the activity and travel system. An extension of the present model describing such interactions is being developed and will be presented in the future.

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Publication of this paper sponsored by Committee on Transportation and Land Development.

Evaluation of RAMS-DO1 as a Tool for Project Programming

EMMANUEL G. FERNANDO, JOHN FOWLER, AND TOM SCULLION

The RAMS series of programs was developed to help the Texas State Department of Highways and Public Transportation with its Pavement Management System activities. The evaluation of the RAMS District Optimization Program in selecting projects to maximize network benefit is described in this paper. The trial involved using the system to analyze decisions made by a specific Texas District in 1985 to allocate its maintenance and rehabilitation funds. Decisions made by the district staff were compared with those recommended by the optimization scheme. The RAMS-DO1 program, the study indicated, has great potential to help the districts allocate their resources. However, only limited agreement was found between projects recommended by RAMS and those selected by the district staff. This was due to the following two reasons. First the district's needs greatly exceeded available funds. The overall district need for M&R work was estimated at $35 million, but the district's allocation was only $12.6 million. Therefore, the district had many miles of pavement in substandard condition and only 36 percent of the funds necessary to address that need. The second reason was that the district concentrated its M&R selections on the higher volume roads, whereas RAMS selected both high- and low-volume projects. This selection was based on its objective function which calculates benefit caused by improving pavement condition independent of the traffic served. This indicated the need to expand the RAMS objective function and a traffic factor was introduced in later runs.

In the early 1980s, the Texas State Department of Highways and Public Transportation (SDHPT) implemented its network-level Pavement Evaluation System (PES). Initially, only a small portion of the state's road segments were inspected. Since then, the sample size has increased considerably and in recent years, every mile of Interstate pavement has been inspected annually.

In general, the main user of PES data has been the Austin office to track network condition and estimate overall funding requirements. However, in an attempt to develop and implement applications at the district level, a project was initiated that had, as one of its objectives, the development of a user-friendly microcomputer package to assist districts with their maintenance and rehabilitation (M&R) operations. This microcomputer package is called MICRO-PES (Release 1.0). MICRO-PES currently contains four application programs:

1. A program to extract a user-selected set of road segments from the master PES data base called the create a subset file program (the file created by this program is used in the other three programs);
2. A program that uses a series of decision trees to help determine first-cut estimates of network M&R needs;
3. A program that selects the optimum set of M&R strategies for a given budget level; and
4. A program that estimates the amount and cost of routine maintenance required on any particular set of road segments.

More information on the MICRO-PES system can be found in the *MICRO-PES Release 1.0 User's Manual* (*1*).

To show how the third program mentioned above (RAMS District Optimization Program or RAMS-DO1) can be used to assist the district engineer in determining the "best" use of allocated M&R funds is the subject of this paper. RAMS, an acronym for Rehabilitation and Maintenance System, is a suite of computer programs developed to help the Texas SDHPT with its PES activities. The RAMS package operates at two distinct levels, the district level and the state level. One program for application at the district level is the RAMS District Optimization Program, referred to as RAMS-DO1. This program was developed to help districts select maintenance and rehabilitation activities that would make the best possible use of available resources for a particular fiscal year. Categories of resources considered include materials, equipment, manpower, and budget constraints.

Figure 1 provides an overview of RAMS-DO1. RAMS-DO1 provides a highway engineer with an analytical tool for evaluating the effects of different budget levels and drawing a budget-versus-benefit profile. The effects of changes in unit costs for manpower, equipment, and materials, or of different minimum rating requirements can also be evaluated.

The utility of RAMS-DO1 is illustrated here by performing a case study on decisions made in the Lufkin District (District 11) in 1985 relative to the selection of M&R projects. This particular district and time period were chosen because complete PES data for District 11 was available for 1985 and 1986. The 1986 data were needed to analyze the effect of decisions made in 1985 without the use of RAMS-DO1 and implemented in 1986. District 11 was also a good choice because most of its road segments are flexible pavements. RAMS-DO1 is currently set up to handle only flexible pavements.

Funds allocated to District 11 in 1985 were not sufficient to allow the proper M&R activity to be performed on each deficient road segment. Therefore, the problem for District 11 in 1985 was to find what M&R strategies should be applied to which road segments to make the best use of the allocated funds.

RAMS-DO1 is a 0-1 linear program that selects the "best" set of road segments and strategies based on a given budget

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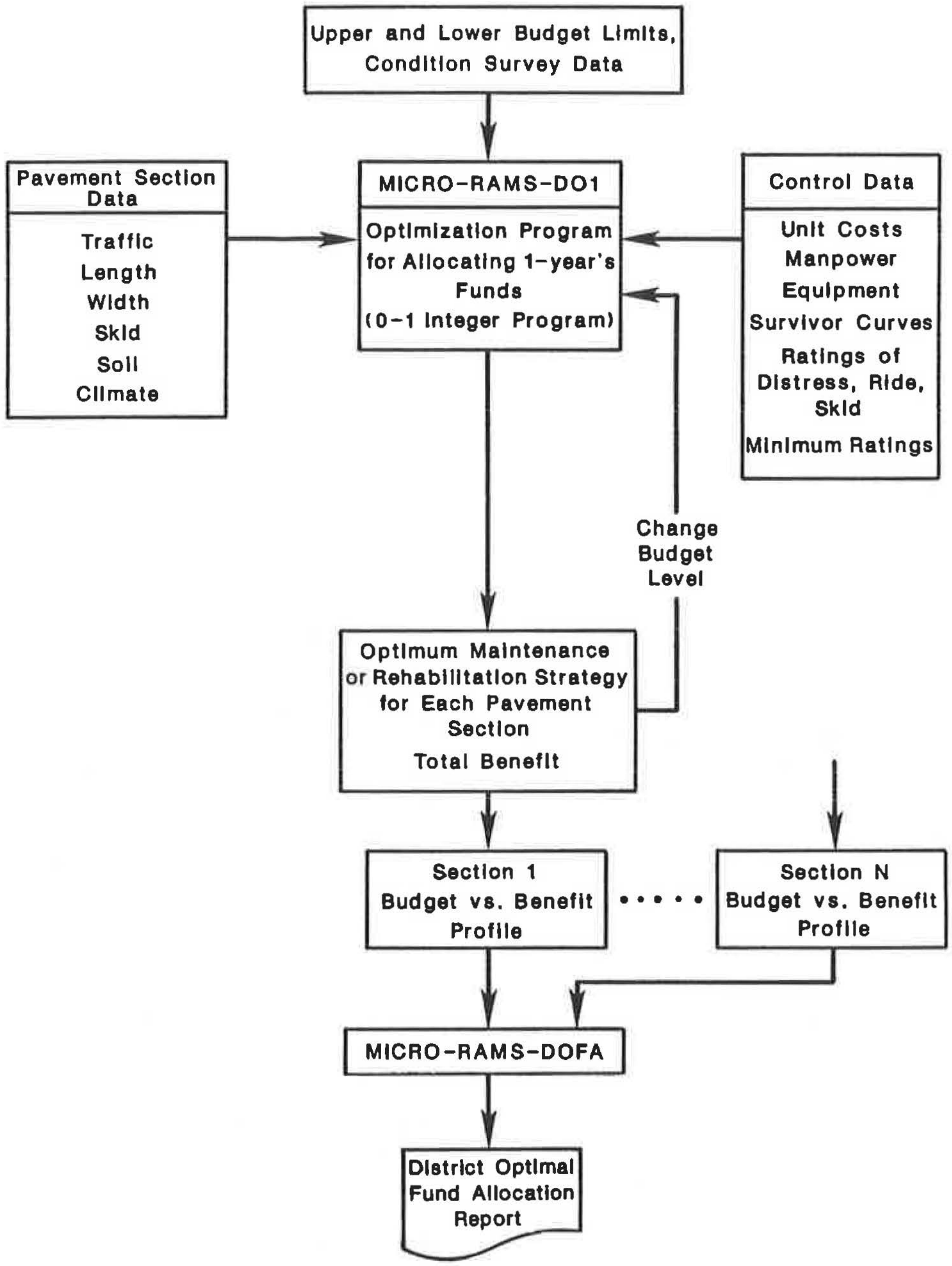

FIGURE 1 Overview of Micro-RAMS-DO1.

level. The best set is the one that maximizes the total "benefit" derived from the application of M&R strategies to road segments. The benefit for a combination of a particular road segment and M&R strategy is a function of the area of the road segment and a weighted measure of how the strategy performs in eliminating existing distresses over the next several years (the number of years is a user-supplied input—usually 10 years). Technical details concerning the program are presented elsewhere (*2–4*) and will not be repeated here. It is emphasized, however, that RAMS-DO1 is only a decision analysis tool. The purpose of the program is simply to assist in the decision-making process. There will always be factors affecting final decisions that are not incorporated into RAMS-DO1. The program, however, will give the district engineer a good idea of the road segments that should be seriously considered for M&R activities.

PRELIMINARY DATA ANALYSIS

This case study was based primarily on information derived from a list of pavement-related projects for fiscal year 1986 for District 11. The first step in analyzing this data was to determine for each project the RAMS-DO1 M&R strategy that most closely resembled the "Type of Work" as specified in the SDHPT projects list. Table 1 lists the M&R strategies currently available in RAMS-DO1.

A few of the project descriptions in the SDHPT list were identical to the names of the RAMS-DO1 strategies (e.g.,

TABLE 1 RAMS-DO1 M&R STRATEGIES

Strategy	Meaning
Fog Seal	As Stated
Seal Coat	As Stated
OGPMS	Open-Graded Plant Mix Seal
Thin Overlay	Less Than 2" Asphalt Concrete Overlay
Moderate Overlay	2"-3" Asphalt Concrete Overlay
Thick Overlay	3"-6" Asphalt Concrete Overlay
Light Duty Reconstruction	Strengthen Base & Surface Treatment
Heavy Duty Reconstruction	Full Reconstruction

seal coat). Most other descriptions differed somewhat from the RAMS-DO1 strategy names. For some of these, it was easy to determine which RAMS-DO1 strategy was most appropriate (e.g., rotomill, seal, and overlay in the SDHPT list was interpreted to be equivalent to a heavy overlay in RAMS-DO1). For others, it was not so easy and required some judgment by the researchers (e.g., resurface in the SDHPT list became a thin overlay in RAMS-DO1). Finally, some SDHPT descriptions differed substantially from any of the RAMS-DO1 strategies (e.g., clear trees and underbrush) and therefore were not included in the study. Of the 64 projects in the SDHPT list, 45 were classified into the eight different RAMS-DO1 M&R strategies and subsequently included in the analysis.

The next step was to determine the average cost per mile-foot for each of the M&R strategies. This was done by dividing the cost for each project of a given strategy by the product of the length (in mi) and the pavement width (in ft) of the road segments in the project and then averaging these values. For all strategies, except for thin overlay, an increase of between 110 percent and 120 percent was calculated over the default cost values recommended in the original RAMS-DO1 package. The increase for thin overlay was higher, but it was believed that some of the projects classified as thin overlay might have been a moderate overlay or base rework and thin overlay. Therefore, to be consistent, the average cost per mile-foot for each strategy, including thin overlays, was set equal to the previous RAMS-DO1 value times 2.15 (i.e., a 115 percent increase). This increase is very close to the overall inflation increase in the years since the original RAMS-DO1 work was developed (1978). Obviously, additional work is needed to get more precise estimates of the unit costs for various strategies. Table 2 shows the unit cost values used in this case study.

The next step was to determine the amount of money used for the projects in each of the nine counties in District 11. These values became the budget levels used in the RAMS-DO1 runs. This was done so that decisions made by RAMS-DO1 could be compared to those made by the district. Table 3 gives the amounts determined for each county. It was nec-

TABLE 2 UNIT COSTS FOR RAMS-DO1 M&R STRATEGIES

Strategy	Cost Per Mile-Foot
Fog Seal	$ 120
Seal Coat	$ 460
OGPMS	$ 2,040
Thin Overlay	$ 1,990
Moderate Overlay	$ 4,300
Thick Overlay	$ 7,630
Light Duty Reconstruction	$ 4,000
Heavy Duty Reconstruction	$ 5,590

TABLE 3 COUNTY EXPENDITURES FOR PROJECTS

County Number	County Name	Expenditures (In Dollars)
3	Angelina	3,191,000
114	Houston	670,000
174	Nacogdoches	406,000
187	Polk	3,810,000
202	Sabine	181,000
203	San Augustine	202,000
204	San Jacinto	204,000
210	Shelby	1,147,000
228	Trinity	2,776,000
Total District Fiscal Year 1986 Allocation		$12,587,000

essary to run the program by county because of the limitation on the number of highway segments that can be accommodated in the microcomputer version of RAMS-DO1. Currently, the number of highway segments that can be analyzed in any given run is 125.

In order to estimate the funds needed by the counties for M&R activities, another program in the MICRO-PES system was run for District 11. It consists of a set of SDHPT decision tables relating pavement type, traffic level, and distress type to the appropriate rehabilitation strategy. Results of that run for flexible pavements are shown in Table 4. Note that the estimated costs in Table 4 are broken down into urban and rural categories. Therefore to determine a county's total requirements, the totals from both categories must be added together. Taking the district as a whole, it is clear that not enough funds were allocated to District 11 to solve all the problems with flexible pavements. In fact, the $12,587,000 is only about 36 percent of the $35,086,764 ($16,933,169 + $18,153,595) needed, as estimated by MICRO-PES.

A result of the inadequate funding for District 11 was a drop in pavement condition between 1985 and 1986. In fact, Table 5 indicates that the average pavement scores for four of the six distress types included in the PES data base were worse in 1986 than in 1985. In the next section, decisions made by the district are compared with decisions provided by RAMS-DO1. The 1986 average pavement condition scores in Table 5 are compared with the values that would have resulted from implementing the RAMS-DO1 decisions. As a final step in preparing to make the RAMS-DO1 runs, it was necessary to create a file of pavement sections to be included in the analysis. Sections with no distress were excluded from the analysis. It was decided to include only those road segments with a pavement score below 80 in this file. A pavement score is an aggregate rating that reflects the overall condition of a pavement section and is a function of the visual distress and roughness. It ranges from 0 to 100, with 100 representing a pavement section in excellent condition.

Only road segments with pavement scores below 80 were analyzed to reduce the size of the county PES files because of the limitation on the number of sections that can be handled by the microcomputer version of RAMS-DO1. A pavement score of 80 was selected as the cutoff score because, in the judgment of the researchers, it is unlikely that road segments with a pavement score of 80 or greater would require any M&R activity.

EVALUATION OF RAMS-DO1

Using the 1985 PES data for District 11, several runs of the RAMS-DO1 program were made to generate, for each county within the district, an alternative list of projects along with the recommended maintenance or rehabilitation treatments. The maintenance and rehabilitation projects selected by the program were subsequently compared to those from the district to evaluate the degree to which RAMS-DO1 matches 1985 district selections. It was found that the results did not agree very well with the district selections. Discrepancies appeared in the projects selected and in the maintenance or rehabilitation treatments to be made.

A plausible explanation for these discrepancies can be obtained when one examines how projects are defined by the districts. In current practice, a project can be an agglomeration of more than one PES segment along a particular route or a subset of a PES segment. Many 1985 District 11 projects, for example, were more than two miles long (the usual PES segment length) and consisted of more than one PES segment. However, the current version of RAMS-DO1 works with the individual highway segments found in the PES data base and provides an optimized list of projects, which are really indi-

TABLE 4 FUNDS NEEDED FOR M&R ACTIVITIES

Summary Of Urban Flexible Pavement Rehabilitation Cost By County (in dollars) - District 11

County	3 in. Overlay	6 in. Overlay	Part. Reconstruct.	Reconstruct.	Total
Angelina	2,201,079.	1,002,376.	331,056.	256,714.	3,791,225.
Houston	579,090.	517,595.	182,952.	0.	1,279,637.
Nacogdoches	880,365.	814,779.	49,833.	197,472.	1,942,449.
Polk	2,673,266.	1,329,897.	284,360.	197,472.	4,484,995.
Sabine	180,966.	0.	69,696.	0.	250,662.
San Augustine	113,271.	0.	0.	0.	113,271.
San Jacinto	536,865.	968,324.	0.	0.	1,505,189.
Shelby	1,306,304.	1,472,917.	0.	0.	2,779,221.
Trinity	147,454.	321,949.	317,117.	0.	786,520.
SUB-TOTAL URBAN	8,618,660.	6,427,837.	1,235,014.	651,658.	16,933,169.
Angelina	1,026,433.	374,351.	988,986.	0.	2,389,770.
Houston	1,546,365.	693,243.	619,598.	0.	2,859,206.
Nacogdoches	654,248.	0.	453,953.	116,160.	1,224,361.
Polk	1,490,039.	684,577.	867,715.	1,403,213.	4,445,544.
Sabine	0.	0.	315,955.	0.	315,955.
San Augustine	86,655.	0.	297,370.	0.	384,025.
San Jacinto	866,554.	363,953.	1,209,923.	598,244.	3,038,654.
Shelby	853,555.	0.	785,242.	0.	1,638,797.
Trinity	996,537.	0.	413,530.	447,216.	1,857,283.
SUB-TOTAL RURAL	7,520,386.	2,116,124.	5,952,272.	2,564,813.	18,153,595.
TOTAL (URBAN AND RURAL)	16,139,046.	8,543,961.	7,187,286.	3,216,471.	35,086,764.

TABLE 5 AVERAGE PAVEMENT CONDITION SCORES BY DISTRESS TYPE

Year	Rutting	Alligator Cracking	Longitudinal Cracking	Transverse Cracking	Failures Per Mile	PSI
1985	11.50	22.97	23.36	18.40	38.29	2.68
1986	11.16	21.99	23.58	18.53	37.21	2.52
MAX*	15.00	25.00	25.00	20.20	40.00	5.00

* The MAX value represents no distress present; therefore decreases in values represent worsening conditions.

TABLE 6 COMPARISONS OF AVERAGE DISTRESS RATINGS FOR PROJECTS SELECTED BY RAMS-DO1 WITH PROJECTS SELECTED BY DISTRICT 11 (PRE-TREATMENT RATINGS)

County	Rutting (0-15)*	Alligator Cracking (0-25)	Longitudinal Cracking (0-25)	Transverse Cracking (0-20)	Failures (0-40)	PSI (0-5)	PES Pavement Score (0-100)
1. Angelina							
a. District 11	8.81	23.10	20.52	14.05	38.06	3.35	62.57
b. RAMS-DO1	11.03	17.97	17.38	13.50	34.69	3.08	43.25
2. Houston							
a. District 11	12.08	22.08	22.25	15.08	40.00	2.94	68.50
b. RAMS-DO1	11.43	18.57	18.29	11.57	40.00	2.77	51.71
3. Nacogdoches							
a. District 11	9.78	21.67	21.33	14.33	37.78	2.59	67.78
b. RAMS-DO1	13.33	21.67	16.67	12.17	36.67	3.15	54.00
4. Polk							
a. District 11	12.40	21.10	20.20	16.30	36.10	3.20	66.45
b. RAMS-DO1	7.75	13.04	17.14	14.75	27.50	2.26	29.54
5. Sabine							
a. District 11	10.27	21.36	25.00	20.00	40.00	2.45	75.91
b. RAMS-DO1	15.00	10.00	25.00	20.00	40.00	2.50	65.00
6. San Augustine							
a. District 11	14.29	25.00	24.00	18.57	40.00	2.94	81.29
b. RAMS-DO1	10.00	15.00	18.00	20.00	40.00	2.20	54.00
7. San Jacinto							
a. District 11	12.14	23.57	25.00	20.00	37.14	2.04	66.86
b. RAMS-DO1	12.00	16.25	13.00	12.25	40.00	3.53	52.25
8. Shelby							
a. District 11	10.00	25.00	22.00	17.57	40.00	3.06	80.43
b. RAMS-DO1	10.30	18.00	18.20	12.60	34.00	2.63	56.40
9. Trinity							
a. District 11	11.25	20.83	22.67	19.42	40.00	2.74	69.42
b. RAMS-DO1	9.64	20.20	20.60	16.44	36.00	2.30	51.16

* Numbers inside parentheses show the range in scores possible for each distress category.

vidual PES segments. These individual segments may not necessarily combine to form the projects selected by a particular county as was the case for this study. Consequently, one of the research needs identified concerns the improvement of RAMS-DO1 to enable the user to specify projects so that the optimization will be made based on a specified pool of projects rather than on two-mile road segments. These projects may be individual PES segments or a combination of such segments.

In addition to evaluating the agreement between the RAMS-DO1 and District 11 lists of projects, a comparison of pavement condition ratings for projects selected by RAMS-DO1, with the ratings for projects selected by the district, was also made. Table 6 provides a comparison of average distress ratings for RAMS-DO1 and 1985 District 11 projects. In most instances, the average distress ratings for projects selected by RAMS-DO1 were lower than those for the district selections. This indicates that the sections selected by the program were, on the average, in a poorer condition than those selected by the district. This is evident in Figure 2 showing the cumulative distributions of pavement scores for each group of projects (i.e., RAMS-DO1 and District 11). From this figure, it is readily apparent that the pavement scores for the RAMS-DO1 group of projects were generally lower than those for the district.

It is of interest to estimate what the average pavement condition scores would have been in 1986 had the RAMS-DO1 selections been implemented. Table 7 compares the 1985 average pavement condition scores with the 1986 averages, after implementation of the District 11 group of projects, and also with estimates of the averages that would have been obtained had the RAMS-DO1 group of projects been implemented. In the latter case, average pavement condition scores were estimated assuming that the distress ratings for projects selected by the district remained at 1985 levels. In addition, for projects selected by RAMS-DO1, the after-treatment scores predicted by the program were used to calculate the average pavement condition scores.

Table 7 indicates that, even if in 1986 the RAMS-DO1 selections had been implemented, the average pavement condition scores for four of the six distress types (i.e., rutting, alligator cracking, failures/mile, and PSI) would have been predicted to decline from the 1985 values. This is evident in Figures 3 to 6 showing cumulative distributions for these distress types. Results shown in the figures are consistent with what occurred in the district in 1986, and indicate that probably not enough money was allocated to District 11 to improve the overall condition of its highways. As presented previously, the district only received about 36 percent of the $35,086,764 it needed for M&R projects. However, Table 7 also indicates that the reductions in average pavement condition scores are predicted to be less had the RAMS-DO1 group of projects been implemented. This may be due to the fact that projects selected by RAMS-DO1 were generally in a poorer condition than those selected by the district. One would consequently expect, that had such projects been repaired, the average pavement condition scores would have been higher than in 1986.

A number of reasons can explain why some roads in poorer condition than those on the 1985 district list of projects were

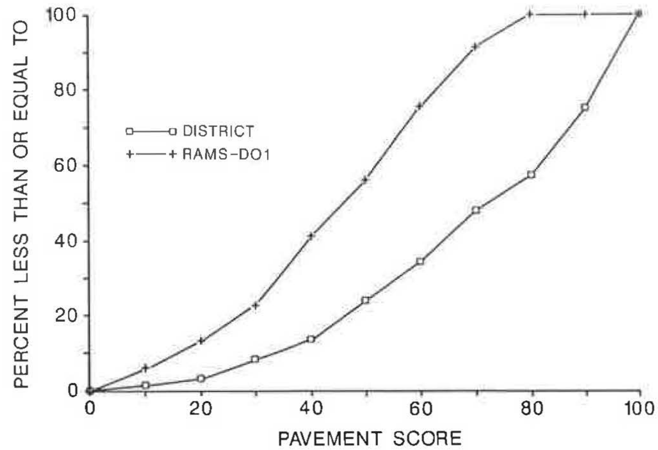

FIGURE 2 Cumulative distributions of pavement scores for District 11 projects and RAMS-DO1 projects (1985 scores).

TABLE 7 COMPARISON OF AVERAGE PAVEMENT CONDITION SCORES

Distress	Average Ratings		
	1985 (Before)	1986 - District 11 (After)	1986 - RAMS-DO1 (Projected)
Rutting	11.50	11.16	11.43
Alligator Cracking	22.97	21.99	22.37
Longitudinal Cracking	23.36	23.58	23.84
Transverse Cracking	18.40	18.53	18.75
Failures/Mile	38.29	37.21	37.69
PSI	2.68	2.52	2.55

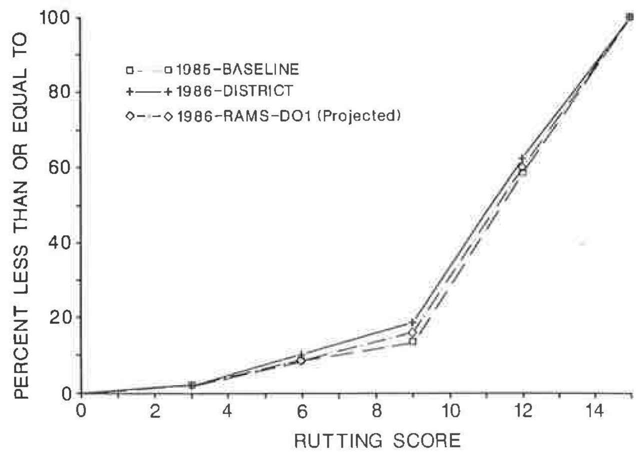

FIGURE 3 Cumulative distributions of rut depth scores.

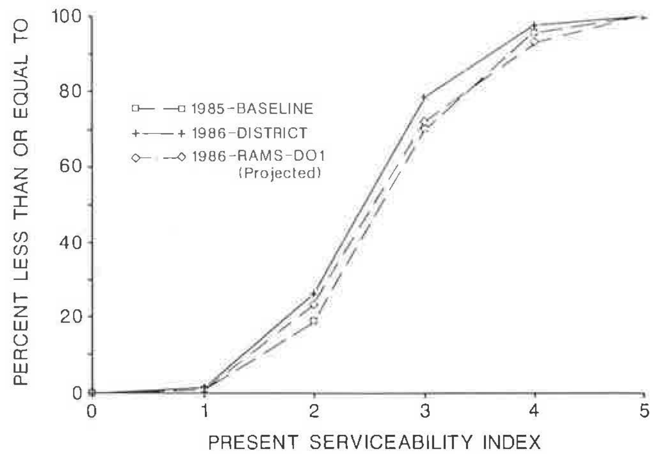

FIGURE 6 Cumulative distributions for Present Serviceability Index.

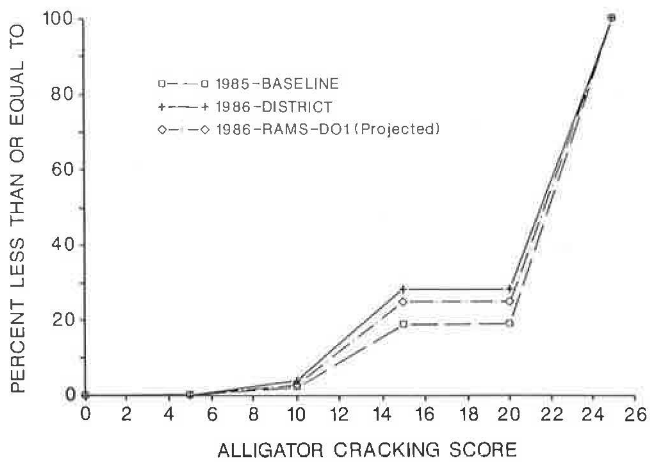

FIGURE 4 Cumulative distributions of ratings for alligator cracking.

not selected. One possible reason is inadvertent omission. This can easily occur when one is faced with the situation of allocating a limited amount of resources among a host of different alternatives. In these situations, of course, a program like RAMS-DO1 can be most useful. By having the capability to consider a significant number of pavement sections in the development of a work schedule for a particular fiscal year, a highway engineer can have a more cost-effective allocation of the limited funds available.

It should be emphasized, however, that RAMS-DO1 is only a decision analysis tool and was never intended to dictate decisions to the highway engineer. Other considerations can play a significant role in the selection of projects that RAMS-DO1 cannot presently account for, including political considerations, project readiness, and the effects of traffic and the environment. In an effort to determine if traffic played an important role in selecting projects within the district, Figures 7 and 8 were prepared to show the distributions of Average Daily Traffic (ADT) and 18-kip equivalent single axle loads (ESALs) for the RAMS-DO1 and District 11 groups of proj-

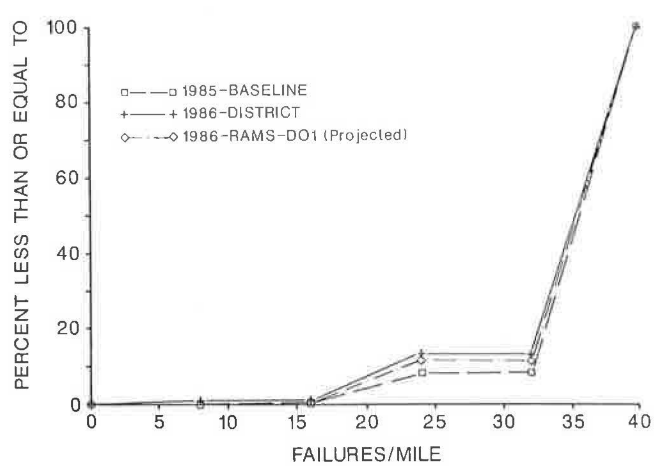

FIGURE 5 Cumulative distributions for failures per mile.

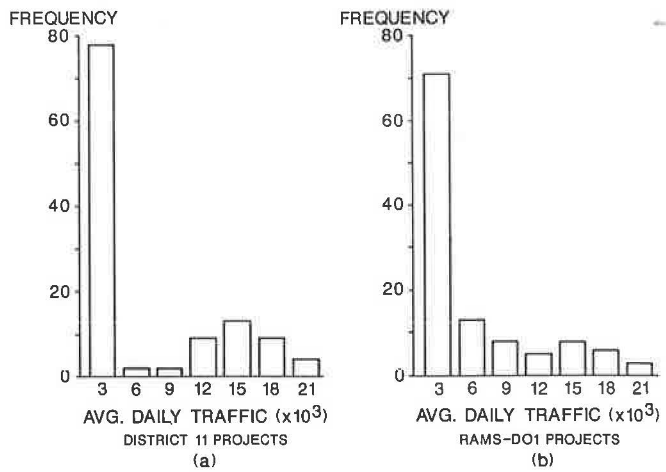

FIGURE 7 Distributions of Average Daily Traffic for: (a) District 11 projects; and (b) RAMS-DO1 projects.

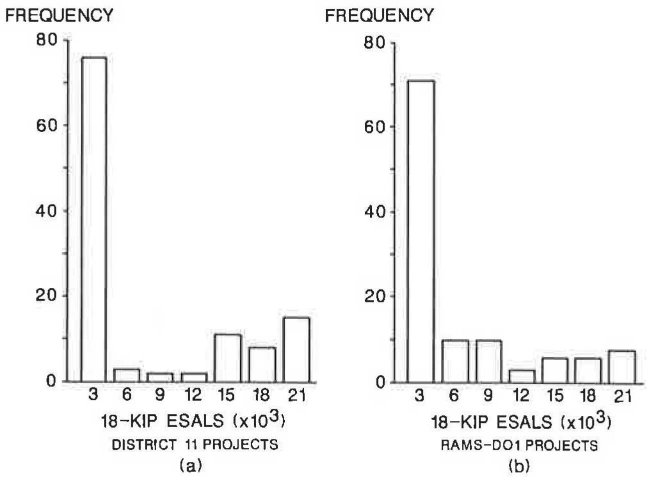

FIGURE 8 Distributions of 18-kip ESALS for: (a) District 11 projects; and (b) RAMS-DO1 projects.

ects. Figures 7 and 8 indicate that the district selections had somewhat higher traffic levels. There are more observations at higher ADTs and 18-kip ESALs for the district selections than for the RAMS-DO1 group of projects. In fact, the means of the ADTs and 18-kip ESALs for the district projects were 6,046 and 6,802 respectively, compared with 3,396 and 3,607 for the RAMS-DO1 selections. This would indicate that traffic was an important factor in the district selection of projects.

The results obtained therefore point to the need for considering traffic in the RAMS-DO1 optimization algorithm. This task would involve generating survivor curves for different traffic levels and developing a scheme for weighting the RAMS-DO1 objective function depending on traffic. Currently, a scheme exists by which a user can specify adjustment factors to account for the influence of traffic level on the survivor curves. Adjustment factors greater than 1.0 can be used to shift the survivor curves to reflect the influence of heavier traffic loadings. However, this feature of the program is not used at the present time. The relationship between level of traffic loading and traffic adjustment factor needs to be further evaluated.

In order to illustrate the effect of this factor on the optimal list of projects generated by RAMS-DO1, a series of runs was made in which a traffic weighting factor equal to log (ADT) was applied to the objective function. This evaluation was conducted using the PES data for Angelina, Polk, and Trinity counties. The results are presented in Table 8. As may be expected, the effect of a traffic weighting factor is to favor the selection of projects with higher traffic levels as reflected in the upward shift of the means for ADT and 18-kip ESALs. In addition, application of a weighting factor can lead to selection of projects with higher condition ratings over projects with lower ratings but with much less traffic. This is evident in the upward shift of the mean pavement scores for Angelina and Polk counties as the objective function is weighted for traffic level. The effect of traffic as illustrated in Table 8 can also help to explain why the district group of projects had higher mean condition ratings than those for the RAMS-DO1 group. Consequently, consideration of traffic in the optimization process is a research item that needs to be addressed in order to more realistically simulate how decisions are made on maintenance and rehabilitation projects.

Another exercise evaluated the effect of budget level on the optimal list of projects generated by RAMS-DO1. One of the useful applications of this program is the development of a budget-versus-benefit profile. This capability for evaluating different budget levels should facilitate budget preparation and help justify funding requests by districts in the state. In order to demonstrate this capability, a series of runs was made in which the optimal list of projects for Angelina, Polk, and Trinity counties was evaluated assuming a budget for each county twice that available in 1985. The benefits of a bigger budget are indicated in Table 9 comparing mean distress ratings predicted under two different budget levels. The mean distress ratings shown represent those that can be obtained immediately after implementation of the RAMS M&R strategy. As may be expected, a higher budget level would enable resident engineers to repair more miles of roadway and thus increase the average condition ratings or further improve overall highway conditions. Table 9 therefore shows the kinds of information that highway engineers can obtain from RAMS-DO1 to justify increased funding requests.

CONCLUSIONS AND DIRECTIONS FOR FURTHER RESEARCH

MICRO-PES is a decision analysis tool with promising potential. RAMS-DO1, an integral part of this package, is not

TABLE 8 COMPARISON OF MEAN TRAFFIC LEVELS AND PAVEMENT SCORES ON PROJECTS SELECTED TO SHOW EFFECT OF APPLYING A TRAFFIC WEIGHTING FACTOR ON THE RAMS-DO1 OBJECTIVE FUNCTION

	No Traffic Weighting Factor Applied			Traffic Weighting Factor Applied		
County	ADT	18-KIP ESALS	Pavement Score	ADT	18-kip ESALS	Pavement Score
Angelina	8147	8904	43.25	9371	10,313	48.05
Polk	5638	6043	29.54	7039	7598	36.65
Trinity	1704	1733	51.16	2217	2143	49.09

TABLE 9 PREDICTED AVERAGE DISTRESS RATINGS AT TWO BUDGET LEVELS AFTER APPLICATION OF RAMS-DO1 MAINTENANCE AND REHABILITATION STRATEGIES

Distress	Angelina		Polk		Trinity	
	At 1985 Budget	At Twice 1985 Budget	At 1985 Budget	At Twice 1985 Budget	At 1985 Budget	At Twice 1985 Budget
Rutting	10.94	11.49	11.29	12.16	11.26	12.24
Alligator Cracking	22.32	23.29	21.51	22.63	22.32	23.48
Longitudinal Cracking	23.31	23.82	23.50	23.80	24.36	24.51
Transverse Cracking	17.88	18.50	18.80	18.96	19.51	19.51
Failures/mile	39.33	39.38	34.09	35.63	36.36	37.98
PSI	2.74	2.79	2.48	2.49	2.32	2.36
Number Of Miles Repaired	63.80	128.50	57.10	105.90	51.90	88.30

meant to replace the decision maker, but rather to assist him or her in determining the "best" combination of M&R activities and road segments.

The program provides three major benefits to the decision maker. First, it can be used early in the decision-making process to identify road segments obviously needing work and suitable candidates for maintenance or rehabilitation. Second, it can be used in the decision-making process to help determine the appropriate M&R treatment for each of the road segments in a group subject to a given funding level. Third, it can help the decision maker prepare a budget-versus-benefit profile for justifying requests for increased funding from the state. All these benefits are likely to save the decision maker time and improve the decisions made.

While RAMS-DO1 is a powerful tool as it is, several areas should be researched in order to improve existing capabilities. Directions for further research include the following:

1. Survivor curves should be developed for the different environmental regions in Texas. Within RAMS-DO1, these survivor curves are used for predicting pavement performance. A survivor curve shows the probability that a given pavement will not require additional maintenance or rehabilitation at a particular time. Survivor curves for various pavement distress types, and maintenance and rehabilitation activities, were determined from the collective judgment and experience of various Texas SDHPT engineers. The curves were subsequently built into the RAMS-DO1 program. It is recognized, however, that the current set of survivor curves may not apply to all districts because of variations in environmental conditions around the state. Consequently, the development of survivor curves for different environmental regions in Texas is appropriate.

2. Results from the case study reported here indicate that traffic was an important factor influencing decisions made by District 11 engineers. Consequently, this factor needs to be considered in the optimization process. It seems logical to give highly travelled road segments more consideration because fixing one of these roads gives more "benefit" to more people in certain circumstances. There are several ways to accomplish this. One possibility is by applying a weighting factor to the RAMS-DO1 objective function as was done in this case study. Another approach is to apply a weighting factor to the survivor curve because pavement performance is influenced by the level of traffic loading. All other conditions being the same, a pavement section subjected to a greater number of 18-kip ESALs per day will deteriorate faster than one subjected to a lower number of 18-kip ESALs. As mentioned previously, the program can accept a user-supplied adjustment factor to shift the survivor curves to account for the influence of traffic loading. However, a procedure for selecting the appropriate adjustment factor for a given level of traffic loading needs to be developed. Still another approach is to use weighting factors in both the survivor curve and the objective function. This would account for both the effect of traffic loading on the service life of the pavement section and the effect of traffic volume on user benefits that can be obtained.

3. The capability to specify projects that are either subsets of existing PES segments or combinations of individual segments is an improvement that will tailor the program more closely to existing practices within individual districts. Currently, RAMS-DO1 will only deal with individual PES data records, most of which are for two-mile road segments. Often, however, the district engineer is considering a project composed of several of these two-mile segments or a project that is a subset of a two-mile segment. Consequently, there is a need to allow the specification of individual projects. This will involve developing rules for assigning distress ratings to projects based on the ratings of the associated PES segments.

4. There is also a need for an interface that will allow the user to specify additional M&R treatments outside of those already included within the RAMS-DO1 program. Through

this interface, the user will be able to specify survivor curves and unit cost data associated with new M&R treatments. This task will also require enlarging the number of M&R strategies that the program can accommodate.

5. Versions of the RAMS-DO1 program should be created that will run on a multi-tasking operating system for a microcomputer. Multi-tasking operating systems already available will address memory above 640K. These versions of the program will allow larger groups of potential projects to be evaluated.

ACKNOWLEDGMENT

This paper is based on results from a project sponsored by the Safety and Maintenance Operations Division (D-18) of the Texas SDHPT. The contents reflect the views of the authors, who are responsible for the facts and accuracy of the evaluation reported here. The contents do not necessarily reflect the official views or policies of the Texas SDHPT or the Federal Highway Administration.

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Publication of this paper sponsored by Committee on Transportation Programming, Planning, and Systems Evaluation.

Combined Road Plan Start-Up Procedures and Operating Experience

FRANK VAN DE STEEG AND JOHN OHRN

The Combined Road Plan (CRP) established as a demonstration by the 1987 Surface Transportation and Uniform Relocation Assistance Act is intended to simulate a block grant for certain highway funds. The Minnesota CRP was designed to reduce federal approvals to a minimum and decrease the exchange of paper between state and federal offices. Minnesota chose to use only federal funds that could be pooled and administered in the manner of a block grant. The key action in getting started was the transfer of 180 existing projects to the demonstration program so that most of the procedures could be implemented immediately. The most significant changes in project procedures were concurrent program approval and authorization and the elimination of FHWA involvement in the final inspection process. Most of the changes in approval authority took place in the state organization to handle the newly delegated approvals. Federal procedures had to be changed to accommodate the new state approvals. The administration of the CRP has proven to be surprisingly easy. Existing procedures are used with less federal involvement. Paper flow has been reduced significantly, particularly in connection with project authorizations. Experience to date indicates that the CRP reduces paperwork and gets contracts under way more quickly at the state level. It also allows federal engineers to focus their efforts on higher-priority projects.

Two purposes serve as the foundation for this paper:

- To document the decisions made and the actions taken to put the demonstration in operation.
- To report on experience with the demonstration procedures during the first 21 months of operation.

It is hoped that the experience of the Minnesota Department of Transportation (Mn/DOT) can be useful to other states considering or already using delegated federal procedures such as the Combined Road Plan (CRP) or Certification Acceptance (CA).

FUNDS, PROJECTS, AND SYSTEMS

Broad decisions about the funds, projects and federal-aid systems to include in the demonstration were made in the enabling legislation. The language in Section 137 of the Surface Transportation and Uniform Relocation Assistance Act (STURAA) of 1987 specifically authorized the use of federal-aid secondary (FAS) funds, federal-aid urban (FAU) funds, and bridge replacement and rehabilitation funds. An interpretation was made that certain other funds (i.e., Interstate substitution) could be used for CRP projects but that these funds could not be pooled with the FAS, FAU, and bridge funds. Minnesota chose to use only funds that could be pooled and administered in the manner of a block grant.

Section 137 specified that CRP projects for highway construction could be on the FAS and FAU systems. CRP bridge projects could be on these two systems and also off the federal-aid system. Interstate (I) and Federal-aid Primary (FAP) funds and any projects on the I or FAP system were not included, as per the original intent of the demonstration adopted by the Congress.

Once the eligible pool of projects had been defined on the basis of the legislation, the key practical decision remaining was how to enter the existing stream of federal-aid projects and begin to set up CRP projects. Both Mn/DOT and the FHWA Division Office wanted to have the demonstration procedures function as fully as possible as soon as possible. A decision was made to include not only new projects under the demonstration, but to convert existing active projects and process them under the CRP. These projects would be picked up wherever they were in the project path and carried from there to completion under the demonstration rules. To make this conversion, a list was compiled of all eligible active projects. After review by Mn/DOT and FHWA, certain projects with controversial features or special needs were left to be completed under regular federal-aid procedures and the rest were converted. As a result, the demonstration had an immediate reservoir of 180 projects with which to establish demonstration procedures. The experience to date is discussed later in this paper.

ADMINISTRATION

The Mn/DOT Office of Highway Programs is primarily responsible for the administration of the CRP. In recognition that the majority of CRP projects are not on the trunk highway system, the Office of State Aid also has substantial responsibility for CRP administration. The Office of State Aid, which acts as the manager for all federal-aid and state-aid projects on local road systems, had in place a communications system with the counties and cities that alleviated many of the start-up problems that normally occur with a new system.

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FHWA monitors Mn/DOT's performance and operations under the plan through the Process Review/Evaluation Program and reports the results. It is Mn/DOT's responsibility to correct any problems found as a result of FHWA's monitoring program.

In addition to the monitoring program by FHWA, Mn/DOT has put in place a monitoring program to ensure prompt expenditure of authorized funds. Mn/DOT also monitors to ensure that completed projects are advanced to final voucher as rapidly as possible. It is a commitment of Mn/DOT to leave no funds idle for an unnecessarily long time.

Although the CRP represents a pool of several different funds, allocation of federal funds to local governments is still necessary. Mn/DOT allocates 65 percent of the FAS funds apportioned to Mn/DOT for expenditure in each fiscal year to the counties for FAS projects on the local portion of the FAS system. The remaining 35 percent is available to Mn/DOT for FAS projects on the Trunk Highway system. Funds are allocated to counties, 50 percent on the basis of each county's FAS system mileage and 50 percent on the basis of each county's financial needs on the FAS system.

Mn/DOT allocates to the urban areas with a population of 5,000 or more their prorated portion of Urban System funds apportioned to Mn/DOT for expenditure in each fiscal year. Funds are allocated to the urban areas on a population basis.

Because of this allocation process, it is currently necessary to track all funds obligated from the CRP pool by original appropriation code to ensure an equitable distribution of federal funds. It is also desirable to be able to demonstrate at the end of the CRP that all needs were considered and met despite the pooling of funds.

As part of its participation in the CRP demonstration project, Mn/DOT has agreed to prepare an annual report summarizing operations, approval actions, recommendations for any changes in plan procedures, revisions to procedure documents, and so on. Annual reports are submitted to FHWA by November 30 of each year. A final summary report will also be prepared at the end of the demonstration program to evaluate the effectiveness of the entire program. This final report will provide an opportunity to assess how well national priorities were met.

PROJECT PROCEDURES

For the demonstration to be worthwhile, it had to significantly affect how projects were handled so as to streamline the process and save effort at both state and federal levels. One measure of this is quicker, easier procedures as the projects go from programming to design to construction to final closeout. The Minnesota CRP was designed to reduce FHWA approval actions to a minimum and decrease the exchange of paper between Mn/DOT and the FHWA division office.

Another measure of the demonstration's effectiveness is the internal efficiencies absorbed in the overall effort. They cannot be measured, but they can be sensed by those involved. One example is the reallocation of time to other duties. FHWA engineers, no longer faced with an accumulation of local project final inspections at the end of the construction season, have concentrated instead on Interstate and Primary projects. Some key changes are discussed below. It should be noted that the following discussion applies predominantly to new CRP projects. The converted projects were affected to varying degrees depending on where they were in the project process when converted.

Federal-Aid Systems and Urban Area Boundaries

Local officials generally initiate requests for revisions to the urban boundaries, functional classification, federal aid secondary, and federal aid urban boundaries. These requests are routed through Mn/DOT district officials. The recommendations of district officials are reviewed by the Office of Highway Programs, Program Management Division, which forwards its determination to the Assistant Commissioner of Program Management for final approval. Informational copies are submitted to FHWA.

Programming

The entire CRP program became one line and one dollar figure in the 105 program (a program of proposed federal-aid projects required by Section 105 of Title 23 of the U.S. Code). Because the CRP is a demonstration, Mn/DOT has maintained both state and federal project numbers and identifiers in its financial record-keeping process. This could be reduced to pure state identifiers under a block grant program or under a federal-aid program in which pooled funds did not have to be identified by category.

Pooling of Funds

Mn/DOT notifies FHWA of the amount of secondary, urban, and bridge funds it intends to make available for pooling. Once the pool is established, Mn/DOT has full authority to work with local governments and spend the funds as it sees fit.

Authorization

A separate letter is issued concurrent with 105 program approval authorizing Mn/DOT to start construction on CRP projects. No further documents are sent to FHWA (with some exceptions as noted below) until an FHWA-37 is submitted requesting obligation of funds for certain projects or groups of projects. This federal-state fiscal document is critical in allowing Mn/DOT to maintain necessary control over obligation authority for CRP funds as related to all other federal highway funds. At the time the PR-37 is submitted to FHWA, Mn/DOT also authorizes the individual CRP projects internally. This internal authorization requires two signatures within Mn/DOT, one to certify that all federal and state regulations have been met and the other to signify that funds are available for the project.

Environment

The CRP program has adopted a form developed under CA that serves as both a checklist and a decision document for environmental actions. This form is prepared by Mn/DOT and records the decision about which environmental category fits each project. FHWA engineers review each form and either concur in the decision as to the environmental category or negotiate a revision with Mn/DOT. This is essentially unchanged from regular procedures.

Design

With the delegation of design exception approvals to Mn/DOT, essentially no formal submittals are made to FHWA during the design process. One exception is major structures as described below. There also are some informational submittals, especially when environmental features are involved. The biggest change has been for urban projects, for which both plans and design exceptions were formerly approved by FHWA. Because Minnesota previously operated under the Secondary Road Plan (SRP) for most of the rural projects now included in the CRP, design exception approval is the only change for these projects.

Major Structure Review

Under the CRP, major structures are bridges costing more than $10 million, unusual bridges, movable bridges, vehicular tunnels more than 700 ft long, pumping stations, and roadway fills that permanently impound water more than 20 ft deep. For these major structures, the Office of Bridges and Structures submits three copies of a preliminary plan signed by the state bridge engineer to FHWA for review.

Construction

Because of previous efficiencies adopted under the SRP, the biggest change is again the inclusion of urban projects and the elimination of FHWA construction inspections. However, under the CRP, Mn/DOT does not submit change orders or supplemental agreements, urban or rural, to FHWA. This saves considerable effort for both Mn/DOT and FHWA.

Fiscal

Mn/DOT continues to use its existing cost accounting system for the CRP projects. Thus, CRP had little effect on state fiscal procedures. The assessment by the Mn/DOT Financial Administration Office is that CRP is an excellent program that is easy to work with, and it creates no additional burden. The FHWA division office issued supplemental instructions on handling final vouchers, but otherwise fiscal procedures have been the same as for regular projects.

Final Inspection

The delegation of final project inspections to Mn/DOT was perceived at first as benefitting FHWA primarily. As work has progressed, Mn/DOT assistant district engineers (inspections cannot be delegated below that level) are finding noticeable efficiencies in scheduling inspections at their own convenience rather than having to coordinate with FHWA engineers.

Project Closeout

Mn/DOT submits basically the same documents to close out a CRP project as it did previously for SRP or regular federal-aid projects. There is additional state certification concerning final project inspection, but the basic elements of the package are the same. In the FHWA office, it has been agreed that the Administrative Manager will sign off on final vouchers for CRP projects without specific engineering review because the engineers have seen no project documents (except environmental actions) unless they were part of a process review. The administrative signoff will be based on state certifications plus information from FHWA process reviews.

Maintenance Certification

Mn/DOT annually prepares a letter of certification covering maintenance of systems included in the CRP. This is handled as follows. District state-aid engineers certify to the state-aid engineer that all projects constructed with federal-aid funds within the counties and municipalities under their administrative responsibilities are being maintained in fulfillment of Section 116. The area maintenance engineers certify to the state maintenance engineer that all projects constructed on state trunk highways with federal-aid funds within their administrative responsibilities are being maintained in fulfillment of Section 116.

Based on the certifications received from the state-aid and state maintenance engineers, the Mn/DOT commissioner certifies that Mn/DOT is fulfilling the obligations of Section 116. The certification process is coordinated within the Maintenance Standards and Operations Unit on an annual basis and completed before December 31 of each year.

APPROVAL AUTHORITIES

The primary goal of the Minnesota CRP is a streamlined, block-grant type operation with approval authority delegated to Mn/DOT whenever possible. As a result, most of the changes in approval responsibility took place within Mn/DOT. This did not affect the workload of Mn/DOT because these approvals were already being made for state purposes. The approval function merely assumed greater importance because approvals are now final, with no further action by FHWA.

Some changes, more like adjustments, were also made in the FHWA division office operations. The more important of these FHWA changes are as follows:

- Because CRP projects are authorized in one lump sum, concurrent with 105 program approval, this action is taken by the engineering coordinator's office rather than the individual area engineers and district engineers.
- Pooling of federal-aid highway funds is a new process. Using instructions from Washington, the division office establishes the pool based on an Mn/DOT request.

• The program stage authorization of CRP projects establishes eligibility of the project costs, but it is not suitable for obligating funds. Mn/DOT decides when funds are to be committed to a project (obligated) and notifies FHWA by submitting a PR-37 form. FHWA then enters those funds in the Federal Management Information System (FMIS) as obligated funds.

• CRP projects undergo environmental review but then progress through final voucher with no review or approval of project documents by FHWA engineers. On these projects, the administrative manager will approve the final voucher without specific engineering review.

• In lieu of specific project reviews, FHWA has established a plan to perform process reviews of each demonstration procedure, some more than once during the demonstration period. These process reviews, coupled with additional Mn/DOT certifications and periodic progress reports, will serve as the basis for FHWA final voucher approval.

PAPER FLOW

The CRP has greatly reduced the paper flow between Mn/DOT and FHWA. Instead of processing an authorization request for each project, FHWA approves one project for the entire federal fiscal year. Once this approval has been made at the time of the 105 program submittal, all future authorizations are internal at Mn/DOT. The FHWA has only four approval functions remaining under the CRP: Transportation Improvement Program and 105 program approvals, environmental clearances, final vouchers, and the authorization of one CRP project for the federal fiscal year. All other approvals are the responsibility of Mn/DOT.

Mn/DOT decided to continue using existing federal forms for some approval functions under the CRP and design new forms for other functions. Mn/DOT retained the final inspection form (1446C) but added a checklist to help the assistant district engineers perform final inspections. The project agreement form (PR2) is used as is. The approval previously given by FHWA is now made by the Mn/DOT federal programs coordinator. A special project authorization form was developed specifically for the CRP. It requires two signatures within Mn/DOT to authorize a project. One signature certifies that the project is ready for advertisement; the other certifies that funds are available.

Mn/DOT uses existing forms for change orders and supplemental agreements. However, approvals are made at the state rather than at the federal level.

DOCUMENTATION AND REPORTING

Because the CRP is a demonstration program, Mn/DOT has basically retained previously existing documentation procedures. If the CRP becomes a permanent program, modifications could be made to recognize the streamlined procedures.

The Office of Financial Operations has been designated within Mn/DOT to keep all official project documents. Records and documentation for any CRP project will be available for review and audit by FHWA in accordance with 23 CFR 17. These records and documents will be available for 3 years after payment of the final voucher.

Under the CRP, secondary and urban system changes are approved by Mn/DOT, as are changes to urban area boundaries. State route revisions on these systems and the appropriate functional classifications will be initiated by Mn/DOT. Local authorities have the right of review of all actions taken by Mn/DOT that affect system and urban boundary changes.

In order to ensure that the Combined Road Plan is working properly and that congressional intent is being followed, the plan requires an annual report to FHWA on the progress of the CRP. This annual report encompasses data on funding, authorizations, final inspections, design standard exceptions, agreements, system changes, and a narrative of the overall activity of the CRP.

EXPERIENCE TO DATE

For the sake of this report, the experience deadline was June 30, 1989. This is the latest date that could be used and still meet deadlines for submittals. This means that the report covers 21 months of operation since October 1, 1987. The first 21 months of the CRP demonstration project went smoothly in Minnesota. The problems encountered were insignificant and easily handled, largely as a result of the thoroughness of the CRP agreement between the Mn/DOT and FHWA. It also reflects the years of experience Minnesota has had with the Secondary Road Plan and the Off-System Road Plan, which are substantially the same as the CRP.

The transfer of projects from regular federal-aid procedures or SRP procedures to CRP procedures was handled easily. To date, 155 of the 180 transfer projects have had their final inspection by Mn/DOT. Fifty of these transfer projects have had the final voucher approved for payment. Two projects that were CRP from beginning to end rather than transferred have also been approved for final payment.

The number of transfer projects and full CRP projects at this time is 145 and 144, respectively. It should be noted that not every project eligible for CRP procedures is included in the demonstration. One example is a computerized signal system project in which Mn/DOT chose to use regular federal-aid procedures in order to have FHWA experts officially involved in the project.

FHWA process reviews to date have indicated that fiscal procedures and project authorizations are being done according to the approved plan. Design exceptions are being approved by Mn/DOT in a carefully controlled manner. Of the 173 exceptions approved to date, the majority (94 percent) has been for horizontal and vertical curvature.

Interviews with FHWA area engineers indicate that the three most significant changes are final inspections, final vouchers, and urban projects, in that order. The time saved has been used mostly on other projects in what is thought to be a better balance of efforts. During the initial 21 months of the CRP, Minnesota authorized 144 CRP projects with a combined obligation value of $45,663,248. These projects were located in every district and federal area in the state. Following is a list of projects split by appropriation code:

Title	*Appropriation Code*	*No. of Projects*	*Value ($)*
Rural secondary	075	43	12,589,913
Urban attributable	W36	7	1,665,540
Urban nonattributable	W32	17	13,249,684
Bridge off system	117	63	6,819,136
Bridge on system	118	14	11,340,975
Total		144	45,663,248

The office within Mn/DOT most affected by the CRP is the Office of State Aid, which manages most projects falling under the CRP. That office's attitude toward the CRP, after 2 years of experience, is very positive. The Office of State Aid has noticed a definite time savings as projects were expedited by a minimization of paperwork and the system of internal, rather than external, approvals. Contracts got under way much more quickly than previously as contract awards were more speedily made.

One drawback to the CRP experienced by Mn/DOT is having some funds eligible for the CRP and other funds used on the same system ineligible. This has created confusion for those not working with the CRP on a daily basis. Bridge replacement funds on the secondary system, for example, are eligible for the CRP, whereas hazard elimination funds used on the same system must use Certification Acceptance procedures. The solution to this, if the CRP ultimately becomes a permanent project process, would be to allow all funds on CRP-eligible systems to be authorized under the CRP.

Mn/DOT believes that the size of the average CRP project, $317,106, is perhaps the most significant argument for the CRP. Projects of this size on minor systems should not be allowed to use an undue amount of human resources in order to accomplish what is currently being accomplished more simply under the CRP.

Publication of this paper sponsored by Committee on Transportation Programming, Planning, and Systems Evaluation.

Changing Environment for Highway Construction: The Utah Experience with Construction Cost Overruns

GLEN S. THURGOOD, LAWRENCE C. WALTERS, GERALD R. WILLIAMS, AND N. DALE WRIGHT

A study of cost overruns in construction projects performed under contract with the Utah Department of Transportation (UDOT) is reported in this paper. The approach looks at historical patterns through largely quantitative and descriptive information covering more than 800 projects completed between 1980 and 1989. Interviews were also conducted with current UDOT personnel, representatives from the State Attorney General's office, and private contractors and their legal counsel to determine current perceptions and assessments of the construction claims environment. Findings suggest that the climate of construction management has changed in recent years. As the Interstate system has neared completion, rehabilitation and reconstruction projects have increased both in number and as a percentage of all projects. These projects are found to be more likely to involve cost overruns. During the same period, UDOT preconstruction staffing levels fell, contributing to numerous design and other preconstruction errors, and an increased opportunity for contractors to seek additional compensation. Lack of cooperation between divisions within UDOT contributed to the decline in relationships between UDOT and the contracting community. Contractors were found to be more willing to file and pursue claims due to an increasingly competitive bidding process and increased access to legal counsel.

In recent years, the dollar amount of cost overruns on construction contracts administered by the Utah Department of Transportation (UDOT) has risen sharply. Figure 1 shows these cost overruns and underruns as a percentage of the original contract amount for 1968 through 1988. The general objective of this study was to conduct a thorough evaluation of the record, attempt to determine those factors leading to cost overruns, and formulate recommendations for actions to reduce the amount of cost overruns. To achieve these objectives, a three-pronged approach was undertaken, involving a review and evaluation of claims, interviews with key participants, and a comparative study of surrounding states. This paper reports on the first two aspects of the study. The complete report may be obtained from the authors.

A review was made of construction contracts completed during 1980–1988 in order to identify and isolate patterns, common causal factors, and so on. Overruns, amount of overrun, events from inception of problem to resolution of overrun, amount of settlement, and methods of administering claims were examined. This review included supplemental agreements, change orders, force account work, and contract claims over a 9-year period, including a representative sample of projects from the period before the upsurge in overruns. The focus was to determine the differences that existed before and after 1985 that could have an impact on final project costs. In accomplishing this and all other tasks, a high level of cooperation was afforded the research team at all levels of UDOT, the Utah Attorney General's Office, and contractors and attorneys in the private sector. Some of the desired data, however, did not exist or could not be found. The procedures and results of the data analysis task are presented in detail in the next part of this paper.

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Interviews were held with representatives of all groups involved in the construction process, including personnel from UDOT administration and the preconstruction and construction divisions. In addition, representatives from the Claims Review Board, the Utah Attorney General's Office, the contracting community, and attorneys for contractors were interviewed. Their observations were sought and evaluated on reasons why there has been an increasing trend in construction cost overruns. These groups understand what the problems are, and many have definite opinions about how to solve them. Findings of the interview portion of this study are discussed in the second part of this paper.

Cost overruns and underruns in highway construction projects arise from several sources and result from many factors (*1*). Nearly every unit price item has the potential to overrun or underrun to some degree because the nature of highway construction is such that the final pay quantities are somewhat different than the estimated quantities (*2*). A reasonable amount of this should be expected. Mistakes and errors in judgment are also made and result in cost changes. When materials provided largely through the acts of nature (e.g., soil) are used, even when technically appropriate tests and evaluations have been performed and evaluated, conditions will be encountered during construction that may differ from those anticipated. All the above have an impact on the final cost of a project. Many adjustments are resolved by simply over- or underrunning a contract item. If the amount involved is great, or if it results from a changed condition, it will be negotiated and resolved through completion of a supplemental agreement to the contract. Some changes, however, are disputed. It was found during this study that the term "claim" is often misused. For purposes of this paper, "claim" refers to a request for a change in the contract price that has not been resolved through negotiation and is in dispute at the time the final estimate was prepared.

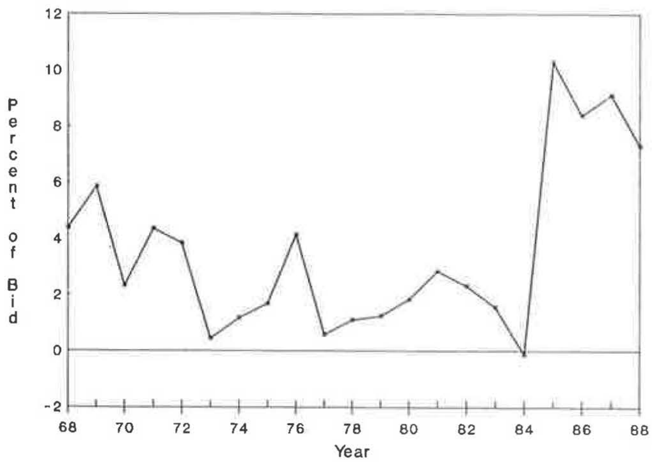

FIGURE 1 Total cost overrun rates, 1968–1988.

PATTERNS AND TRENDS IN PROJECT COST OVERRUNS

In this section, the patterns and trends in project cost overruns are assessed and the relationship between those trends and other management factors is examined. This analysis focuses on nine questions, and the findings are structured accordingly. The questions are as follows:

1. What is the pattern of aggregate project cost overruns over time?
2. What is the pattern of project-level cost overruns over time?
3. Has the amount of construction work performed under contract with UDOT changed over time?
4. Has the average size of a construction project changed over time?
5. Has the number of projects undertaken and completed changed over time?
6. Have UDOT staffing levels and patterns changed over time?
7. What is the relationship between project cost overruns, the number of projects carried out, the value of those projects, and UDOT staffing patterns?
8. What is the relationship between the type of construction project, the type of highway, and project cost overruns?
9. What are the principal causes of claims resulting in project cost increases?

After a brief discussion of the data employed in the analysis, each question is addressed.

The initial data analyzed consisted of quarterly summary reports of projects finalized for the period 1980–1988. The information provided in these reports consisted of project identification number, location, contractor, project engineer, completion date, original estimate, winning bid amount, final cost estimate, and the amount and percentage of overrun or underrun. This information was then summarized by quarter and year. A preliminary analysis was conducted to identify trends and potentially important patterns between contractors, project engineers, districts, and type of project. On the basis of this initial assessment, a sample was drawn from the 817 total projects. This sample included

- All projects with unusually large overruns ($100,000 or larger),
- All projects carried out by contractors with an unusually high percentage of contracts with large overruns,
- All projects supervised by project engineers with an unusually high percentage of projects with large overruns, and
- A 10 percent random sample of the remaining projects.

The final sample size was 106 projects, accounting for 95 percent of all overrun dollars paid between 1980 and 1988.

For the more detailed information required by the sample, UDOT project files and archives were searched and additional information was extracted on start dates, highway type, type of project, claim and adjustment amounts, reason for claims, and so forth. These data were further supplemented with project-specific information taken from the UDOT Comptroller's Construction and Payment Management System.

Some of the information collected for the sample required subjective assessments by the research team. Of particular note here are the reasons for cost adjustments. The list of potential reasons was first generated by engineers on the team and then reviewed by other team members. The data collection instrument, with the revised list of 18 potential reasons for cost adjustments, was then used to collect and categorize information about the projects and claims. In reviewing criteria used to categorize reasons for claims, it was determined that some ambiguities remained. The team reviewed each project again and revised assigned categories as needed. Three additional categories were created.

To summarize, the data used began with the quarterly summary reports provided by UDOT, supplemented by other project-specific UDOT information. In addition to using these data, a sample was drawn, and extensive primary data collection was undertaken for the sample. In combination, these data permitted the research team to address the nine questions identified. The data present a fairly striking picture of cost overruns. To fully understand this picture, each question will be addressed in turn.

Aggregate Project Cost Overruns over Time

Using the summary data provided by UDOT, it was possible to compute total overruns for the period 1968–88. Figure 1 shows the overrun trend for this 21-year period, calculated by taking the difference between the final estimate and the original winning bid amount, expressed as a percentage of the bid amount. Thus, an overrun of 10 percent indicates that the final cost of the project exceeded the winning bid amount by 10 percent.

It will be noted that, as was previously recognized by UDOT, overruns as a percentage of bid amount were relatively stable (between 0 and 6 percent) until 1985. Since 1985, however, overruns have totaled 8 to more than 10 percent of bid amounts. Although the trend line suggests that overruns have been reduced since 1986, the level of overruns as a percentage of original bid amount remains relatively high compared with earlier years. This suggests that the situation has not returned to "normal," and further investigation is needed. One immediate question is whether these aggregate trends also hold at the individual project level.

Project-Level Cost Overruns over Time

Again using the quarterly summary data, the overrun as a percentage of winning bid for each project was plotted by year. Substantial overruns and underruns on individual projects have occurred with some regularity through the period considered. This is not surprising because any given project may encounter unforeseen problems, or may be expanded or cut back in response to engineering, fiscal, political, or other concerns. Traditionally, UDOT has been comfortable with this wide variance in project overruns as long as the total overruns for a given year did not exceed about 3 to 4 percent of total bid amounts. It is also the case, however, that since 1985, more projects have had overruns in excess of 15 percent than was common earlier. Indeed, the average overrun has increased significantly since 1984. Thus, the pattern of increased overruns observed in the aggregate seems to be present at the individual project level as well.

Amount of Construction Work Performed Under Contract with UDOT

To address the issue of amount of construction work performed, it is necessary to adjust the quarterly summary information for changes in construction costs over time. This adjustment was made using the Federal Highway Administration's published highway construction cost index for the relevant years. The constant dollar (1986 dollars) value of work completed is shown in Figure 2. From 1968 through 1979, the value of work finalized declined sharply from a high of more than $180 million to less than $60 million.

This pattern reversed in 1979 and the value of work performed began to increase again, and by 1987 equaled or exceeded levels observed in the late 1960s. It seems likely that this dramatic fourfold shift in construction activity would tax any organization, but to understand fully the kind of effect such a change had on UDOT, it is necessary to address two related questions regarding the size of projects and the number of projects undertaken.

Average Size of Construction Projects

The final estimate and original bid amounts for each project completed between 1980 and 1988 were converted to constant 1986 dollars using the same Federal Highway Administration highway construction cost index. Figure 3 shows the trend in constant dollar average original bid amount. The figure suggests that although projects completed in 1983 on average were quite a bit larger and those completed in 1985 were somewhat smaller, the average size of projects completed between 1986 and 1988 was not substantially different from the average project size in the early 1980s. Figure 3 also shows a similar trend in the constant dollar average final cost of projects completed. With the exception of 1983 and 1985, the average size of projects appears quite similar. This suggests that with the total value of work increasing during this period but the average size roughly stable, one would expect increases in the number of projects undertaken.

Number of Projects Undertaken and Completed by UDOT

Figure 4 shows a plot of the number of projects completed each year between 1980 and 1988. Note that the count for 1980 is not complete, because one quarter's data were missing. The trend shown is nonetheless quite striking. The number of projects completed each year before 1984 ranged between 60 and 70. In 1984 this number began a steady, marked increase.

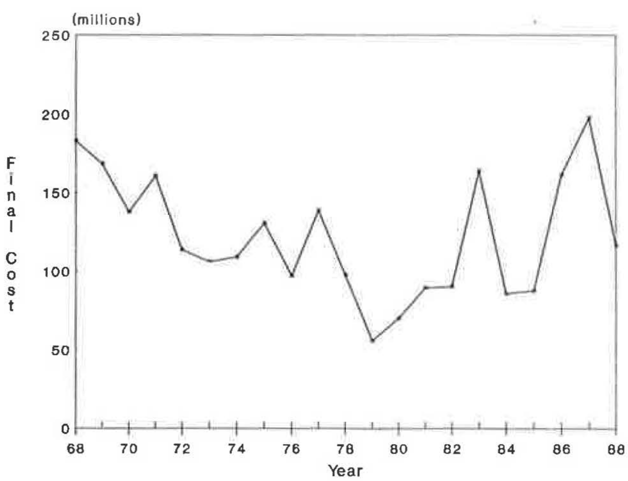

FIGURE 2 Value of work completed, constant 1986 dollars, 1968–1988.

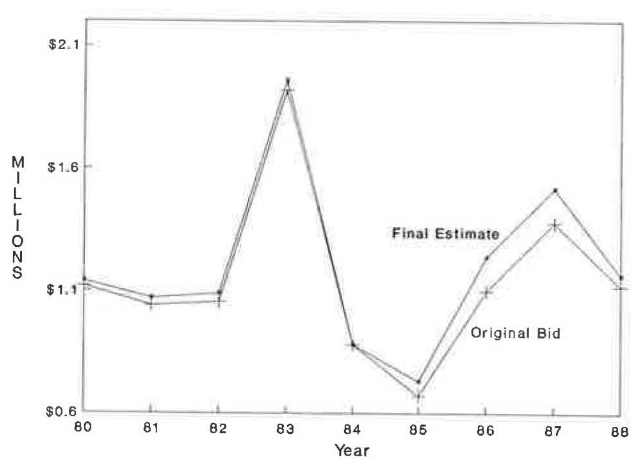

FIGURE 3 Average project original bid and final estimate by year of project completion using constant 1986 dollars.

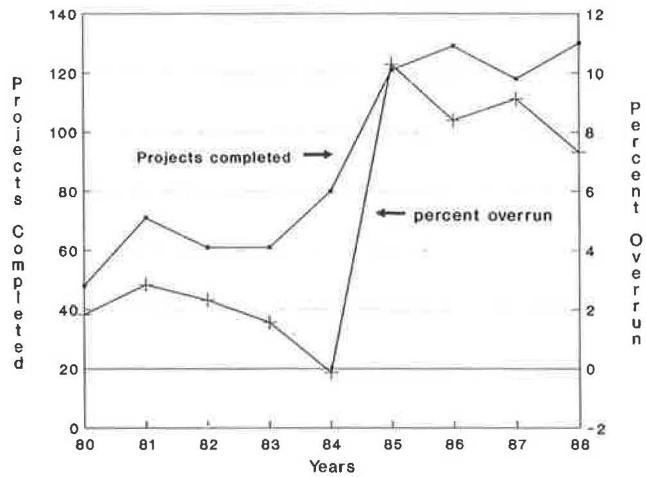

FIGURE 4 Number of projects completed and total cost overrun rate, 1980–1988.

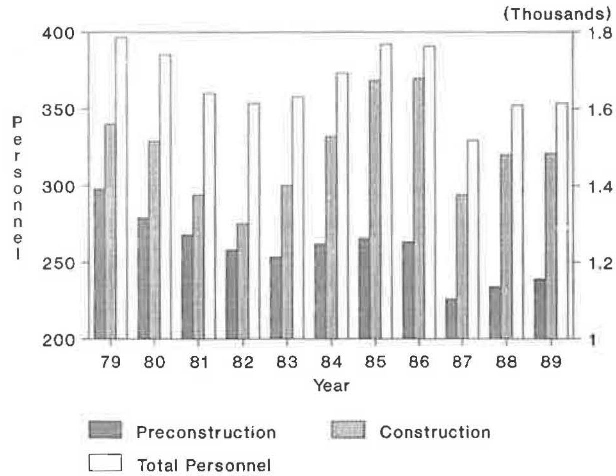

FIGURE 5 UDOT preconstruction, construction, and total personnel by year.

By 1986 the figure had more than doubled. Since 1985 UDOT has completed 120 to 130 projects each year.

Figure 4 also juxtaposes this trend with the pattern of increased overruns. Note that the level of overruns tracks fairly closely with the number of projects completed. This suggests that as the number of projects to be completed has increased, the level of overruns has increased as well. To understand this phenomenon, it is important to consider both UDOT staffing patterns for this period and the nature of the work being done.

UDOT Staffing Levels and Patterns Over Time

Actual full-time equivalent (FTE) personnel counts were obtained as of the end of December for the years 1979 through 1988. In addition, an estimate of the 1989 level was developed. The trends are summarized in Figure 5.

The preconstruction FTE pattern shows consistent reductions in staff from 1979 through 1983, slight increases followed by general stability from 1983 to 1986, then a dramatic drop in staffing levels due largely to the early retirement "window" provided to all state employees in 1987. Since 1987 some effort has been made to rebuild the preconstruction staff, but clearly the new personnel are younger and less experienced than those they replace. This was, after all, the intention of the early retirement program.

The construction division FTE pattern shows a decline through 1982, then a marked buildup in response to increased work loads through 1986. Again, a dramatic drop occurred in 1987 due to early retirements, followed by some rebuilding since then. Total staffing levels also show a similar trend for the same period.

In addition to these overall trends in staffing levels, UDOT experienced some internal realignment of staff. Table 1 shows

TABLE 1 UDOT STAFFING LEVELS AND PATTERNS BY YEAR

	Staffing Levels			Percent		Headquarters Preconstruction
Year	Const	Preconst	Total	Const	Preconst	% of All Preconst
79	340	298	1786	19.0	16.7	73.8
80	329	279	1741	18.9	16.0	72.4
81	294	268	1641	17.9	16.3	70.1
82	275	258	1615	17.0	16.0	70.5
83	300	253.50	1631	18.4	15.5	68.8
84	332	262	1693	19.6	15.5	67.9
85	368	265.75	1768	20.8	15.0	68.0
86	370	263.25	1763	21.0	14.9	68.5
87	294	226	1518	19.4	14.9	68.1
88	320	234	1610	19.9	14.5	65.8
89	321	239	1615	19.9	14.8	66.9

total UDOT staffing levels in preconstruction, construction, and overall. In addition, the table shows preconstruction and construction staff as a percentage of total staff, and the percentage of preconstruction staff in the UDOT central office. It appears from these data that preconstruction staff have declined in both absolute size and size relative to the rest of the department. In addition, a smaller percentage of preconstruction staff is located in the central office now than 10 years ago. Investigations regarding reasons for these reductions and realignments are outside the scope of this study. The interest here is to note the changing patterns and attempt to relate the observed changes to cost overruns.

Relationships Between Cost Overruns, Number of Projects, and Staffing Levels

Relating these data to cost overruns is somewhat difficult. The project data discussed so far are for projects completed in each year. Clearly, the preconstruction staffing levels of interest are those in place when the projects were conceived and designed, not those existing when the projects were completed. Construction personnel are involved in projects during the entire construction phase, which may last for several years. In an effort to understand the relationships between staffing levels, work loads, and cost overruns, the construction initiation year was identified for as many projects as possible. With the help of UDOT personnel, these data were obtained for 499 projects. Based upon the size and type of these projects, the duration and starting years for the remaining projects were estimated.

The projects being considered here were finalized between January 1980 and March 1989. Projects completed in 1980 include projects begun and finished during 1980, and larger projects begun in earlier years but finalized in 1980.

Thus, for the years before 1980, virtually all projects considered were fairly large. For example, our data include 12 projects begun in 1978. Clearly other projects started in 1978, but they had been completed before 1980. Likewise, at the end of the period considered, only smaller projects appear in the data. Large multiyear projects started in 1987 and 1988 are still in progress and not included.

Despite the inherent limitations created by this censoring, several insights are obtained by relating staffing levels to these data. Figure 6 shows a plot of the number of projects and aggregate overrun rates by year of construction initiation. Focusing on the years 1980 through 1985, the association between number of projects started and the eventual overruns on those projects appears quite strong. The lines in Figure 6 are dotted after 1985 to reflect the substantial censoring in these years, because large projects initiated during this period were not yet completed by the end of 1988. Overall, the correlation between project cost overruns and the number of preconstruction engineers working for UDOT in the year prior to construction initiation was $-.62$. Thus, the pattern suggests that cost overruns tend to increase as the size of the design staff decreases.

It should be noted that because of the delay between the design phase and actual project completion, the full effects of the early retirement may not yet have been felt in terms of project cost overruns. Many of the projects designed since

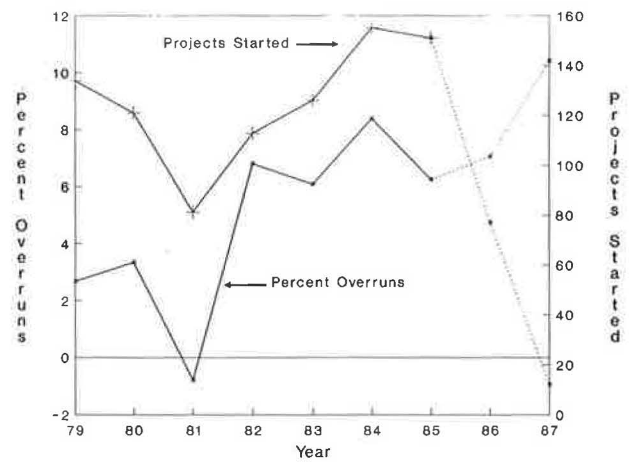

FIGURE 6 Number of projects and total cost overrun rate by year of construction initiation. See text for explanation of dotted lines.

1987 are just now being completed. If the above pattern holds, higher project overruns can be expected.

Relationship Between Type of Construction Project, Type of Highway, and Project Cost Overruns

Table 2 is computed from data on project authorizations from 1979 through 1988, and shows the percentage of project authorizations by type of project each year. Thus, in the top row of Table 2, Interstate projects (Type I) accounted for 19.9 percent of all authorizations in 1979. By 1988 this figure had fallen to 8.8 percent (second to the last column). Overall, Interstate projects accounted for 14.5 percent of all authorizations between 1979 and 1988 (last column of the table). Several trends in Table 2 are worth noting. First, as mentioned above, the emphasis on building the Interstate system has declined as that system has neared completion. While Interstate projects accounted for 19 to 20 percent of authorizations in the 1979–1981 period, the level fell to 9 to 10 percent in the last three years.

At the same time, Interstate rehabilitation projects (Type IR) have increased sharply. These projects accounted for less than 3 percent of all authorizations prior to 1981. In 1984, Interstate rehabilitation projects were increased to 15.5 percent of all authorizations. By 1987, the figure had grown to roughly one-fourth of all authorizations. This timing coincides with the increases in cost overruns, given that projects first authorized in one year will likely be finalized in subsequent years.

Other trends worth noting include the decline in state-funded Interstate projects (Type NI). In recent years, such projects have virtually disappeared. Note also the increase in emergency projects (Type ER) from 1983 to 1987. This may reflect the creation of a new category, or, as seems more likely, it may result from repairing flood damage from extensive flooding that occurred in 1983.

In an effort to ascertain the effect of this changed project environment, in which Interstate construction is being replaced by Interstate rehabilitation, the sample of 105 projects was

TABLE 2 AUTHORIZATIONS BY TYPE OF PROJECT

Type of Project	Percent of All Authorizations 79	80	81	82	83	84	85	86	87	88	Total
I	19.9	19.2	19.0	10.0	21.3	8.2	13.5	9.0	11.3	8.8	14.5
NF	12.9	1.4	3.4	15.0	18.1	14.5	13.5	12.4	4.8	17.5	12.0
IR	1.8	2.7	6.9	10.0	9.6	15.5	18.3	12.4	22.6	29.8	11.6
R	8.8	9.6	1.7	8.8	9.6	11.8	8.7	7.9	8.1	8.8	8.7
F	7.0	9.6	6.9	3.8	4.3	8.2	3.8	7.9	6.5	1.8	6.1
M	5.8	8.2	3.4	6.3	3.2	2.7	4.8	9.0	12.9	8.8	6.1
NM	9.4	0	5.2	6.3	6.4	7.3	3.8	3.4	4.8	5.3	5.7
BROS	0.6	4.1	15.5	7.5	6.4	5.5	3.8	4.5	4.8	0	4.7
S	5.8	11.0	6.9	2.5	4.3	5.5	1.0	0	6.5	3.5	4.6
NI	7.0	9.6	6.9	6.3	4.3	1.8	1.9	2.2	1.6	0	4.3
NS	2.3	0	0	2.5	1.1	2.7	4.8	9.0	1.6	3.5	2.9
ER	0	0	0	0	2.1	3.6	9.6	4.5	3.2	0	2.5
HES	1.8	2.7	5.2	3.8	1.1	1.8	2.9	2.2	0	1.8	2.2
OTHER	17.0	21.9	19.0	17.5	8.5	10.9	9.6	15.7	11.3	10.5	14.1
Total	100	100	100	100	100	100	100	100	100	100	100

Key:

Project	Designation Description
I	Interstate 1956 and subsequent act construction
NF	State funded highway project on Federal-aid Primary System
IR	Interstate (4R)
RS & RRS	Rural Secondary & Railroad Crossing
F	Federal-aid Primary project
M	Urban system attributable
NM	Non Participating Urban System
BROS	Bridge replacement off system
S	Federal-aid Secondary, Construction
NI	State funded highway project on Interstate System
NS	State funded project on Federal-aid Secondary System
ER	Emergency Repair
HES	Hazard elimination

used to determine reasons for cost adjustments by type of project. Table 3 summarizes these findings. In the table, all projects sampled have been grouped into either Interstate rehabilitation or "all other." The table shows the percentage of projects sampled that had cost adjustments for each of our predetermined reasons. Using a Chi-square test, field design changes were found to be significantly more common in Interstate rehabilitation projects than in other types of projects.

Table 4 shows the average number and size of contract adjustments per year for the sample projects. The most striking finding in the table is that the average contract adjustments for contracts initiated between 1982 and 1984 were substantially higher than for other years.

If the combination of more field design changes, greater difficulty with traffic control, and problems with obtaining appropriate construction materials are combined, the vision that emerges is that Interstate rehabilitation projects appear to present UDOT with design difficulties not found in other types of projects. The final question to be addressed here then is whether such reasons are related to project overruns.

Principal Causes of Claims Resulting in Project Cost Increases

To address this question, the sample of projects was divided into two groups: those with overruns greater than or equal to 10 percent of the original bid amount and all other projects. Because of the nature of our sample, a high percentage of the projects fell into the "10 percent or more" group. The percentage of projects sampled that had cost adjustments for each of our predetermined reasons was computed for each group. The findings are summarized in Table 5.

Reasons found to be significantly different (Chi-square test, $p > .05$) in the two project groups are underlined in the table. With the exception of subsoil problems, all the significant differences correspond to problems found to occur more frequently in Interstate rehabilitation projects. This suggests that the design difficulties associated with rehabilitating the Interstate system are directly related to high project cost overruns.

Our findings suggest that significant changes have occurred in the highway construction and management environment in

TABLE 3 REASON FOR ADJUSTMENT BY TYPE OF PROJECT

Reason for Adjustment	Percent of Projects by Project Type: IR	All Other
1. Quantity estimate error	30.8	36.7
2. Technical design error	65.4	63.3
3. Time estimate error	15.4	12.0
4. Unclear specification	11.5	11.4
5. Archaeological	0.0	1.3
6. Environmental problems	0.0	6.3
7. Field design change	92.3	72.2
8. Groundwater	11.5	25.3
9. Labor violation/dispute	3.9	6.3
10. Subsoil	11.5	19.0
11. Traffic control problem	34.6	27.9
12. Traffic damage	3.9	3.8
13. Weather	26.9	17.7
14. Construction materials	11.5	6.3
15. Utility relocation	3.8	12.7
16. Zoning change approval	0.0	0.0
17. Other	9.2	11.4
18. Other	3.8	3.8
19. Traffic safety improvements	3.9	13.9
20. Design concept change	0.0	1.3
21. Surface water	0.0	3.8
Total N	26	79

TABLE 4 AVERAGE SIZE AND NUMBER OF ADJUSTMENTS PER PROJECT BY YEAR

Project Start Year	Average Number Adjusts.	Average Amount Adjust.	Total Number of Adjusts.	Total Amt Adjusts.
80	12.0	298,207	12	298,207
81	11.5	-13,059	46	-52,237
82	9.4	311,344	94	3,113,437
83	13.9	323,732	111	2,589,859
84	9.5	371,050	218	8,534,139
85	7.6	138,414	189	3,460,342
86	7.5	188,070	82	2,068,768
87	3.9	42,480	55	594,715
88	2.0	22,879	4	45,758

the past 10 years. As the Interstate system has neared completion and as the Interstate has aged, emphasis has shifted to rehabilitation projects. These projects appear to present a somewhat different set of design and construction issues. Coupled with this shift has been a substantial increase in the number of projects undertaken by UDOT and a marked reduction in preconstruction staff. The result seems to be that fewer people are being required to do more and different design work than previously. Not surprisingly, the result is an increase in the number of field design changes and resulting project cost overruns.

This analysis has been based upon an examination of historical data stretching back as much as 20 years and has focused on general patterns and trends. While this effort has proven very fruitful in understanding the nature and sources of past cost overruns, it is also important to consider the current environment and conditions affecting construction, design, and management. The following sections detail the research efforts and findings regarding current conditions and perceptions in UDOT and in various organizations with which UDOT interacts in the construction process.

PERSPECTIVES OF UDOT PERSONNEL AND OTHER INVOLVED PARTIES

A series of interviews was held with 17 UDOT personnel, including preconstruction and construction engineers on both the state central office and district office level. Interviews were also held with representatives of eight construction companies, representatives from the Attorney General's Office, and attorneys representing the contracting community. The central theme of these interviews was to discover reasons for cost overruns on construction projects.

Eight Utah highway construction contractors who do substantial UDOT contract work were interviewed. They were selected with the aid of the Utah Association of General Contractors, who helped arrange interviews based on two criteria. First, the goal was to talk with enough contractors to get a fair idea of the views of various small, medium, and large contractors in Utah. Second, all contractors not in the first group who wanted a chance to have input to the study were given an opportunity to meet. Meetings with high level representatives of the eight contractors lasted for approximately one hour each.

Principals in two Utah law firms experienced in handling litigation of construction claims against UDOT were recommended by UDOT as respected opponents in the claims litigation process and interviewed. Both attorneys were cooperative, aided in the attempt to understand reasons for cost increases in highway construction contracts, and were willing to suggest ways to reduce or eliminate them. They were particularly able at asking questions that helped identify variables to test in the empirical analysis of cases, such as, the effect of rushing jobs, the relationship between the dollar volume of work let and the incidence of underbidding, and changes in the profile and operating procedures of project engineers, effect of size of contracts, etc.

These interviews were done independently of the collection and analysis of data from the records of construction projects

TABLE 5 REASON FOR ADJUSTMENT BY SIZE OF OVERRUN

Reason for Adjustment		Percent of Projects by Size of Overrun Less than 10%	10% or more
1.	Quantity estimate error	35.0	35.4
2.	Technical design error	57.5	67.7
3.	Time estimate error	10.0	15.4
4.	Unclear specification	15.0	9.2
5.	Archaeological	2.5	0.0
6.	Environmental	0.0	7.7
7.	Field design change	62.5	86.2 *
8.	Groundwater	15.0	26.2
9.	Labor violation/dispute	7.5	4.6
10.	Subsoil	5.0	24.6 *
11.	Traffic control problem	20.0	35.4 *
12.	Traffic damage	5.0	3.1
13.	Weather	10.0	26.2 *
14.	Construction materials	7.5	7.7
15.	Utility relocation	15.0	4.8
16.	Zoning change approval	0.0	0.0
17.	Other	10.0	15.4
18.	Other	5.0	3.1
19.	Traffic safety improvements	7.5	13.9
20.	Design concept change	0.0	1.5
21.	Surface water	0.0	4.6
TOTAL N		40	65

* difference is statistically significant at .05 level

described previously. To ensure as much independence and objectivity as possible, these two simultaneous research activities were conducted by different members of the research team. The focus in the data analysis reported in the previous section was to let analysis of the record lead researchers to appropriate observations and conclusions. The intention of the interviews was to gain the perception of the various parties involved in the process about factors contributing to the changed overrun picture. Results of the interviews showed considerable agreement with those conclusions reached through analysis of the project data as summarized above.

It should be noted, however, that the data analyzed reflect what was happening largely in the 1980–1988 period. The information gleaned from the interviews reflects attitudes and feelings of the persons involved at the time of the interview (1989) and their reflections on what was happening in prior years. The two are not necessarily the same, and this fact should be kept in mind as the results of the data analysis and the interview process are compared.

The groups interviewed agreed that the contractors were bidding more tightly because of increasing competition in the industry and the Utah economy. UDOT employees said companies were bidding too low and this caused them to seek additional profits through supplemental agreements or claims. Contractors believed that the low bids prohibited them from accommodating the state by performing additional work or changes for little or no additional cost, and stated that the past practice was to try to help the state by doing the work for minimal increased costs. This was no longer feasible because of low profit margins in the bids submitted.

A second point of agreement between these groups was that a major cause of cost overruns is due to design problems and the inability of project engineers to make timely corrections. They agreed that a need for design changes has always existed and indeed may be a normal part of the industry. However, from the viewpoint of those interviewed, problems in design and specifications on highway projects in Utah seem to have increased in recent years.

The design and specification problems are exacerbated by an increasing inability on the part of UDOT project engineers to take corrective action in a timely way. All groups stated that it is easier and less expensive to make corrections as quickly as possible and on the lowest organizational level possible. Contractors said that doing this is increasingly a problem and the length of time needed to make corrections and "get on with the work" has increased. Contractors also stated that this has led to larger overruns and created a great deal of "ill will."

An important observation made by all UDOT personnel interviewed is that an increasing work load has not been compensated for by an increased staffing level. This is illustrated in Figure 5.

Many of the observations made by UDOT staff illustrated the impact of the staffing/work load problem discussed above. UDOT preconstruction engineers are under pressure to increase productivity by producing a greater number of plans and specifications during a shorter time because of an increasing work load, in general, and opportunities on occasion to receive additional federal funding. This spurs the department to get projects into the field quickly so that funds will not be lost.

According to those interviewed, many of the problems that result in cost overruns arise from design errors and omissions, inadequate materials investigations, and inadequate standard specifications and special provisions. Interviews with contractors corroborated this view. Many supplemental agreements and claims deal with problems or inadequacies in these areas.

Partially in response to the early retirement offered to state employees, the state has begun to use consultants to compensate for declining staff levels and promote privatization. Two potential problems were noted with respect to consultant performance: the learning curve and their lack of ownership in the project.

It takes time for any new employee to become acquainted with and understand UDOT procedures as well as the technical aspects of the job. Consultants are no exception, and in fact may face greater problems because of the temporary nature of many of their assignments. Illustrations were given both of consultants being transferred to other jobs in midstream and of consultants undertaking only one project for the state. For most engineering firms in the state, doing UDOT design and construction work represents a new activity.

In preconstruction, consultants lack a sense of ownership in the project. Once the design is completed, generally few provisions are made for further involvement of the design engineers; they have no further responsibilities and any problems must be resolved by UDOT staff. Attempts have been made to address both these issues in consultant contracts; however, the provisions have not completely solved the problem.

Another effect of increasing work load has been to bypass the preconstruction review process, or at least to give inadequate attention to the review process. Many interviewees stated that the project engineer to be assigned to the project should be present at the plan-in-hand review, or even while the project is being "scoped." In addition, many instances were cited in which some steps in the review process were overlooked. UDOT is currently implementing a new "scoping" procedure that, if followed, should resolve this issue.

Another problem related to problems of design, as observed by UDOT personnel, has been a lack of construction experience on the part of design engineers. Many believed that a design engineer should have three to six years experience in construction before beginning work in design. There was general agreement that this would improve the quality of plans being produced. Conversely, few project engineers have any preconstruction design experience, and thus have little appreciation for the difficulties involved in producing complete, error-free designs and specifications.

There is also an attitude held by both UDOT personnel and contractors that the reduction in personnel and increasing work load, in conjunction with early retirement, has led to a decreased experience level of construction project engineers. This in turn has led to a reduced ability to make independent decisions in the field. Having decisions and actions made at the lowest level is the best policy from both the state's and contractor's viewpoint. Project engineers who lack experience tend to elevate decisions to the district or the headquarters level. This lengthens decision-making time, which in many cases increases the amount of the individual cost overrun and certainly contributes to the frustration level of contractors.

Most state employees interviewed stated that the use of consultants for inspection required greater supervision on the part of UDOT to ensure the maintenance of state standards. The use of consultants presents some problems in that UDOT supervisory requirements are higher. This seems to be less of a problem when consultants are used in materials investigations rather than design or construction.

The natural processes of wear and aging are creating an increasing need to do rehabilitation to the Interstate system. Many of those interviewed said that rehabilitation projects involving the Interstate system created many new problems of design, traffic control, and technology. UDOT is thus involved in unfamiliar activities involving a developing technology. These projects are difficult to design and carry through to construction. In addition, rehabilitation projects have had delay and design problems caused by utility concerns, railroad rights-of-way, and the problems of traffic using the Interstate while rehabilitation projects are underway. Traffic control is a particularly difficult problem on these projects because rehabilitation work must be done in the face of heavy traffic. UDOT has had little experience with this kind of traffic control and has difficulty with the traffic control portions of the specifications.

SUMMARY OF FINDINGS AND RECOMMENDATIONS

The quantity and complexity of work performed by UDOT personnel have increased over the past 10 years. The changing complexity includes regulations, new technology, and different types of design and construction problems encountered. UDOT has experienced a fundamental change in the nature of work carried out as construction has been replaced by reconstruction and rehabilitation, both of which were found to be more subject to cost overruns than were other types of projects.

Staffing levels have at the same time declined, especially in preconstruction. The data suggest that staffing levels have a direct effect on later cost overruns. This relationship is further complicated by the increased work load and complexity mentioned. The staffing problem led to bypassing quality assurance reviews in the preconstruction phase which, in turn, were correlated with field design changes during construction.

The declining staffing and experience level led to a centralization of decision making during the construction phase. This created delays in resolving design changes and subsequently to increased claims by construction firms. It also contributed to a deteriorating relationship between contractors and UDOT.

The increasingly competitive economic environment in the construction industry has resulted in tighter bidding and a decreased willingness on the part of contractors to "cooperate" with UDOT. Very low profit margins led to pressures to protect or enhance profits through change requests or claims. The interaction of these factors contributed significantly to the pattern of increased cost overruns.

UDOT should adhere to the preconstruction review process in place and sufficient preconstruction staff should be available to make certain that procedures are followed. UDOT should provide training, strengthen the project engineers, and decentralize the decision-making process, so that design changes can be made in a timely manner. The claims process should be improved to be less costly for both UDOT and construction firms in terms of time, energy, and money. Finally, an organizational development effort should be undertaken to improve communication and decrease the sense of division between various units.

The cost overrun problems experienced by UDOT in the recent past are not atypical. Many state departments of transportation face aging Interstate systems, retiring staff, changing technologies, external pressures to privatize significant portions of their activities, and increased competition among contractors. While a number of issues raised in this study bear further exploration, the findings and recommendations are likely relevant for many states.

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Funding support for this research was provided by the Utah Department of Transportation. The findings, conclusions, and recommendations contained in this paper reflect the views of the authors, who are responsible for the accuracy of the analyses and data presented herein. The contents do not necessarily reflect the official views of the Utah Department of Transportation, or of Brigham Young University or any of its units. This report does not constitute a standard, specification, or regulation.

Publication of this paper sponsored by Committee on Transportation Programming, Planning, and Systems Evaluation.

Use of the Preconstruction Engineering Management System To Develop, Schedule, and Monitor the North Carolina Highway Capital Improvement Program

LARRY MCPHERSON, LUBY MOORING, AND CHET NEDWIDEK

The preconstruction engineering procedures required to develop highway improvement programs are inherently complex. Procedural complexity along with normal increases in the size of improvement programs have tended to focus attention on the need for new management systems capable of improving the efficiency and effectiveness of highway programming personnel. The Federal Highway Administration (FHWA) made an effort in the late 1970s to improve highway agency management practices by initiating the development of an information system called the Preconstruction Engineering Management System (PCEMS). The primary objective for this study was to test and evaluate PCEMS' potential for accomplishing the preconstruction functions of highway project scheduling and progress monitoring. Testing and evaluation results showed that the system could be effective in administering a large capital program and was subsequently used to schedule nearly sixteen hundred highway projects in the 1990–1996 Transportation Improvement Program. PCEMS will be used to monitor progress of that scheduled work during 1990 and determine the percentage of those projects that meet construction contract-letting dates. This paper describes how PCEMS was implemented and how it is being used to assist the preconstruction engineering staff with the scheduling phase of program development in North Carolina. Many of the study findings should be of interest to preconstruction engineering managers who must make scheduling decisions that involve balancing the money, time, and manpower required by the highway program developmental process.

The engineering tasks required for highway improvement program development and control have become very complicated. Engineers are increasingly concerned that management tools currently used for the development, scheduling, and monitoring of multimillion dollar highway programs are no longer adequate (*1*). Recently the Federal Highway Administration (FHWA) has made a concerted effort to assist highway agencies in improving their management practices. In 1979, the FHWA initiated a study to develop more effective management techniques (*2*). That study resulted in a prototypical computer system called the Preconstruction Engineering Management System (PCEMS).

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PCEMS is based on an operations research networking technique known as the Critical Path Method (CPM). CPM now enjoys wide acceptance among highway construction officials because it offers an excellent management technique for defining the most efficient approach to accomplishing any highway construction work program. Although several highway agencies have reported saving both time and money by using CPM during the construction phase of highway programs, it has seldom been used for the preconstruction phase (*2–4*).

Therefore the main thrust of this research effort was to investigate how the CPM concept could be used to more effectively manage all the preconstruction engineering activities required for implementation of the North Carolina Transportation Improvement Program (NCTIP). More specifically, the primary objective was to test and evaluate PCEMS' potential for accomplishing the preconstruction functions of highway project scheduling and progress monitoring.

The CPM provides the mathematical foundation for a major component of PCEMS known as the multiple project scheduling subsystem. This PCEMS subsystem can provide managers with a more rational approach for overcoming decision-making weaknesses in all preconstruction activities ranging from project programming to contract award. It could be expected that an improvement in management practices would lead to a less costly, more timely accomplishment of program objectives.

METHODOLOGY

The PCEMS is a computerized model designed to manage highway preconstruction engineering processes consisting of numerous activities. A computer is required to handle the large amount of data collected for or generated by those preconstruction engineering activities. The 71 computer programs contained within the PCEMS environment permit the creation, operation, maintenance, and reporting of numerous data files including CPM networks, activity responsibility, personal availability, planning values, calendar work days, project characteristics and status, multiple project schedules, and an archive of completed projects. These data files are utilized in the functional areas of (a) program development, (b) multiple project scheduling, (c) progress monitoring, and (d) activity planning value updating.

Program development is the functional area in which information is generated for use by executive level management for work program development. Multiple project scheduling is the functional area in which projects in the work program are scheduled in a multiple-project environment while considering personnel availability.

Progress monitoring is the functional area in which progress of highway projects is assessed and compared to the schedules estimated to meet desired bid awarding dates.

Activity planning value updating is the functional area that provides for the capability of updating estimated planning values to reflect changed work conditions and technical processes (*5–7*).

DATA SOURCE

The PCEMS is designed to use data currently residing in files that are generated by a highway agency's normal planning, design, construction, operational, and administrative processes. Data extracted from such existing files serve as the original input required for PCEMS computer runs that build several basic data files. These minimum data requirements that initiate the program development phase of PCEMS include a CPM network file, an activity responsibility file, a base planning value file, a calendar file, a person-hour availability file, a schedule period file, and a project characteristics value description file.

Provisions exist in the PCEMS model for both the development and updating of its data base. New data may be added and old data changed or deleted in any PCEMS file at any point in the preconstruction engineering process (*5–7*).

OVERVIEW OF THE NORTH CAROLINA HIGHWAY PROJECT DEVELOPMENT PROCESS

The highway project development process includes many preconstruction engineering activities from planning, programming, design, and traffic operations. Activities from each of these functional areas must be properly interfaced and linked as a continuum to ensure the timely delivery of a safe, dependable, and cost-effective highway service (*8*).

A generalized procedural framework providing that interface is shown in Figure 1. The framework and time requirements as shown in this figure are very similar to those used by the NCDOT and indicate that the programming phase of the developmental process consists of 15 steps. The scheduling step is now being handled by the Program and Policy Analysis Branch using the PCEMS. PCEMS was used to schedule almost 1,600 highway projects in November 1989 and will be used to help monitor progress of the scheduled work during 1990.

Based on that feedback, management can determine the system's overall effectiveness by the percentage of projects meeting the scheduled construction contract-letting dates. Such information will also suggest changes in system parameters that may be required to increase that effectiveness over time.

Because of its potential for work-progress monitoring and a proven scheduling capability, PCEMS may become one of the most important management tools used for the annual update of NCTIP.

Highway projects considered for inclusion in the annual update of NCTIP are identified and initiated from both technical and nontechnical sources. Technical sources include the Highway Performance Monitoring System (*9*), the Bridge Management System (*10*), and the Urban Transportation Planning Process (*11*). Nontechnical sources include private citizens, special interest groups, and elected officials (*12*).

Currently the NCTIP has a seven-year planning horizon and contains more than 1,500 projects. Figure 2 illustrates how a wish list of highway projects is generated each year and subsequently analyzed, prioritized, programmed, and finally published as the NCTIP (*4,13*).

ORGANIZATION, MANAGEMENT, AND STAFFING REQUIREMENTS

Organizational structure and management style are the most important factors contributing to the successful implementation and operation of PCEMS. Teamwork between management and the technical support staffs provides the only assurance that PCEMS will work. Active participation in the implementations of PCEMS by agency personnel already involved in the preconstruction engineering process encourages teamwork.

It should also be noted that implementation team members from the chief executive officer to the working technician can develop an understanding of and commitment to the philosophy and function of PCEMS. A firm commitment from top management is certainly required to assure the initial success of system implementation, but even greater commitment and support from working level engineers and technicians is required to ensure the operational success of PCEMS over time.

The PCEMS implementation manual proposes an organizational structure designed to accomplish the participation, understanding, commitment, and support objectives mentioned above. That organizational proposal has structural components consisting of a steering committee, a computer operations group, and several technical panels. Proposal specifications relative to personnel composition, duties, responsibilities, roles, and working relationships are given in an Implementation Manual (*1*). NCDOT engineers used those specifications with minor modifications to successfully implement PCEMS in December 1985 with an implementation staff of approximately 30 engineering professionals.

The Steering Committee

The steering committee was composed of the Highway Administrator and his staff. During PCEMS implementation, the steering committee provided policy and procedure guidance, approval authority for technical recommendations, and top management support.

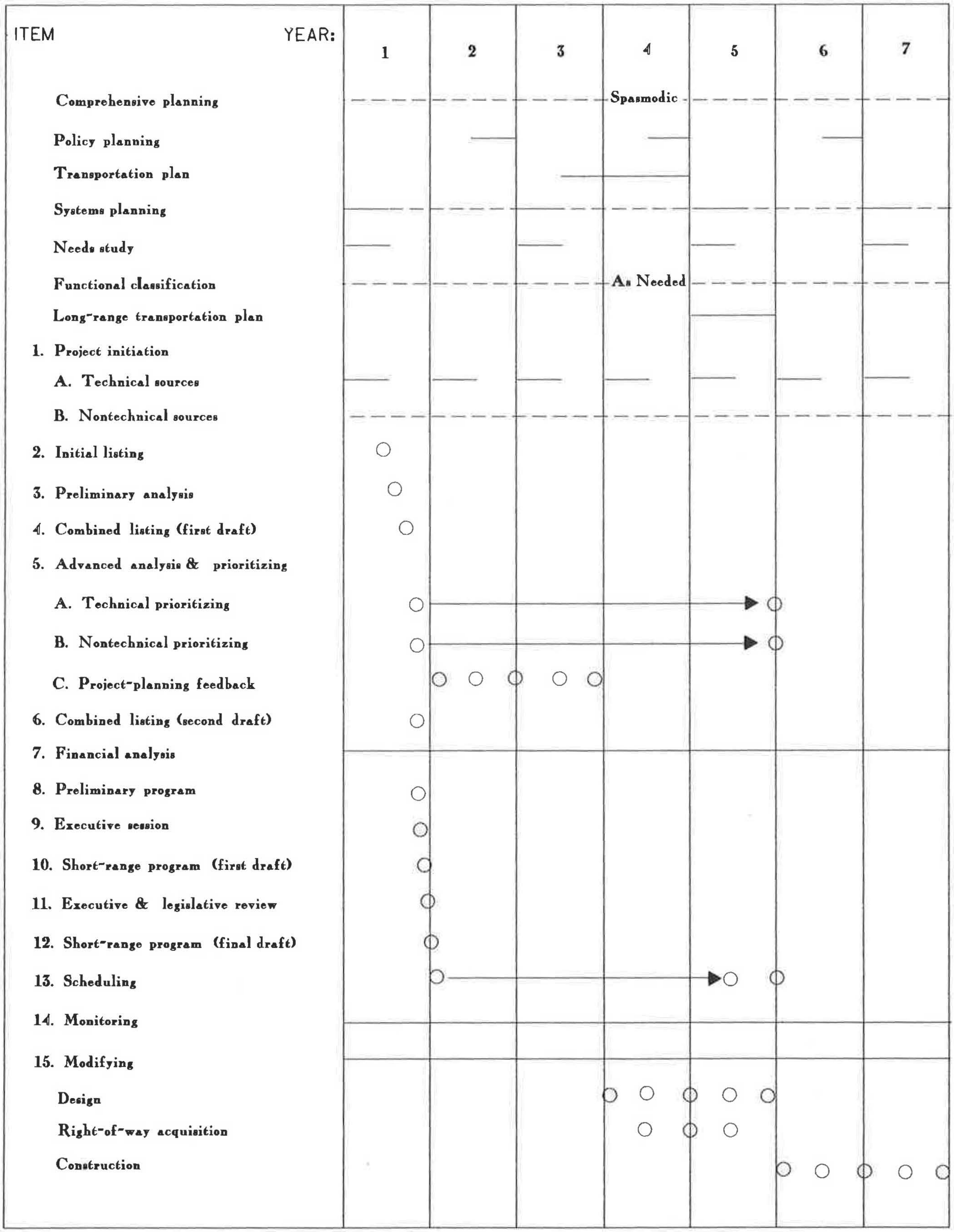

FIGURE 1 Planning, programming, and design process phasing (*7*).

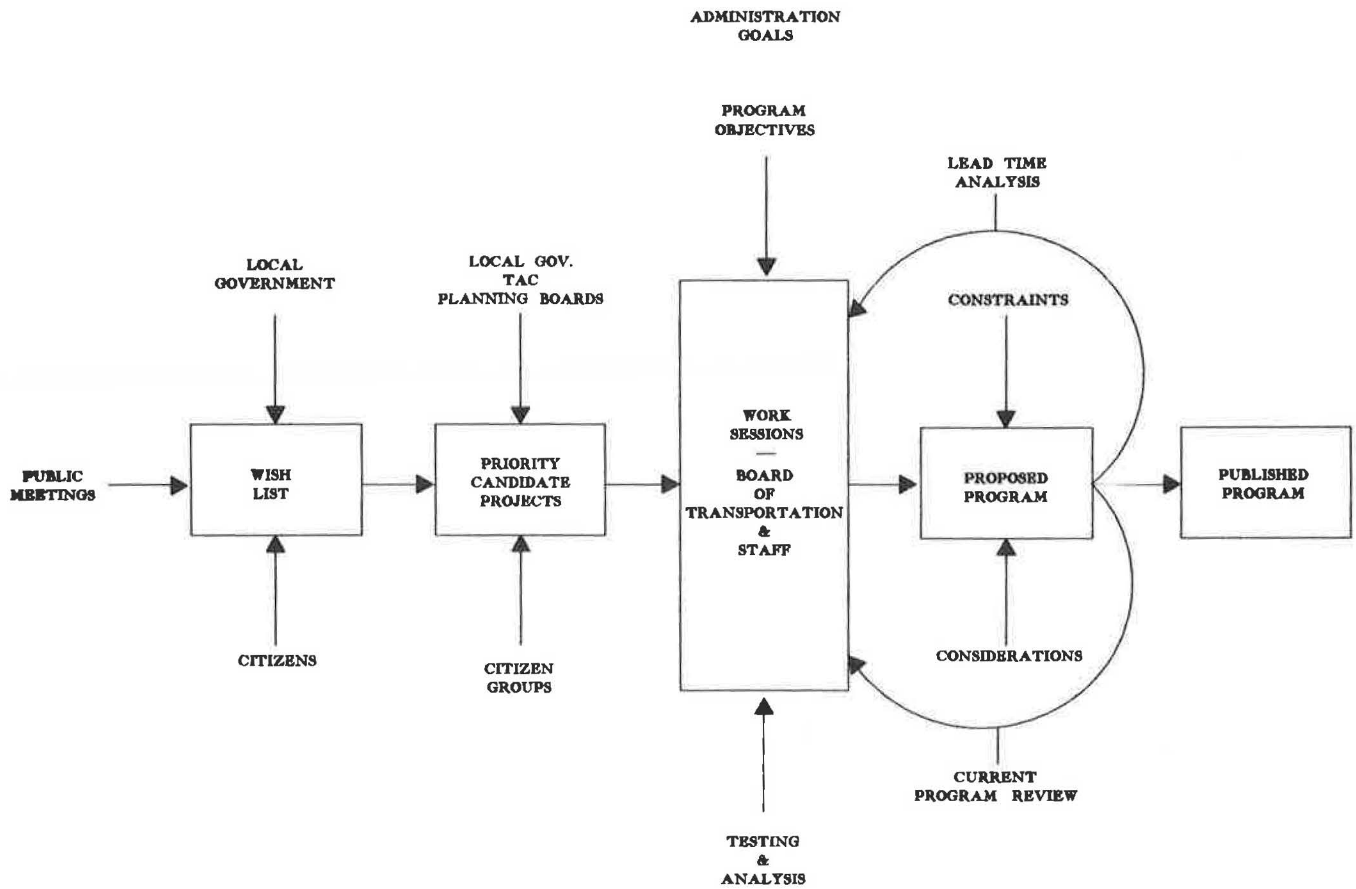

FIGURE 2 Highway needs identification (*6*).

Computer Operations Group

The computer operations group implemented the computer system and was responsible for staff training, documentation of the internal procedures required for continuous system operation, and liaison between the steering committee and the technical panels. The computer operations group consisted of two management operation engineers and a data processing representative.

Technical Panels

The technical panels contained two or three engineering specialists in the functional areas of planning, right-of-way, geotechnical investigation, location and surveys, traffic operations, design, hydraulics, and materials engineering. The technical panels worked with the computer operations group to develop detailed activity descriptions, time requirements, and logical networks used to build computer models that accurately represent the ongoing North Carolina Department of Transportation (NCDOT) highway project development process.

Technical panel responsibilities included developing the task, activity, and network hierarchy required for CPM of analysis and scheduling; developing base person hours, base elapsed time, complexity factors for each activity and additives used by PCEMS to calculate total activity time requirements; and determining and recommending improvements to increase the efficiency and productivity of the NCDOT preconstruction engineering process.

FACTORS, PRINCIPLES, AND PROCEDURES FOR MODIFICATION, IMPLEMENTATION, AND OPERATION OF PCEMS

As with any prototypical computer system, PCEMS must be modified and adapted to the organizational and operational requirements of the implementing agency. Such efforts are greatly influenced by factors relative to the agency's internal fiscal, legal, and administrative policies. PCEMS' scheduling and monitoring subsystems are sensitive to these influencing factors. The literature discusses how such influencing factors can be identified and reflected in modification principles that in turn can serve as the rational basis for the procedural steps required for system implementation and subsequent operation (*5,13*).

Factors Influencing the Modification of PCEMS

The most important factors influencing the modification and adaptation of PCEMS to a particular highway agency are

• Type, form, and stability of the highway capital improvement program per se;
• Agency's organizational structure;
• Management's goals and information requirements;
• Preconstruction work analysis, scheduling, reporting, and monitoring policies; and
• External agency actions.

Guiding Principles for Modification of PCEMS

The literature suggested that the main principles serving as criteria for the conceptual redesign or modification of PCEMS should be reflected from the influencing factors listed (*13,14*). The most important of those principles relative to PCEMS are restated as follows:

1. A prioritized improvement program is the primary input for project scheduling.
2. The importance of the project scheduling effort is directly related to the size and complexity of the highway network as well as increased funding availability.
3. Project scheduling must be integrated with financial procedures.
4. Top level management support is essential to a successful project scheduling and monitoring effort.
5. Scheduling and monitoring policies are a function of management goals and objectives.
6. Information needs for each level of management must be met by the project scheduling and monitoring system.
7. Scheduling allows management to balance project workloads with available person resources.
8. Scheduling procedures must be adapted to the agency's existing organizational structure.
9. Responsibility for project scheduling and monitoring functions should be housed in a high level office responsive to the chief executive officer.
10. The project management system must be able to accommodate policy changes.
11. All external review, approval, or coordination activities must be scheduled.
12. Scheduling must be able to accommodate uncontrollable factors such as federal funding action, inflation, labor problems, and changes in technology.
13. Scheduling and monitoring procedures must identify and accommodate legal restraints.
14. Standard agency terms should be used to describe components of the schedule.
15. The complete description of the preconstruction engineering work required for a particular project can be effectively represented by a network of activity arrows.
16. Realistic time estimates must be assigned to each activity.
17. Project schedules must be developed relative to both single- and multiple-project environments.
18. Activity schedule reports should provide scheduling information tailored to meet the needs of management and operations personnel.
19. Utilization of project schedules depends on and is initiated by effective monitoring procedures.
20. Project progress must be monitored regularly.
21. Project activity progress reports should be concise, simple, and timely.
22. The monitoring function should supply the project status information needs for each management level.
23. Progress reports provide management with a means for assessment and a basis for action.
24. Analysis of project status information may alert management to planned schedules not being met.
25. Once it has been determined that a project's planned schedule will not be met, then management action is required.
26. Improvement in project scheduling and monitoring methods enables management to identify and correct the causes of schedule delay.

Procedural Steps for PCEMS Implementation

The following procedural steps can be used to define the sequential process required to initialize use of the PCEMS system (*5*). These steps are reflected from or based upon the 26 scheduling and monitoring principles listed above and discussed elsewhere (*13*).

Step 1: Organize personnel into work centers for each functional area.

Step 2: Identify activities required for each network and define their relationship relative to project type.

Step 3: Estimate activity base-time requirements and define their relationship to project complexity characteristics.

Step 4: Prepare, code, and submit data for computer run to build the activity responsibility, calendar, schedule period, project characteristics value descriptions, report headings, activity networks, base planning time values, and personnel availability files.

Step 5: Code project attribute information for each project to be scheduled and build the project characteristics file.

Step 6: Use the project characteristics and base planning value files as input to generate the activity time and duration file.

Step 7: Distribute the activity time and duration reports to each work center for review.

Step 8: Code any necessary changes to the computer-generated activity times and duration values and submit for a computer override run.

Step 9: Use the updated activity time-duration and network files as input to generate the single project schedules.

Step 10: Distribute the single project schedule to the work centers for their review of the anticipated bid-letting dates and verification of start and finish dates for all project activities.

Step 11: Prepare and submit computer code to update the single project schedule with new or revised bid-letting dates.

Step 12: Prepare and submit code for computer runs that produce the multiproject schedules and reports.

Step 13: Review workload balance and if changes must be made loop back to Step 8. If workload is balanced, then distribute multiproject schedules to management.

Step 14: Prepare and submit code for computer runs that create the manpower report files and produce the short-range bid-letting schedule, the long-range bid-letting schedule, and the personnel utilization reports. Distribute reports to the appropriate management level.

Step 15: Monitor project progress, then prepare and submit code for computer runs updating the project schedule exception and status reports. These reports provide management with a rational basis for corrective action required by those projects not meeting the planned schedule.

COMPUTER FILE DEVELOPMENT

The PCEMS provides computerized file generation support for three distinct phases of the highway project development process. Figure 3 shows how PCEMS files are generated sequentially and suggests how they can be operationally maintained and/or updated during each phase as required. An overview of the data content for several of the more important PCEMS files is provided in the following paragraphs. A complete description of PCEMS' file generation, operation, updating, and maintenance functions is provided elsewhere (*5–7*).

Program Development Phase

NCDOT annually updates and reschedules the highway capital improvement program during the program development phase. Files either created or updated during this phase include CPM networks, activity responsibility, activity planning values, a work day calendar, personnel availability, the schedule period, project characteristics, and activity time and duration.

CPM network file–contains the logical arrangement of activities required for the preconstruction engineering development on each of several highway project types including new construction, reconstruction, rehabilitation, widening, and structures.

Activity responsibility file–provides a description for each network activity and specifies the work center type responsible for accomplishing each activity.

Activity planning value file–contains base estimates of person hours and days duration required to accomplish a particular activity. The computer will automatically adjust the base values according to project type and complexity.

Calendar file–specifies work days possible from 1978 through 2033 and is used for date and duration calculations.

Personnel availability file–provides work center names, managers, and person hours available for each scheduling period in both the single and multiple project scheduling environments.

Schedule period file–contains schedule periods of one, two, three, or four week lengths spanning a maximum of 10 years.

Project characteristics file–contains both general and specific characteristics for each new project that enters the PCEMS and serves as the basis for calculating the complexity and additive factors that may be required for activity time and duration adjustment.

Activity time and duration file–contains the person hours and days duration factors for each project activity. The computer automatically adjusts these time factors relative to the project length and complexity of the information obtained from the project characteristics file.

The program development phase concludes with the creation of the single project activity (SPA) schedule file.

Multiple Project Scheduling Phase

PCEMS actually begins the multiple project scheduling phase by preparing the SPA file for the multiple project scheduling environment and concludes with the creation of the multiple project schedule (MPS) file.

SPA-MPS interface file–contains the single-project activity schedules prepared for input to the multiple project prescheduler.

MPS preschedule file–contains reformatted SPA-MPS records needed by the main scheduling program. The prescheduler program eliminates all SPA-MPS dummy activities (i.e., activities required only for network logic and have no time requirements) and other activities whose late start dates prohibit their multiple project scheduling.

MPS schedule file–contains records of all the scheduled project activities output by the main scheduling program and based on project priority, early start date, and available personnel required to accomplish the preconstruction engineering work.

Progress Monitoring Phase

Activity progress reporting must be timely and accurate so that management can determine how well the actual start and completion dates for each project activity compare with those scheduled by PCEMS. If over time, the average difference between the actual and planned scheduled dates, is significant, then the activity planning value file containing the base time and duration estimates can be adjusted or updated and the entire capital improvement program easily rescheduled.

Progress/expenditure file–contains actual activity start date, completion date, or percentage completion information.

Archived project file–contains all those completed projects removed from active project files but kept for historical reasons.

Base planning value file–contains base estimates of time, duration, and complexity factors that can be modified or updated as revealed through progress monitoring.

PCEMS OUTPUT

Figure 3 shows that the PCEMS generates 18 computer reports. These reports are designed to provide management with timely scheduling and manpower utilization information. PCEMS Report 9 serves as an example and is shown in Figure 4.

In addition to printed reports, real-time monitor displays of reports 10, 11, 12, 16, and 17 can be invoked with the Customer Information Control System (CICS) procedures. These procedures provide an immediate response to management inquiries concerning project status and manpower utilization.

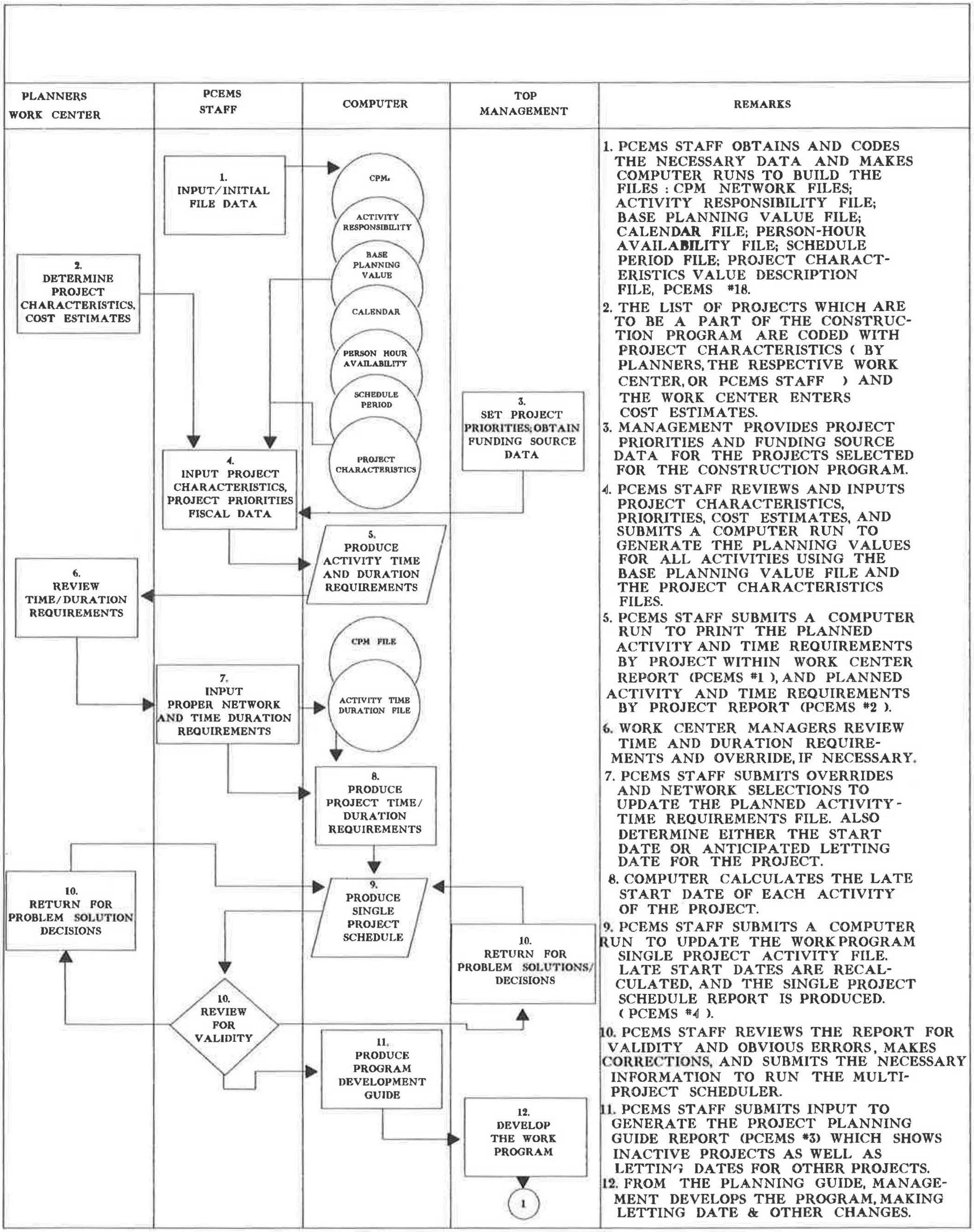

FIGURE 3 **Program development, multiple project scheduling, program monitoring, and planning value updating (*1*). (*continued on next page*)**

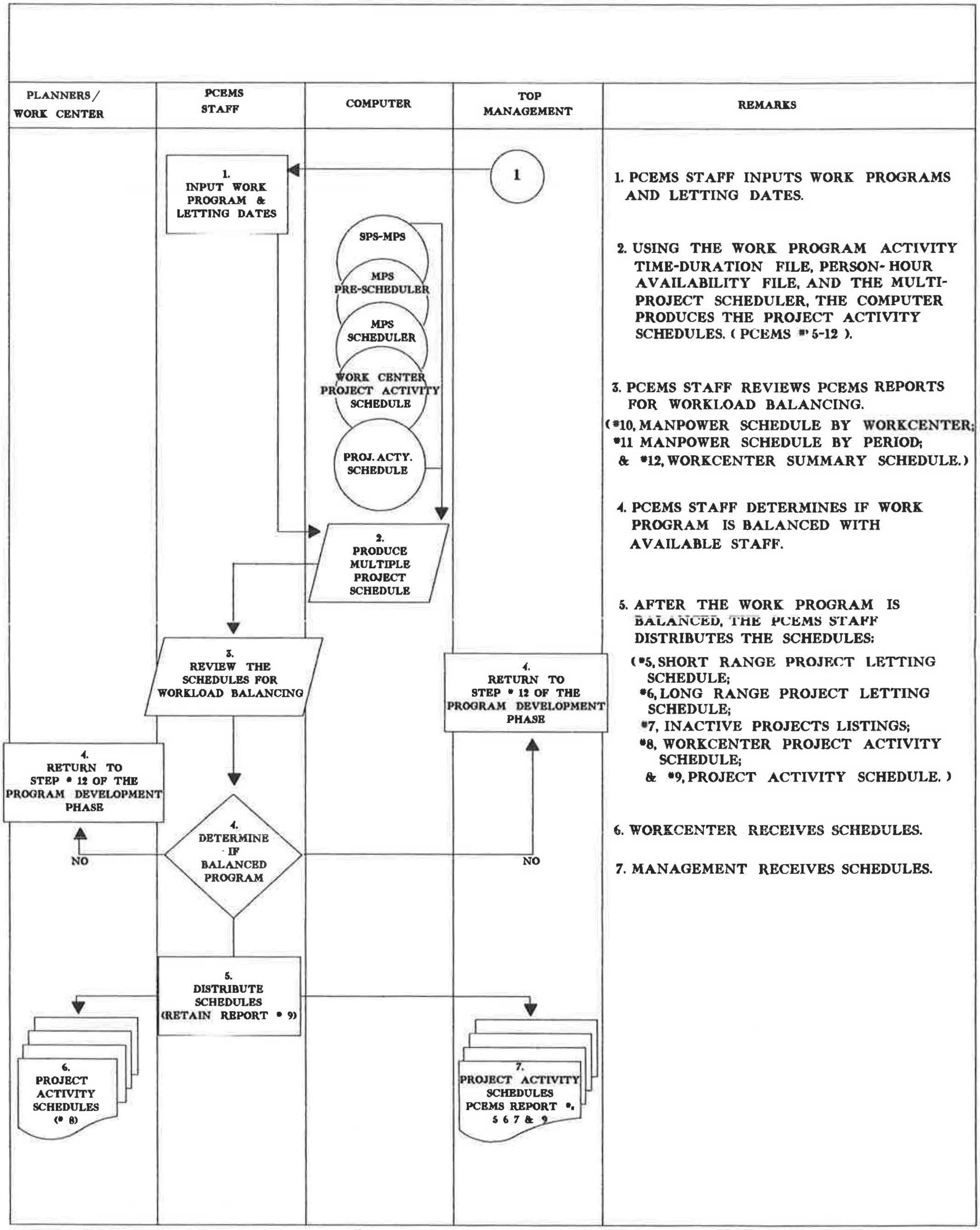

FIGURE 3 *(continued on next page)*

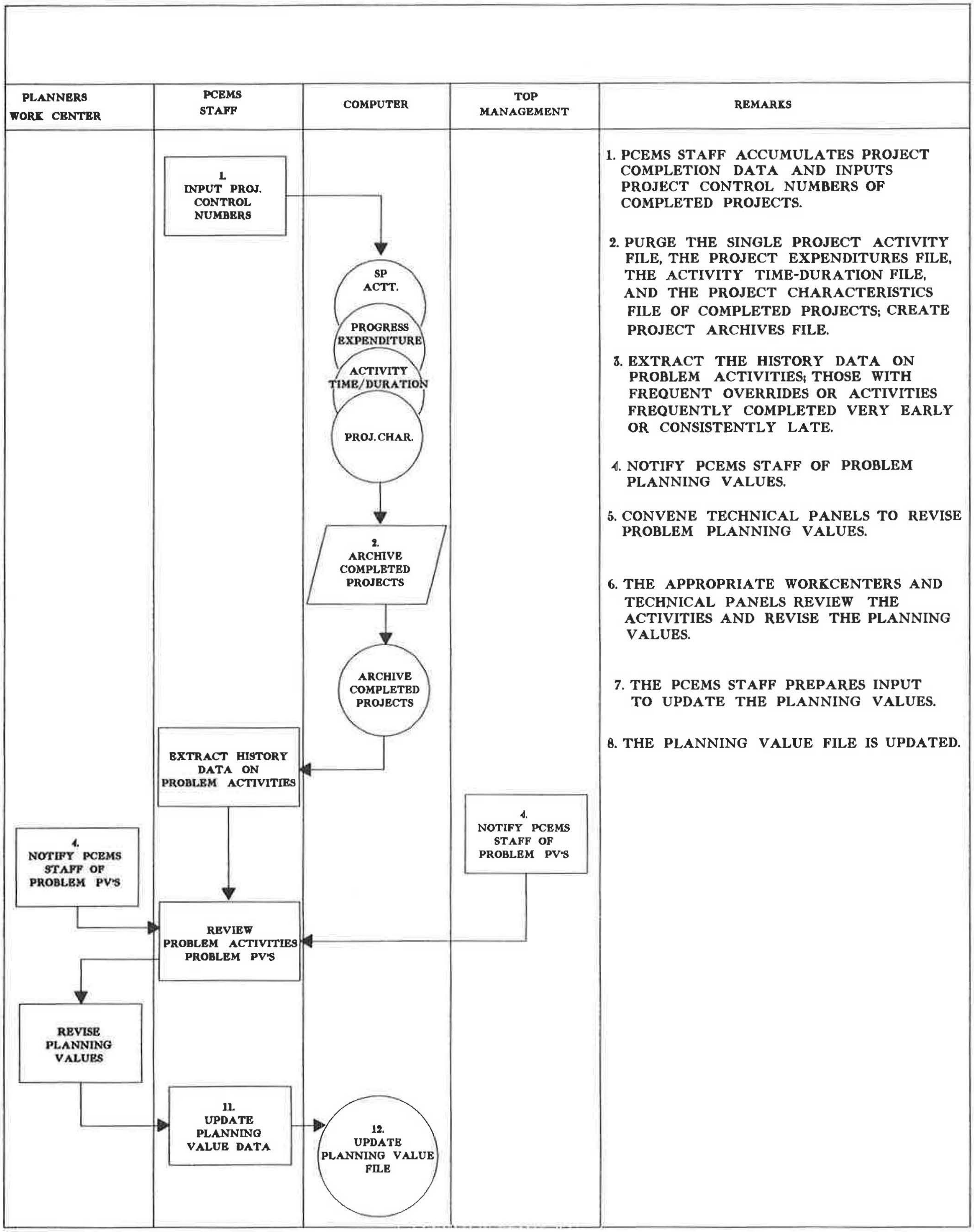

FIGURE 3 *(continued on next page)*

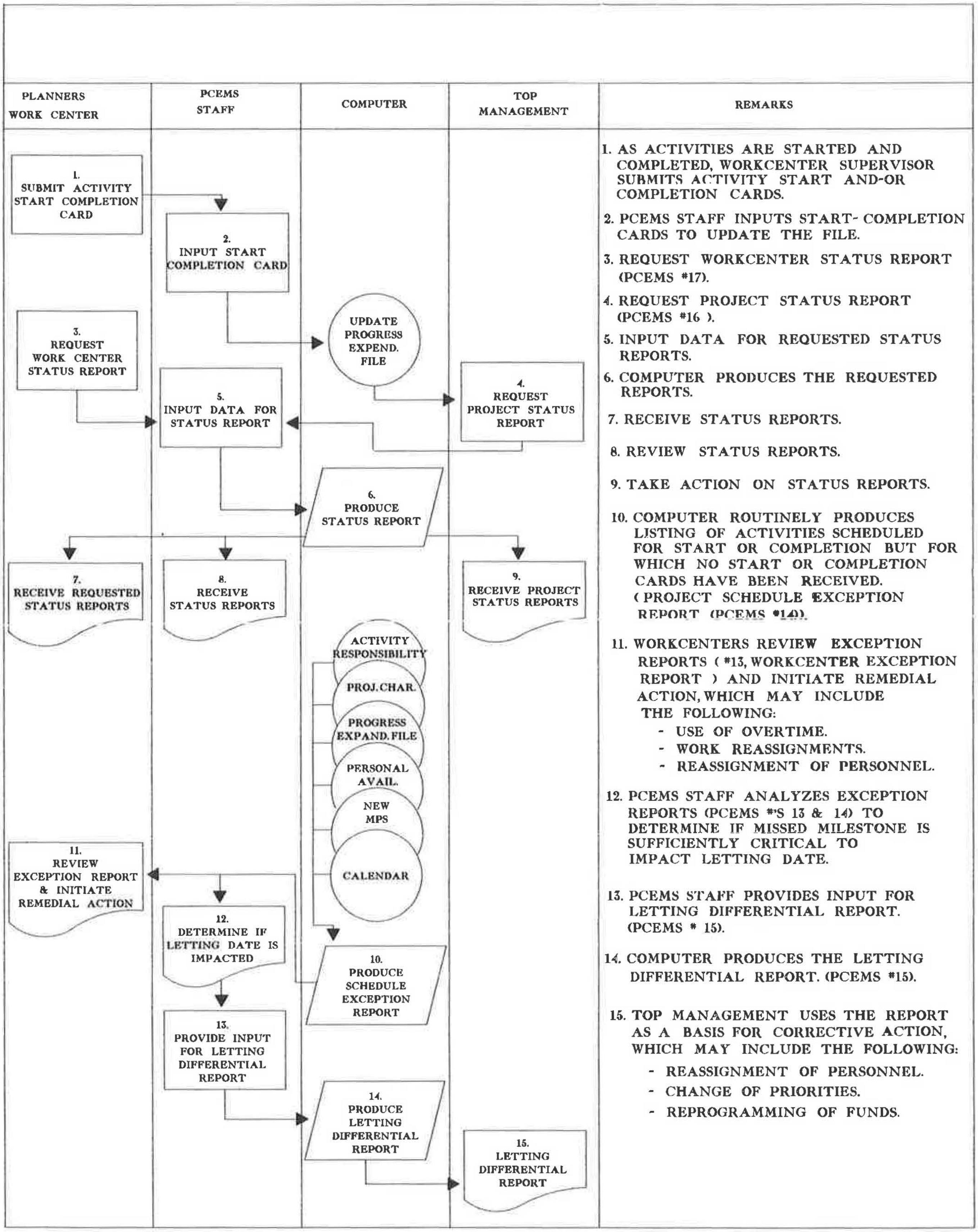

FIGURE 3 *(continued from previous page)*

PAGE NUMBER 223

PCEMS REPORT #9 NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
PROGRAM NO. HC044200
RUN DATE 12/21/89 P R O J E C T A C T I V I T Y S C H E D U L E

CONTROL NO. 0569 PROJECT NO. B-2572 NEW HENDERSON COUNTY

LOCATION/DESCRIPTION US 176. REPLACE BRIDGE NO. 127

ACT NO.	ACTIVITY DESCRIPTION	WORK CENTER	********** S C H E D U L E D ************ MANHRS	DURATION	START	COMPLETION
A195	PROJ.CONCEPT PREP.EXCEPT "W"	6700	130	14	09/09/93	09/28/93
A701	"W" PROJECT CONCEPT PREP.	7600	10	40	09/09/93	11/03/93
A101	PRLM.ENGR.ENVIR.FUNDS AUTH.	6200	1	10	11/04/93	11/18/93
A112	PRELIM. ENGR. FUNDS AUTH.	7300	1	20	11/04/93	12/06/93
A402	PRELIM. BRIDGE STUDY	3704	8	1	12/07/93	12/07/93
A341	BRIDGE DATA COLLECTION	3804	10	15	12/07/93	12/29/93
A551	TENTATIVE PAVEMENT DESIGN PREP	8400	8	3	12/08/93	12/10/93
A652	HYDRAULIC DESIGN	4400	120	8	12/08/93	12/17/93
A205	MATL (BORROW) DETERM.& REPORT	4000	120	20	12/08/93	01/07/94
A490	DESIGN REPORT TO MRG	3600	2	1	12/20/93	12/20/93
A704	MARKING & DELINEATION DESIGN	7700	5	5	12/20/93	12/28/93
A384	PRELIMINARY SIGNING (FOOTINGS)	3804	8	10	12/20/93	01/05/94
A720	PRELIMINARY SIGNING DESIGN	7800	80	30	12/20/93	02/02/94
A491	DESIGN APPROVAL	3600	2	10	12/21/93	01/06/94
A712	EARLY TRAF.CONT.REQUIR.STUDY	7700	2	5	01/07/94	01/13/94
A214	MATERIALS LAB TESTING	4900	24	15	01/24/94	02/11/94
A221	MATERIALS LAB TESTING & REPORT	4900	78	60	01/24/94	04/18/94
A219	MATERIALS REPORT PREPARATION	4900	1	1	02/14/94	02/14/94
A445	PROVIDE PRELM. CONST PHASE PLN	3704	8	1	04/19/94	04/19/94
A427	PREPARE STRUCTURE RECOM.	3704	8	1	04/19/94	04/19/94
A173	FHWA APPROVAL	7300	1	20	04/20/94	05/17/94
A713	PREP.PRELIM.TRAF.CONTR.CONCEPT	7700	5	20	04/20/94	05/17/94
A428	RECOM. TO STRUCTURE DESIGN	3704	8	1	05/18/94	05/18/94
A340	TYPE,SIZE & LOCATION DESIGN	3804	40	10	05/19/94	06/02/94

FIGURE 4 Example of PCEMS output.

During the course of this study PCEMS report numbers 1–6, 8–12, and 16–18 were printed and used extensively in the program development and multiple-project scheduling phases of the highway project development process for the 1990–1996 NCTIP (*13*). It is anticipated that reports 7 and 13–15 will prove useful for the monitoring phase in 1990.

An explanation of purpose, along with a printed sample showing content and format of the standard PCEMS reports 1–18, is contained in an installation guide (*3*). The report number titles are given in Figure 3.

SUBNETWORKING WITH A MICROCOMPUTER

A PCEMS network may contain a maximum of 300 activities. For a particular project type network, these 300 activities could be scheduled over eight or more years. Given this time frame, it is common for many PCEMS activities to have scheduled durations of 12 months or longer. For example, an activity representing an environmental impact statement (EIS) for an environmentally sensitive project may have a scheduled duration of two years. From a project management perspective, it would be desirable to divide such an activity into several subactivities that could be further scheduled on a weekly or even daily basis.

Because of the maximum activity constraint, the PCEMS does not internally provide this subsectioning capability. Externally, however, subnetworking can be easily accomplished by considering each type of PCEMS network as a supernetwork in which each activity can be broken into smaller, independent subnetworks. Given this conceptualization, work center managers can subsection each PCEMS activity into a logical network of subactivities with weekly or even daily time durations. Such networks can be conveniently scheduled with microcomputers.

An important secondary objective accomplished during this study was to specify a working interface between the mainframe-based PCEMS and microcomputer-based project management systems. A simple description of that interface is to use the activity start date as calculated in the PCEMS multiple-project scheduling environment as a starting point for further scheduling on the microcomputer. This means that an activity as output by PCEMS may have a very long duration that can be rescheduled on the microcomputer to yield weekly or even daily schedules.

SUMMARY

Management of the highway project development process requires consideration of many social, economic, and environmental factors. Over time, such factors tend to increase both in number and degree of complexity for preconstruction scheduling and monitoring activities required by the highway development process. Currently the single most important management tool used for highway project development is perceived to be a good scheduling and progress-monitoring system. There has even been national recognition of the need for a computer system design that could be used by state or regional highway agencies to resolve scheduling and monitoring problems.

In response to that national perception of need, the FHWA developed PCEMS, designed as a prototypical computer system that could be adapted to the management needs of any highway agency. Within the PCEMS environment is a scheduling and monitoring subsystem that management can use to ensure that each highway project in the capital improvement program advances through to the contract-letting date on time and within the budget constraints.

The primary objectives for this study were to (a) install, modify, and adapt the PCEMS scheduling and monitoring subsystem to the particular needs of the NCDOT; (b) use PCEMS to schedule all preconstruction engineering activities for the almost 1,600 projects in the capital improvement program; (c) develop a microcomputer method based on subnetworking concepts that could be used to convert long duration activity schedules output by PCEMS to short duration schedules; and (d) determine the effectiveness of PCEMS as a progress-monitoring tool. Three of these objectives were accomplished by the end of 1989 and study findings should be of interest to highway agency managers at all levels. It is anticipated that the effectiveness of PCEMS as a progress-monitoring tool will be determined in 1990.

FINDINGS

During this study, it was found that the PCEMS would (a) initialize and build several permanent computer files basic to project management of preconstruction highway engineering; (b) accept a prioritized listing of programmed projects and their particular characteristics as primary input from management; (c) schedule the projects relative to resource constraints; and (d) generate 18 reports providing preconstruction schedules for every management level responsible for developing the highway system.

CONCLUSIONS

The ways in which NCDOT engineers use PCEMS to develop, schedule, and monitor the preconstruction process for each project in its seven-year highway capital improvement program is described in this paper. The study focus was testing PCEMS' ability to help preconstruction engineering managers more effectively plan, schedule, budget, and monitor the work progress required in the highway project developmental process.

Based on study findings, it was concluded that PCEMS greatly improves the manager's effectiveness in accomplishing the goals of the highway program by assuring that the bid-letting date for each highway project is met. It is further concluded that PCEMS will continue to provide better scheduling and monitoring information to management which should lead to more effective decision making over time.

A final conclusion was that microcomputers can be used as a subnetworking tool to conveniently convert activities with long duration schedules into subactivities yielding weekly or even daily schedules.

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Publication of this paper sponsored by Committee on Transportation Programming, Planning, and Systems Evaluation.

Small Computers and Project Management in Transportation Consulting

Kim Eric Hazarvartian, John Collura, Steven W. Floyd, and Paul W. Shuldiner

Micro- and minicomputer applications to project management in transportation consulting are examined. The goals are to examine the external, organizational, and individual aspects of the implementation of small-computer-aided project management techniques in transportation consulting and to conceptualize a prototype small-computer-aided project management system for transportation consultants. Data collection efforts include mail questionnaires sent to 412 transportation consulting firms with a response rate of 56 percent. Analysis of the data shows that system/work fit (fit between small computer *system* technology and project management *work*), satisfaction with noncomputerized project management methods, organizational innovativeness, level of general computer use, and slack resources are associated with levels of adoption of small-computer-aided project management. Analysis also indicates that small-computer-aided project management is associated with the adequacy of the amount of time that project managers spend on nonquantitative elements of project management.

Transportation consultants conduct their work on a project-by-project basis and must manage these projects to ensure quality and adhere to cost budgets and time schedules. Project management is, in fact, so important to the successful execution and profitability of such projects that it has emerged as an art/science in its own right.

The small computer (micro- and minicomputer) that has evolved during the past decade is an accepted tool used by transportation consultants to help make a wide variety of engineering and planning analyses. It is also clear, however, that the small computer can be applied to elements of project management in transportation consulting. It has become apparent that the application of the small computer can improve both the ease and quality of project management in transportation consulting. Moreover, in recognition of the benefits of computerization, a growing number of software packages are being marketed for application to general-purpose (that is, not limited to transportation consulting) project management.

An overview of the elements of project management is first presented as essential background information. Then, the potential for computerization is discussed. A brief review of the state-of-the-art of small computer applications to project management follows.

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After this discussion, the research project recently completed at the University of Massachusetts at Amherst is presented. The research goals are discussed first. Second, the research model is presented. Third, data collection and analysis are described. Finally, a prototype small-computer-aided project management system is conceptualized.

The effort is believed to be one of the first major formal investigations of the integration of computer technology into the transportation consulting industry, based on a review of the literature. In fact, it may be the first such major inquiry for the greater engineering consulting service industry as a whole.

A "core" application of computer technology, as opposed to the more familiar "peripheral" applications, is the focus. Specifically, project management is at the "mission-essential" core of the transportation consulting. This contrasts with a more traditional application of computer technology such as word processing, which is more peripheral in that it automates a "support" function of transportation consulting.

A key finding of this research is that the transportation consulting industry is beginning to *depend* on computer aids to project management. However, it also found that the potential does exist for increased adoption of computer-aided project management. This finding indicates that the research has both practical value and value as exploratory theory-building.

PROJECT MANAGEMENT IN TRANSPORTATION CONSULTING

Elements of Project Management

The elements of good project management can be summarized into groups of project management objectives, tasks, and interpersonal skills, as listed below:

- Objectives
  —Conforming to professional ethics and proper practices
  —Providing client satisfaction
  —Completing contractual tasks
  —Meeting contractual schedules
  —Meeting profit objectives
- Tasks
  —Planning
  —Organizing and staffing

—Directing
—Monitoring and controlling progress
—Conclusion of the project

- Interpersonal skills
  —Communicating
  —Leading
  —Motivating
  —Managing conflict
  —Negotiating

The above-listed project management tasks concerning planning, monitoring and controlling progress, and conclusion of the project include quantitative measures and, therefore, lend themselves to computer applications. These tasks are discussed in more detail below. This discussion is based on the case of a traffic impact and access study, a typical project for transportation consultants. (A traffic impact and access study evaluates the traffic impacts and access requirements of a proposed land development, particularly with regard to transportation system capacity and safety.) However, the principles and methods can be transferred to other types of transportation consulting projects.

Planning

Because the key constraints imposed on the project manager are money (labor and expenses) and time (delivery dates), two key elements of the project plan are a budget and a time schedule breakdown. Both these plans can be formulated in such a way that they can function as baselines and tools to be used in the postplanning monitoring and control that may be required until the project is concluded.

Project Budget

Three key steps of formulating a detailed project budget are as follows:

- Define the project tasks and subtasks,
- Establish the labor classifications that could be employed in the project, and
- Estimate the distribution of labor hours by labor classification and task.

A sample project budget chart for a traffic impact and access study is shown in Figure 1 (data from Richard S. Bryant). Although this particular detailed project budget centers on labor hours, expenses can also be included.

Time Schedule Breakdown

The time schedule breakdown essentially establishes the planned chronology of tasks to be completed in order to meet the previously set time schedule for delivery of the final product. The first three steps of devising the time schedule breakdown are the same as the three steps in development of the project budget. All that remains to produce the time schedule breakdown is to show the relationship between the subtasks and systematically list them using a graphic tool. The two chief types of tools are bar charts (Gantt or milestone charts) and network diagrams (Critical Path Method and Project Evaluation and Review Technique networks). The simpler of the two tool types, the bar chart, is adequate for most projects in transportation consulting. An example of a bar chart for a traffic impact and access study is shown in Figure 2.

Periodic and Cumulative Labor Budgets

Project planning can be carried to a higher level of detail by establishing periodic and/or cumulative labor budgets. These budgets, which relate the rate of budget expenditure and the passage of time, require information from the detailed project budget and the time scheduling breakdown. The periodic and/or cumulative labor budgets would normally be more applicable to larger projects in transportation consulting. Sample periodic and cumulative labor budgets based on the project budget chart (Figure 1) and project bar chart (Figure 2) are shown in Figure 3.

The periodic labor budget in Figure 3 tabulates the dollar amount of labor planned for expenditure each week of the project effort. The periodic expenditures are broken down by task. The cumulative labor budget shows the cumulative dollar amount of labor planned for expenditure by the end of each week of the project effort. Because this cumulative labor budget is presented in histogram form, it is a readily comprehensible profile of anticipated labor expenditures.

Project Monitoring and Control

If properly executed, the project planning effort described above has defined valid baseline conditions and tools for project monitoring and control. With these tools in place, the next priority in project monitoring and control is to ensure that adequate and timely information is available to measure actual progress against planned progress. On the basis of this comparison, corrective action, if necessary, can be taken.

Information Needs and Monitoring Methods

To monitor progress, the project manager must have timely and adequate information on a periodic basis on the status of project tasks and subtasks and the labor hours/dollars actually expended.

This information can be used to compare actual progress with planned progress, as previously established in the project budget and time schedule breakdown. This comparison can be made graphically by marking charts similar to Figures 1, 2, or 3.

Control

In project control, the project manager takes corrective action, if necessary, on the basis of the findings from the monitoring effort. Possible findings of this effort are shown in the project control matrix depicted in Figure 4. As the figure shows, this

DISTRIBUTION OF MANHOURS BY STAFF CATEGORY AND TASK   XC: FOC/JMM/RB

Client:	TASHJIAN CORPORATION	Job No.	1958
Project:	YEREVAN ACRES	Prep by:	KEH
Budget:	$9000	Date:	1-26-1987

Tasks and Subtasks	Manhours Prin/ Assoc	Sr Proj Mgr	Proj Mgr	Sr Proj Engr	Proj Engr	Word Proc	Draft	Tech	Task Charge
11-DATA COLLECTION 8963									
A. TMC'S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	53.0	53.0
B. MRC'S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	2.0
C. Accidents	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	8.0
D. Data Reduction	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.5	6.5
E. Other	0.0	0.0	0.0	1.0	0.0	0.0	0.0	4.0	5.0
Subtotal	0.0	0.0	0.0	1.0	0.0	0.0	0.0	73.5	74.5
Cost	$0	$0	$0	$51	$0	$0	$0	$1,617	$1,668
12-REPORT PRODUCTION									
A. Word Proc. - Draft	0.0	0.0	0.0	0.0	0.0	8.0	0.0	0.0	8.0
B. Word Proc. - Final	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	4.0
C. Report Graphics	0.0	0.0	0.0	0.0	0.0	0.0	16.0	0.0	16.0
D. Concept Plans	0.0	0.0	0.0	0.0	0.0	0.0	8.0	0.0	8.0
Subtotal	0.0	0.0	0.0	0.0	0.0	12.0	24.0	0.0	36.0
Cost	$0	$0	$0	$0	$0	$432	$600	$0	$1,032
13-BASIC ENGINEERING									
A. Project Initiation	2.0	0.0	2.0	4.0	0.0	0.0	0.0	0.0	8.0
B. Field Visit	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	4.0
C. Background Research	0.0	0.0	0.5	4.0	0.0	0.0	0.0	0.0	4.5
D. Background Development	0.0	0.0	0.5	4.0	0.0	0.0	0.0	0.0	4.5
E. Existing Networks	0.0	0.0	0.5	4.0	0.0	0.0	0.0	0.0	4.5
F. Trip Distribution	0.0	0.0	0.5	3.0	0.0	0.0	0.0	0.0	3.5
G. Trip Generation/Assign	0.0	0.0	0.5	4.0	0.0	0.0	0.0	0.0	4.5
H. Analysis	0.0	0.0	0.5	10.0	0.0	0.0	0.0	0.0	10.5
I. Evaluate Alternatives	2.0	0.0	1.0	8.0	0.0	0.0	0.0	0.0	11.0
J. Concept Plans	1.0	0.0	0.5	12.0	0.0	0.0	0.0	0.0	13.5
K. Documentation-Draft	2.0	0.0	3.0	16.0	0.0	0.0	0.0	0.0	21.0
L. Documentation-Final	1.0	0.0	2.0	4.0	0.0	0.0	0.0	0.0	7.0
M. Permit Preparation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtotal	8.0	0.0	11.5	77.0	0.0	0.0	0.0	0.0	96.5
Cost	$760	$0	$644	$3,927	$0	$0	$0	$0	$5,331
14-MEETINGS									
A. Client Meetings	4.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	6.0
B. Public Meetings	4.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	8.0
Subtotal	8.0	0.0	0.0	0.0	0.0	2.0	4.0	0.0	14.0
Cost	$760	$0	$0	$0	$0	$72	$100	$0	$932
GRAND TOTAL	16.0	0.0	11.5	78.0	0.0	14.0	28.0	73.5	221.0
COST	$1,520	$0	$644	$3,978	$0	$504	$700	$1,617	$8,963

FIGURE 1 Sample project budget chart.

PROJECT BAR CHART

Client:	TASHJIAN CORPORATION	Job No:	1958
Project:	YEREVAN ACRES	Prep by:	KEH
Budget:	$9000	Date:	1-26-1987

Tasks and Subtasks	Task Charge	Week 1	2	3	4	5	6	7	8	9	10
11-DATA COLLECTION 8963											
A. TMC'S	$1,166	*****	***								
B. MRC'S	$44	*****	***								
C. Accidents	$176	*****	***								
D. Data Reduction	$143	*****	*****								
E. Other	$139	*****	*****								
Subtotal Cost	$1,668										
12-REPORT PRODUCTION											
A. Word Proc. - Draft	$288						*	**			
B. Word Proc. - Final	$144								**		
C. Report Graphics	$400			*****	*****	*****	*****	**	**		
D. Concept Plans	$200								**		
Subtotal Cost	$1,032										
13-BASIC ENGINEERING											
A. Project Initiation	$506	***									
B. Field Visit	$204	***									
C. Background Research	$232	*****	*****								
D. Background Development	$232	*****	*****								
E. Existing Networks	$232			*****							
F. Trip Distribution	$181			*****							
G. Trip Generation/Assign	$232			*****							
H. Analysis	$538				*****						
I. Evaluate Alternatives	$654					*****					
J. Concept Plans	$735					*****					
K. Documentation-Draft	$1,174						****				
L. Documentation-Final	$411								***		
M. Permit Preparation	$0										
Subtotal Cost	$5,331										
14-MEETINGS											
A. Client Meetings	$452							***			
B. Public Meetings	$480										*****
Subtotal Cost	$932										
GRAND TOTAL COST	$8,963										

FIGURE 2 Sample project bar chart.

corrective action can include replanning the remainder of the project effort to ameliorate the effects of budget and/or schedule slips. If necessary, and justified, corrective action can take the form of an increase in fee and/or length of schedule as negotiated with the client.

Project Conclusion

The key purpose of the project conclusion is to document what happened during the project to help in future projects. In particular, the project conclusion effort can be instrumental in creating a solid data base of previous project efforts. As previously discussed, this data base can be an important aid in planning future projects.

Project conclusion documents can summarize what happened during the project in terms of task accomplishment, time schedule, and budget. The documents could include

- Project profile,
- Project budget chart,
- Project bar chart, and
- Periodic and cumulative labor budgets chart.

The project profile describes the efforts and products of the project. In the case of a traffic impact and access study, descriptive information could include

- Types and amounts of data collected;
- Format and length of report;
- Type and number of report graphics;
- Number and means of establishing traffic flow networks;
- Analysis locations, scenarios, and methodologies;
- Number of client and public meetings; and
- Names and labor classifications of primary project personnel.

The project budget and bar charts included in the project conclusion documents could simply be the bar chart used for project planning, monitoring, and control, but updated to reflect what happened throughout the project. The periodic and cumulative labor budgets charts included in the project

PERIODIC AND CUMULATIVE LABOR BUDGETS

Client: TASHJIAN CORPORATION Job No.: 1958
Project: YEREVAN ACRES Prep by: KEH
Budget: $9000 Date: 1-26-1987

Tasks		Task Charge	Periodic Labor Budget, by Week 1	2	3	4	5	6	7	8	9	10
11-DATA COLLECTION	8963	$1,668	$1,007	$661	$0	$0	$0	$0	$0	$0	$0	$0
12-REPORT PRODUCTION		$1,032	$0	$0	$83	$83	$83	$179	$225	$377	$0	$0
13-BASIC ENGINEERING		$5,331	$942	$232	$645	$538	$1,389	$1,174	$0	$411	$0	$0
14-MEETINGS		$932	$0	$0	$0	$0	$0	$0	$452	$0	$0	$480
TOTAL		$8,963	$1,949	$893	$728	$621	$1,472	$1,353	$677	$788	$0	$480

Cumulative Labor Budget

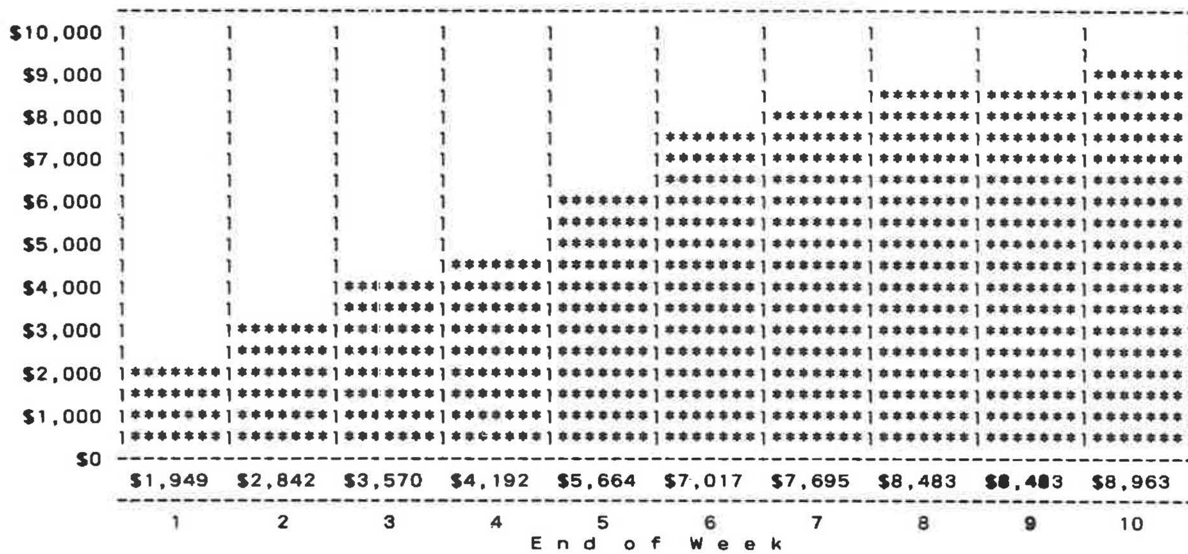


FIGURE 3 Sample periodic and cumulative labor budgets chart.

	Ahead of Schedule	On Schedule	Behind Schedule
Below Budget	• Consider replanning to make best use of the additional remaining budget and schedule.	• Consider replanning to make best use of additional remaining budget.	• Determine/rectify causes of the schedule slip. • Consider replanning to make use of additional remaining budget as a means of accelerating remaining schedule. • Consider negotiating a later delivery date.
On Budget	• Consider replanning to make best use of the additional remaining schedule.	• The remainder of the project effort will require monitoring to avoid budget or schedule slips.	• Determine/rectify causes of the schedule slip. • Consider replanning to accelerate remainder of schedule. • Consider negotiating a later delivery date. • The remainder of the project will require monitoring to avoid further schedule slips.
Above Budget	• Determine/rectify causes of the budget slip. • Consider replanning to make use of additional remaining schedule as a means of reducing remaining expenditures. • Considering negotiating a higher fee	• Determine/rectify causes of the budget slip. • Consider replanning to economize remaining budget expenditures. • Consider negotiating a higher fee. • The remainder of the project will require monitoring to avoid further budget slips.	• Determine/rectify causes of the budget and schedule slips. • Consider replanning to economize remaining expenditures. • Consider negotiating a higher fee. • Consider replanning to accelerate remainder of schedule. • Consider negotiating a later delivery date.

FIGURE 4 Project control matrix.

conclusion documents could likewise be an updated and finalized report.

SMALL COMPUTER APPLICATIONS TO PROJECT MANAGEMENT

Potential for Small Computer Applications

In the preceding discussion of project management in transportation consulting, several project management tools were presented. Each tool can be used manually or computerized. The samples depicted in Figures 1 through 3 were devised on the popular Symphony microcomputer spreadsheet (Lotus Development Corporation, Cambridge, Massachusetts 1984).

Computerization has two chief advantages. The first is that clear, legible charts can be created more quickly on the computer than with manual methods. This assumes that the software has been mastered and/or the appropriate spreadsheet template has been created. The project budget and project bar charts can be quickly built with the computer greatly speeding the normal trial and error approach. With the Symphony spreadsheet shown previously, once the project budget and project bar charts are established, the periodic and cumulative labor budgets chart is automatically constructed.

The second chief advantage of computerization is the ease with which changes can be made to any of the charts. The ability to readily change the charts facilitates project replanning, should it be necessary, and allows quick modification of the charts to convert plans of action to reports of actual action.

Another potential application of computers is the storage and management of the data base of previous project efforts. In particular, the project conclusion documents (project profile, project bar chart, and periodic and cumulative labor budgets chart) could be stored in such a manner that the material could be readily accessed to aid in future project planning efforts.

Carrying things one more step, the data base, if large enough, could be examined and manipulated by statistical means to create more powerful planning tools. For example, regression analysis could show a correlation between the number of intersections (or other independent variables) and the total project budget amount and/or shortest practical delivery schedule (or other dependent variables).

Any of the potential areas for computer application can be addressed with mainframe computers. However, small computers (micro- and minicomputers) are significantly lower in acquisition cost than mainframe computers. In fact, microcomputers are within the financial reach of small consulting firms. In light of this affordability, a review of the state-of-the-art of microcomputer applications to project management has been conducted and is presented in summary form.

Existing Software

Review of the state-of-the-art of microcomputer applications to project management indicates the availability of a number of project management software packages. Moreover, many of these packages are quite powerful, yet cost only several hundred dollars.

Existing microcomputer programs are particularly applicable to project planning, monitoring, and control. Commercially available programs have incorporated many of the standard planning, monitoring, and control tools to include Gantt-type charts, project networks, and budget control charts.

These microcomputer aids complement competent project management. In particular, they can facilitate planning of projects and help ensure timely and frequent tracking of progress. The results can be improved project plans, earlier detection of noncompliance with those plans, timely corrective action, or, if necessary, simplified project replanning.

RESEARCH PROGRAM

Preceding sections of this paper have shown that significant potential exists for applying small computers to project management in transportation consulting. A review of the state-of-the-art shows that a number of software packages are available. However, significant untapped potential also exists. Therefore, the University of Massachusetts at Amherst has conducted a research program to more fully explore the use of small computers in project management by transportation consultants.

Research Goals

The goals of the research effort are to (a) examine the external, organizational, and individual aspects of the implementation of small-computer-aided project management in transportation consulting and (b) conceptualize a prototype small-computer-aided project management system for transportation consultants.

Research Model

The first goal of this research effort is to examine the external, organizational, and individual aspects of small-computer-aided project management techniques in transportation consulting. Pre-existing research, theory, and concepts suggest the overarching research model depicted in Figure 5. The model first posits that external factors, organizational factors, and individual factors are associated with adoption/use of small-computer-aided project management systems. The model also posits that adoption/use of small-computer-aided project management systems is, in turn, associated with benefits to be realized.

Propositions

The research model suggests four research propositions:

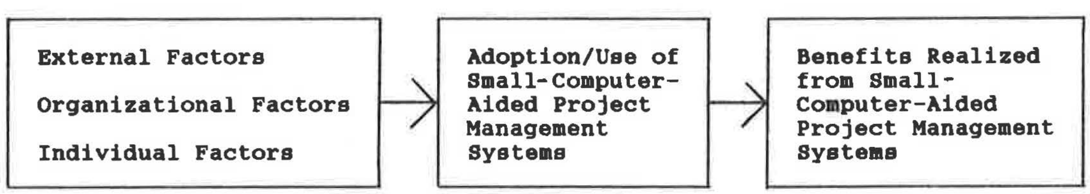
Proposition I External factors affect the adoption/use of small-computer-aided project management systems by a transportation consulting firm.
Proposition II Organizational factors affect the adoption/use of small-computer-aided project management systems by a transportation consulting firm.
Proposition III Individual factors affect the adoption/use of small-computer-aided project management systems.
Proposition IV Adoption and use of small-computer-aided project management systems have resulted in benefits to firms that have adopted those systems.

These propositions were translated into hypotheses tested by using data collected from a sample of transportation consulting firms within the United States.

Data Collection and Analysis

Mail Survey

A mail survey provided information on both current practice in the general application of small computers in transportation consulting and on the specific application of small computers to project management in transportation consulting. The study population was the 662 United States consulting firms in the consultants listing of the Institute of Transportation Engineers (ITE) *Membership Directory: 1988* (*1*). The overall response rate was considered adequate to good. Two hundred twenty-nine of the 412 total firms surveyed by mail returned useable responses representing an overall return rate of approximately 56 percent. The 229 firms represented approximately 35 per-



Note: This is an overarching research model. External factors, organizational factors, and individual factors are associated with adoption/use of small-computer-aided project management systems. Adoption/use of small-computer-aided project management systems, in turn, is associated with benefits to be realized.

FIGURE 5 Research model.

cent of the total population of 662 firms listed in the ITE *Membership Directory: 1988* (*1*).

Analysis of the mail survey data is summarized in Table 1. This analysis is structured in terms of 19 research hypotheses. As shown in Table 1, support for the hypotheses is described in qualitative terms such as "weak" or "moderate." These labels were assigned after making judgments including the data presented in Table 2, a statistical summary of hypothesis analysis. [As is standard practice in the behavioral/social sciences, characterization of strength of support for each hypothesis was based on the *significance* of the regression statistics. This was appropriate because the hypothesis analysis used regression as a tool for exploring the *existence* and *direction* of associations between variables. This differed from frequent practice in engineering analysis in which regression is used to derive equations that can be used to *predict* the value of the dependent variable given a value of the independent variable. With this practice, the explanatory or predictive power of regression (in terms of, for example, the regression coefficient r or the coefficient of determination R^2) would explicitly be important, as well as measures of statistical significance.]

A number of the 19 research hypotheses were supported in various degrees. Support was moderate or moderate to strong for the hypothesized relationship between "adoption/use of small computer-aided project management systems" and the following variables:

- "System/work fit between small computer *system* technology and project management *work*" (positive association),
- "Satisfaction with preexisting noncomputerized project management methods and tools" (negative association),
- "Organizational innovativeness" (positive association),
- "Intensity of general small-computer use within the firm" (positive association), and
- "Slack resources within the firm" (positive association).

Support was very weak, weak, or weak to moderate for the hypotheses that the following variables were associated with

TABLE 1 HYPOTHESIS ANALYSIS SUMMARY

Propositions and Hypotheses		Levels of Support*
Proposition I: External Factors**		
Hypothesis A:	Industry-Level Adoption	Weak
Hypothesis B:	System/Work Fit	Moderate to Strong
Hypothesis C:	Hardware/Software Cost	Weak***
Hypothesis D:	Pre-Existing Satisfaction	Moderate^
Hypothesis E:	Time/Effort Cost	Not Significant^
Hypothesis F:	Resistance by Personnel	Weak to Moderate^
Proposition II: Organizational Factors**		
Hypothesis G:	Organization Innovative.	Moderate to Strong
Hypothesis H:	Management Style	Weak^^
Hypothesis I:	General Computer Use	Moderate to Strong
Hypothesis J:	Number of Employees	Not Significant
Hypothesis K:	Resource Wealth	Moderate
Proposition III: Individual Factors**		
Hypothesis L:	Individual Innovativeness	Weak
Hypothesis M:	Other Individual Factors	Not Supported***
Hypothesis N:	Education/Credentials	Not Significant
Hypothesis O:	Years of Experience	Weak to Moderate^
Proposition IV: Benefits^^^		
Hypothesis P:	Financial Performance	Very Weak
Hypothesis Q:	Firm Quality	Very Weak
Hypothesis R:	Span of Responsibility	Weak
Hypothesis S:	Less Quantitative Tasks	Moderate

* Hypothesized associations are positive, unless otherwise noted.

** External, organizational, and individual factors are posited to be independent variables associated with the dependent variable level of adoption of small-computer-aided project management systems.

*** Lack of association is hypothesized.

^ Negative association is hypothesized.

^^ Firms with participative (as opposed to autocratic) management styles/structures are hypothesized more likely to adopt/use small-computer-aided project management systems.

^^^ Level of adoption of small-computer-aided project management systems is posited to be the independent variable associated with benefit dependent variables.

TABLE 2 STATISTICAL SUMMARY OF HYPOTHESIS ANALYSIS

Propositions and Hypotheses	Four-Page Questionnaire		Two-Page Questionnaire	
	Significant Regressions	Mean R^2 *	Significant Regressions	Mean R^2
Proposition I: External Factors				
Hypothesis A	1 of 4	0.045**	1 of 5	0.079**
Hypothesis B	3 of 4	0.130***	4 of 5	0.260****
Hypothesis C^	0 of 4	NA^^	0 of 5	NA
Hypothesis D	4 of 4	0.079***	1 of 5	0.065
Hypothesis E	0 of 0	NA	0 of 5	NA
Hypothesis F	1 of 4	0.121****	2 of 5	0.107***
Proposition II: Organizational Factors				
Hypothesis G	2 of 4	0.043**	4 of 5	0.175***
Hypothesis H	3 of 4	0.064***	0 of 5	NA
Hypothesis I	4 of 4	0.231****	5 of 5	0.172***
Hypothesis J	0 of 4	NA	Not included in this questionnaire.	
Hypothesis K	2 of 4	0.055***		
Proposition III: Individual Factors				
Hypothesis L	0 of 0	NA	4 of 5	0.130**
Hypothesis M^^^	3 of 4	0.157***	0 of 5	NA
Hypothesis N	0 of 0	NA	Not included in this questionnaire.	
Hypothesis O	2 of 4	0.086***		
Proposition IV: Benefits				
Hypothesis P	0 of 1	NA	1 of 5	0.078**
Hypothesis Q	1 of 1	0.068**	0 of 5	NA
Hypothesis R	1 of 3	0.081**	4 of 10	0.139***
Hypothesis S	1 of 2	0.078***	4 of 5	0.115**

* The mean of only the R^2 that are significant at $p < 0.05$.
** $p < 0.05$. This is the mean p for significant R^2 only.
*** $p < 0.01$. This is the mean p for significant R^2 only.
**** $p < 0.001$. This is the mean p for significant R^2 only.
^ This hypothesis posits lack of association. Because no R^2 are significant, this lack of association is at least weakly supported.
^^ NA stands for Not Applicable. No significant R^2 exist.
^^^ This hypothesis posits lack of association. Because some R^2 are significant, this lack of association is not supported.

"adoption/use of small computer-aided project management systems":

- "The perceived extent of diffusion of small-computer-aided project management systems in the transportation consulting industry" (positive association),
- "Computer hardware/software cost" (no association),
- "Resistance to the technology by organizational personnel" (negative association),
- "Participatory management style" (positive association) versus "autocratic management style" (negative association),
- "Individual innovativeness of project managers" (positive association), and
- "Project manager years of experience" (negative association).

Support was not found for the hypotheses that the following variables were associated (or, in one case, not associated) with "adoption/use of small computer-aided project management systems":

- "Time and effort for system implementation" (negative hypothesized association),
- "Number of firm employees" (positive hypothesized association),
- "Individual project manager differences other than innovativeness" (no hypothesized association), and
- "Level of project manager education and professional credentials" (positive hypothesized association).

Analysis also indicated that "adoption/use of small-computer-aided project management systems" had a moderate positive association with "adequacy of time project managers spent on nonquantitative elements of project management." Weak support was also found for the hypothesis that "adoption/use of small-computer-aided project management systems" was positively associated with "attainment of project, budget, and schedule goals"; "quality of work at a firm"; or "increased spans of responsibility of project managers."

Field Visits

Field visits were conducted to provide qualitative data on applications of small computers in transportation consulting. These visits were important because they allowed firsthand observation of the organization and climate at several consulting firms and provided a basis for interpreting the quantitative results.

Five firms were studied. Only one person was interviewed at four of these firms. At the fifth firm, five individuals were interviewed. All visits were to southern and central New England because of the practical limits on travel. Each visit centered on a one-hour partly structured interview. Findings from the field visit effort are summarized in Table 3.

CONCEPTUAL PROTOTYPE COMPUTER-AIDED PROJECT MANAGEMENT SYSTEM

Several findings justify the conceptualization of a prototype small-computer-aided project management system. First, firms have become dependent on small-computer-aided project management systems, although it must be noted that many of these systems are oriented mainly to accounting and relatively simple project cost-tracking and reporting. Second, in consonance with the dependency that seems to have developed, the transportation consulting industry overall would like to advance, as opposed to regress, in its use of computer-aided project management. Third, room for advancement industrywide clearly does exist. Fourth, individuals within the industry have suggested specific areas for improvement and advancement.

The primary goal of a small-computer-aided project management system would be to create net benefits to transportation consultants that, in turn, would help them better serve the public. The net benefits would hopefully include improvements in firm performance.

To meet this goal, a number of objectives have been identified for such a system.

- The system should have a comprehensive range of capabilities that integrate project management and accounting applications.
- The user interface should be very flexible and "user friendly."
- The system should be very flexible with regard to computer hardware.

TABLE 3 FIELD VISIT SUMMARY

	Young Major Firm	Mature Major Firm	Young Mid-size Firm	Young Small Firm	Regional Office of Small Firm
Age in Years	10	75	6	4*	20
Number of Employees	300	270	80	5	5 **
Number of Offices	4	2	1	1	3
Number Interviewed	5	1	1	1	1
Computer-Aided Project Management	Yes	Yes	Yes	Yes	Yes
General Computer Types	Mini Micro	Mini	Micro (partial network at both these firms)	Micro	Micro
Future Plans	***	^	^^	^^^	-

* Including predecessor corporation. The corporation under its present name was on the order of two years old.

** Five employees in regional office. Twelve for firm as a whole.

*** Additional project management capabilities on minicomputer. Improved timeliness of project reporting.

^ Refinements to existing system. Tracking of direct (non-labor) expenses. Better tracking of profit/loss. Computerized invoicing.

^^ Complete the network and add new microcomputers. More comprehensive project management capabilities.

^^^ Network all microcomputers. Improved accounting software with a good interface between accounting and project management functions.

\- More comprehensive use of computer-aided project management.

- A comprehensive documentation package should be integrated with the system.
- The system should be designed to facilitate customization.
- Full training and support should be available although little should be required.
- The clear benefits of the system should encourage voluntary use.

It is important that the system *integrate* classical project management and accounting capabilities. The goal here would be to reduce duplicated effort and facilitate communication between the project management and accounting functions. Although the integrated system would have a number of sophisticated features, any of these capabilities should be easy to bypass. Some capabilities may not need to be invoked except, for example, on very large or complicated projects.

The project management capabilities should include a wide array of tools for project planning, monitoring, and control. In addition, flexible project cost summary reporting facilities should be included. The system should also be capable of managing and analyzing a data base of previous project efforts. Two key accounting capabilities should be included. The system should include automated invoicing of clients and automated tracking and reporting of aged accounts receivable.

Several classifications of transportation consulting firm personnel would have key roles in the implementation, use, and very important ongoing evaluation of the small-computer-based project management system. These classifications would include project managers and the project staff personnel, accounting personnel, computer system managers, and upper level management (*2*).

CONCLUSION

The transportation consulting industry is in the process of adopting computer technology for a number of uses. Moreover, many of these are *core* uses, such as engineering analysis, as opposed to more peripheral uses, such as word processing. The adoption of computer technology to project management in transportation consulting is slightly less advanced than these other computer applications. In addition, adoption for project management was generally more advanced for project management uses that overlapped with accounting functions, such as labor and expense tracking and billing. However, the general indication is that firms plan to expand and refine their computer use in project management.

Data analysis indicated that system/work fit, satisfaction with noncomputerized project management methods, organizational innovativeness, level of general computer use, and slack resources were associated with levels of adoption of small-computer-aided project management. The analysis also indicated that small-computer-aided project management was associated with the adequacy of time project managers spent on nonquantitative elements of project management.

ACKNOWLEDGMENTS

This paper is based on research conducted for the Transportation Program of the Department of Civil Engineering at the University of Massachusetts at Amherst. The authors thank Susan Lee for her supervision of research administration and John Michael Moschella for his assistance in data collection.

The Institute of Transportation Engineers (ITE) also participated in this research. The authors especially thank the ITE Consultants Council and Thomas W. Brahms, Executive Director of the ITE, for their efforts.

The authors also thank the Department of Civil Engineering at Merrimack College, North Andover, Massachusetts, for its support. In addition, they thank Vanasse Hangen Brustlin, Inc., 60 Birmingham Parkway, Boston, Massachusetts, with special acknowledgment of Robert D. Vanasse, Richard S. Bryant, Christopher D. Brandon, and Paul J. Oullette.

Finally, the authors thank the hundreds of transportation consultants who anonymously provided data essential to this research.

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Publication of this paper sponsored by Committee on Transportation Programming, Planning, and Systems Evaluation.

Approach To Combine Ranking and Optimization Techniques in Highway Project Selection

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In pavement and bridge management systems, often two different techniques are employed for selecting rehabilitation and replacement projects. Prioritization or ranking techniques provide a list of projects ranked according to a given set of criteria. Optimization, on the other hand, gives a list of projects that satisfies a set of criteria including budget and other constraints over a certain period. The two may produce two different sets of results because of the difference in approaches. To have consistency in decision making, it is desirable to connect the two project selection models so that their results are comparable. The ranking and optimization models would then have a direct correspondence and the results could be compared and analyzed on the basis of common criteria. An approach combining ranking and optimization techniques is presented. The approach is illustrated by using an example of bridge management for Indiana. First, the ranking and optimization models are briefly introduced, and the concepts of the new approach based on the existing models are presented and explained. A numerical example is given, and the results from the new approach and the existing ranking model are compared and discussed through the example.

Ranking and optimization are two of the techniques most widely used to select highway projects. However, these two approaches are very different in concept. Ranking techniques evaluate several related factors of a project simultaneously and yield a quantitative ranking value based on the evaluation of these factors. Thus, all the considered projects are ranked according to their corresponding ranking values. The ranking methods do not necessarily give an optimal solution. Nevertheless, a ranking approach is simple to use and provides the relative order of importance of different projects. Such an ordered list can be used to make final decisions on the basis of project ranking values.

On the other hand, an optimization technique produces an optimal solution of a highway system while the projects are selected subject to a set of constraints. The optimal solution is obtained either by maximizing the system benefit or by minimizing the total negative effect on the system caused by undertaking the selected projects. Different from ranking methods, optimization techniques do not follow the rule of "choosing the projects with the worst conditions." Instead, the optimization techniques select the projects that contribute the most benefit to the highway system, while all the constraints are satisfied simultaneously.

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Like many other pavement and bridge management systems, the Indiana Bridge Management System (IBMS) provides two models, ranking and optimization models, for selecting bridge rehabilitation and replacement projects. Thus, decision makers have two alternative methods for bridge project selection. However, because of the different concepts of the two techniques, the two models produce two different sets of results. It would be desirable to combine the techniques so that the ranking and optimization models would have a direct connection, and the results could be compared and analyzed on the basis of common criteria. An approach to combining ranking and optimization techniques is presented. The existing ranking and optimization models are briefly introduced, and the concepts of the new approach based on the existing models are presented and explained. An example is given to illustrate the proposed approach, and the result of the approach and that of the existing ranking model are compared and discussed through the example.

RANKING MODEL

Setting priorities on pavement and bridge-related projects is usually a multiattribute decision-making problem, requiring decision makers to evaluate simultaneously several related factors. The ranking model of IBMS was developed using the technique of the analytic hierarchy process (AHP) (*1*). This model not only helps decision makers set the relative order of importance of different projects, but also indicates how much importance one may have over the other.

The AHP method is a useful tool to rank projects when subjective judgments are involved. However, a direct application of the method may not be practical when the number of projects is large. For example, even when there are only 22 bridge projects to compare, one must make 231 pairwise comparisons for each evaluation criterion [22(22 − 1)/2]. Assuming that six criteria are under consideration, the number of pairwise comparisons is 1,386. The number of projects may range between 500 and 1,000, and the direct use of the AHP is thus impractical.

This problem, however, can be solved by including the concept of utility. In a highway facility management system, utility is the level of overall effectiveness that can be achieved by undertaking a project. If an appropriate utility is assigned to projects with respect to certain evaluation criteria, the expected utility of each alternative project can be evaluated. Then, the top priority project is the alternative with the highest expected utility value. An example of a utility curve is shown in Figure 1. In order to apply the concept, it is necessary to find factors common to all projects. The best candidates for bridge projects are physical attributes of the bridges because all bridges can be described by such attributes as structural condition and deck widths.

Figure 2 illustrates the hierarchy system of the ranking model for IBMS. This four-strata hierarchy consists of an overall goal of the ranking exercise, objectives that bridge managers would like to achieve, evaluation criteria with utility curves, and individual bridges. The criteria weights can be obtained by applying the eigenvector approach proposed by Saaty (*1*).

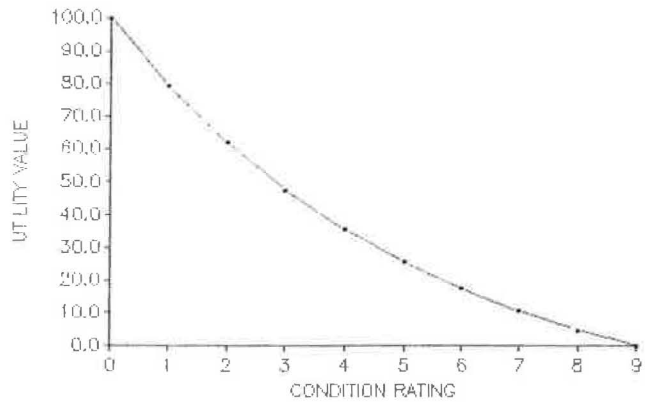

FIGURE 1 Utility curve of bridge condition rating.

OPTIMIZATION MODEL

Optimization techniques are used to obtain a list of projects so that an objective function, such as systemwide condition or level of service, can be optimized subject to a set of budget and other constraints over time. For the IBMS, such a model was developed on the basis of dynamic programming and integer programming (*2*). Markov chain transition probabilities of bridge structural conditions were used in the model to predict or update bridge structural conditions at each stage of the dynamic programming (*3*).

The dynamic programming considers the available federal and state funds of each year in terms of several possible spend-

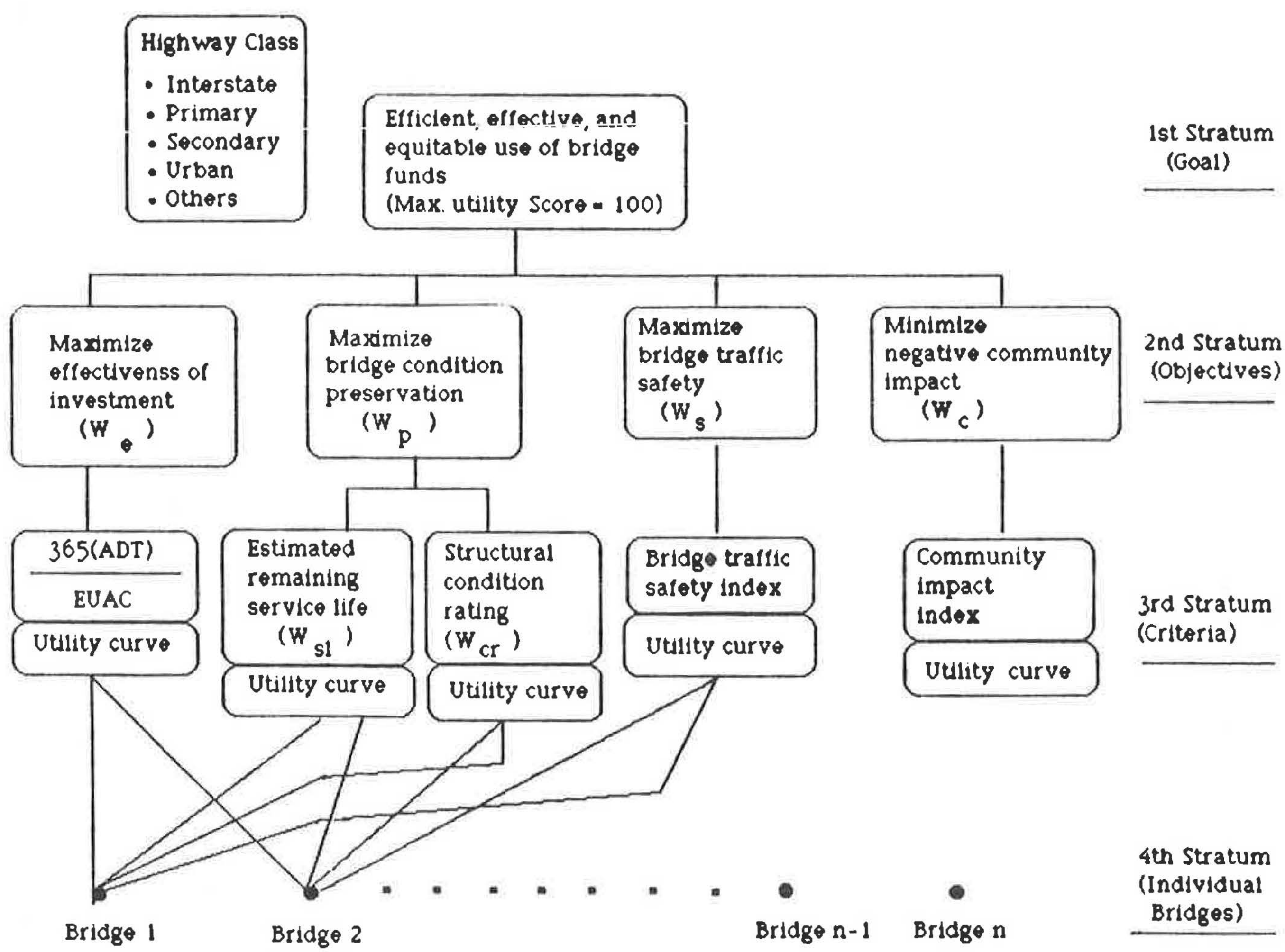

FIGURE 2 Hierarchy system of the ranking model.

ing portions, and the integer linear programming selects projects by maximizing yearly systemwide effectiveness subject to different budget spendings. The dynamic programming chooses the optimal spending policy, which maximizes the system effectiveness over a program period, by comparing the values of effectiveness of these spendings resulting from the integer linear programming.

In dynamic programming, each year of the program period is a stage. The federal and state budgets are state variables. Each activity of a bridge is a decision variable of the dynamic programming as well as of the integer linear programming. The effectiveness of the entire system is used as the return of the dynamic system.

At each stage, a decision must be made as to the optimal solution from Stage 1 to the current stage. When a decision is made, a return (or reward) is obtained and the system undergoes a transformation to the next stage. The bridge conditions are updated for the next stage by the Markov transition probabilities obtained in the performance model (*3*). For a given program period, the objective of the model is to maximize the effectiveness of the entire system. The formulation of the model along with the definition of system effectiveness is discussed as follows.

The effectiveness of a bridge improvement activity was defined as follows:

$$E_i = \text{ADT}_i * A_i(a) * (1 + \text{Csafe}_i) * (1 + \text{Cimpc}_i) \quad (1)$$

where

- E_i = effectiveness gained by bridge i if activity a is chosen;
- a = improvement activity ($a = 1$ corresponds to deck reconstruction; $a = 2$ to deck replacement; and $a = 3$ to bridge replacement);
- ADT_i = average daily traffic on bridge i;
- $A_i(a)$ = representation of average area under performance curves of components of bridge i due to the increase of condition ratings caused by undertaking activity a;
- Csafe_i = transformed coefficient of traffic safety condition (primarily based on bridge geometrics) of bridge i, ranging from 0.0 to 1.0; and
- Cimpc_i = transformed coefficient of community impact of bridge i in terms of detour length, ranging from 0.0 to 1.0.

Considering that budgets can be carried over from year to year, the mathematical model for maximizing the overall effectiveness of various activities over a program period T was formulated:

$$\max \sum_{t=1}^{T} \left[\sum_i \sum_a X_{i,t}(a) * E_i * d_i(t) \right] \quad (2)$$

The model is subject to the following constraints:

Available federal budget,

$$\sum_{t=1}^{T} \left[\sum_i \sum_a X_{i,t}(a) * c_i(a) * F_i \right] \leq C_{BF} \quad (3)$$

Available state budget,

$$\sum_{t=1}^{T} \left[\sum_i \sum_a X_{i,t}(a) * c_i(a) * (1 - F_i) \right] \leq C_{BS} \quad (4)$$

One activity cannot be undertaken more than once on one bridge in T years,

$$\sum_{t=1}^{T} X_{i,t}(a) \leq 1 \quad (5)$$

Constraints in Equations 6 to 10 correspond to an integer linear programming:

Maximize system effectiveness of year t,

$$\max \sum_i \sum_a [X_{i,t}(a) * E_i * d_i(t)] \quad (6)$$

Spending constraint of year t for federal budget,

$$\sum_i \sum_a [X_{i,t}(a) * c_i(a) * F_i] \leq \eta_{tF} \quad (7)$$

Spending constraint of year t for state budget,

$$\sum_i \sum_a [X_{i,t}(a) * c_i(a) * (1 - F_i)] \leq \eta_{tS} \quad (8)$$

No more than one activity can be chosen on one bridge in year t,

$$\sum_{a=1}^{3} X_{i,t}(a) \leq 1 \quad (9)$$

Decision variable,

$$X_{i,t} = 0 \text{ or } 1 \quad (10)$$

Update bridge conditions by Markov chain transition probabilities if bridge i is not selected in year t,

$$R_{i,t+1} = R_{i,t} * p_i(R,t) + (R_{i,t} - 1) * (1 - p_i(R,t)) \quad (11)$$

Improvement of bridge condition if bridge i is selected in year t for activity a,

$$R_{i,t+1} = R_{i,t} + R_i(a) \quad (12)$$

where

- $X_{i,t}(a)$ = 1, if bridge i is chosen for activity a; = 0, otherwise;
- $d_i(t)$ = the absolute tangent value on performance curve of bridge i at time t;
- C_{BF} = total available federal budget for the program period;
- C_{BS} = total available state budget for the program period;
- F_i = federal budget share of bridge i;
- $1 - F_i$ = state budget share of bridge i;
- $c_i(a)$ = estimated cost of bridge i for activity a;
- η_{tF} = spending limit of federal budget in year t;

$\eta_{t,S}$ = spending limit of state budget in year t;
$R_{i,t}$ = condition rating of bridge i in year t;
$p_t(R,t)$ = Markov condition transition probability of bridge i with condition rating R in year t; and
$R_i(a)$ = condition rating gained by bridge i for activity a.

Equations 2 through 12 constitute a dynamic programming that includes an integer linear programming (Equations 6 to 10) as part of the constraints. The model's objective is to obtain optimal budget allocations and corresponding project selections over T years so that the system effectiveness can be maximized. The number of spending level combinations, N, can be expressed in terms of the number of possible spendings of each year, S, and the program period, T, as $N = S^{T-1}$. When T is large, the number of possible spending combinations becomes so large that the search for the optimal path of spendings from year 1 to year T requires great effort and computation time.

Dynamic programming is an efficient technique to search for the optimal path among the combinations of spendings. Rather than examining all paths, dynamic programming looks at only a small number of these paths. According to the principle of optimality, at each stage the programming finds the optimal subpath up to the current stage, and only this subpath is used to search for the optimal subpath to the next stage. Paths that do not belong to the optimal subpath are abandoned as the search goes on. This makes the search efficient and saves a great deal of time.

PROPOSED APPROACH

Either of the two models for project selection, ranking or optimization, can be used to select bridge projects based on priority order or optimization with respect to systemwide benefit. However, because the two models rely on different techniques and concepts, it is difficult to find a common ground for comparing the result of the ranking model with that of the optimization model. That is, there is no direct relationship between a utility value of the ranking model and an effectiveness value of the optimization model. It is desirable that the results of different approaches be comparable. A common criterion should be adopted to make the two models interacting.

As can be seen, the AIIP ranking model for IBMS used such factors as average daily traffic, bridge activity cost, estimated service life, structural condition rating, bridge traffic safety index, and community impact as ranking criteria. Inclusion of these factors in the process of bridge project selection made the resulting utility values reflect the main concerns of bridge rehabilitation and replacement activities. The utility values produced by the ranking model thus can be used to measure the effectiveness criterion in the optimization model.

With utility values as common measures for the ranking and optimization models, the proposed approach can be developed easily by modifying the existing models. Because the utility values range from 0 to 100, with 0 being the utility value of a "perfect" bridge and 100 the value of the "worst" bridge, the utility value of a bridge will decrease after a rehabilitation activity is undertaken. Thus, the difference in utility values before and after a bridge activity is undertaken indicates the improvement in overall utility. This difference, therefore, can be defined as the effectiveness or benefit of the bridge activity. Incorporating this definition into the dynamic optimization model, the programming objective thus becomes to maximize the total decrease in utility values of the bridge system subject to the budget constraints.

The only modification of the dynamic programming formulation needed to combine the two models is to change Equation 1 to the following:

$$E_i = U_{ib} - U_{ia} \tag{1a}$$

where

E_i = effectiveness gained by bridge i if an activity is undertaken,
U_{ib} = utility value of bridge i before the activity is undertaken, and
U_{ia} = utility value of bridge i after the activity is undertaken.

Thus, the formulation of the new approach is obtained by substituting Equation 1a for Equation 1; Equations 2 through 12 remain unchanged. The value of E_i would be available from the ranking model. This value is the weighted summation of individual utility differentials for economic efficiency, remaining service life, structural condition, traffic safety, and community impact.

The change of Equation 1 to Equation 1a combines the ranking model and the optimization model. Thus the result obtained from the optimization model can be directly compared with that of the ranking model in terms of the total gain in utility values. The change in the computation will be to have Equation 1a as a subroutine of the dynamic optimization program. This subroutine is, in effect, the ranking program. At each stage of the dynamic optimization process, the ranking program, as a subprogram, computes the system benefit, or the total gain in utility values, and the dynamic programming as the main program makes optimal project selection according to the system benefit.

APPLICATION EXAMPLE

To compare results of the ranking model with the new approach, 50 state highway bridges in Indiana needing rehabilitation or replacement were selected and the ranking and new approach programs were run. Table 1 presents the result of the ranking model.

Because the project selection in the new approach depends on available budgets, the new approach program was run several times using different given budgets. One result, shown in Table 2, was obtained with a given budget of $11,128,000, or about 25 percent of the total budget needed for repairing and replacing all 50 bridges. The total gain in utility, or the systemwide benefit, was 900.0. With the same budget, one can also select bridge projects from the ranking list in Table 1. Selecting the bridges from the top of the list, the first six bridges in Table 1 could be chosen with the given budget. With this selection the total cost is $10,081,180 and the total gain in utility is 272.6.

By dividing the total gain in utility by its corresponding total cost, the gain in utility for the proposed approach is

TABLE 1 OUTPUT OF THE RANKING MODEL

Bridge No.	Priority	U_i	E_i	ΣE_i	C_i	ΣC_i	Activity
31	1	72.9	52	52	2159	2159	BRP
30	2	72.5	50	102	1210	3369	BRP
47	3	72.3	46	148	1549	4918	BRP
27	4	70.4	53	201	5000	9918	BRP
49	5	69.9	51	252	65	9983	DRC
24	6	69.0	21	273	98	10081	DRC
25	7	68.9	18	291	1993	12074	DRC
26	8	68.0	52	343	500	12574	BRP
46	9	67.6	50	393	965	13539	BRP
33	10	65.0	50	443	545	14084	BRP
50	11	65.0	50	483	280	14364	BRP
28	12	63.2	48	541	6228	20593	BRP
37	13	61.2	50	592	840	21433	BRP
48	14	60.5	50	642	420	21853	BRP
32	15	60.1	51	693	3409	25262	BRP
42	16	60.1	50	743	1571	26833	BRP
40	17	59.4	50	793	193	27026	BRP
17	18	59.0	46	839	1090	28116	DRC
43	19	59.0	50	889	1029	29145	BRP
44	20	59.0	50	939	388	29533	BRP
45	21	59.0	50	989	288	29821	BRP
23	22	55.7	40	1029	296	30117	DRC
35	23	52.7	42	1071	635	30759	BRP
34	24	51.7	42	1113	1297	32049	BRP
10	25	51.7	29	1142	330	32379	DRC
38	26	50.0	41	1183	3153	35532	BRP
36	27	49.2	38	1221	840	36372	BRP
39	28	46.0	37	1258	295	36667	BRP
11	29	42.0	15	1273	269	36936	DRC
29	30	42.0	33	1306	2192	39128	BRP
13	31	36.0	23	1329	201	39329	DRC
22	32	36.0	13	1342	164	39493	DRC
41	33	35.9	29	1372	385	39878	BRP
9	34	32.6	15	1387	257	40135	DRC
12	35	32.0	19	1406	201	40336	DRC
21	36	31.9	9	1415	247	40583	DRC
8	37	30.3	15	1430	1300	41883	DRC
18	38	28.6	8	1438	66	41949	DRC
7	39	28.4	12	1450	210	42159	DRC
3	40	28.2	12	1462	387	42546	DRC
6	41	27.0	10	1472	121	42668	DRC
20	42	26.9	8	1480	119	42787	DRC
14	43	26.8	4	1484	476	43262	DRC
16	44	26.6	10	1494	154	43416	DRC
15	45	23.0	4	1498	74	43491	DRC
4	46	22.3	8	1506	281	43771	DRC
5	47	21.9	8	1513	107	43878	DRC
1	48	20.4	8	1521	235	44113	DRC
2	49	20.0	8	1529	276	44389	DRC
19	50	19.9	4	1533	124	44512	DRC

Note: U_i = Utility Value of Bridge i.
E_i = Effectiveness, or Change of Utility Value, of Bridge i.
C_i = Cost of the Activity of Bridge i, in $1000.
BRP = Bridge Replacement.
DRC = Deck Reconstruction.

TABLE 2 OUTPUT OF THE PROPOSED APPROACH

Bridge No.	E_i	C_i	Activity
1	8	235	DRC
4	8	281	DRC
6	10	121	DRC
7	12	210	DRC
9	15	257	DRC
10	29	330	DRC
11	15	269	DRC
12	19	201	DRC
13	23	201	DRC
15	4	74	DRC
16	10	154	DRC
17	46	1090	DRC
18	8	66	DRC
19	4	124	DRC
20	8	119	DRC
21	9	247	DRC
22	13	164	DRC
23	40	296	DRC
24	21	98	DRC
26	52	500	BRP
33	50	545	BRP
35	42	635	BRP
36	38	840	BRP
37	50	840	BRP
39	37	295	BRP
40	50	193	BRP
41	29	385	BRP
44	50	388	BRP
45	50	288	BRP
46	50	964	BRP
48	50	420	BRP
50	50	280	BRP

Note: E_i = Effectiveness, or Change of Utility Value, of Bridge i.
C_i = Cost of the Activity of Bridge i, in \$1000.
BRP = Bridge Replacement.
DRC = Deck Reconstruction.

900.0/11,128,000 = 81 units per million dollars, and that for the ranking method is 272.6/10,081,180 = 27 units per million dollars. Therefore, the value of the proposed approach is three times as large as the value of the ranking method in this example.

Figure 3 presents a comparison of the results from the two approaches in terms of system benefits and available budget. The proposed approach always gives a better solution than the ranking approach when the available funds are less than 100 percent of the need.

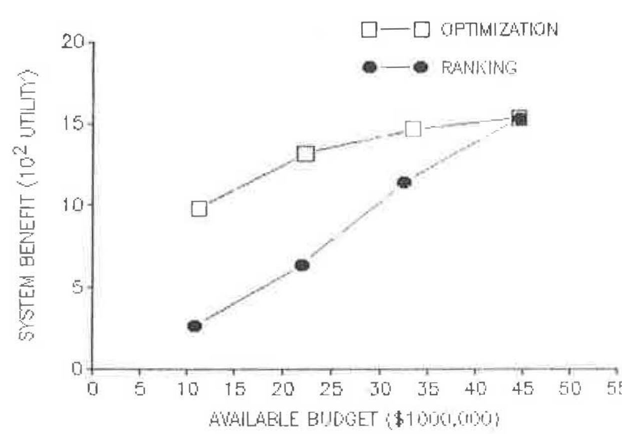

FIGURE 3 Comparison of ranking and optimization approaches.

CONCLUSIONS

By defining the system benefit as the total gain in utility values, the ranking and optimization models can be combined.

An example of 50 bridge projects demonstrated the usefulness of this proposed approach. In pavement and bridge management systems, both ranking and optimization techniques are used for project selection. By adopting an approach that allows a direct linkage of these two approaches, decision making can be improved.

ACKNOWLEDGMENTS

This paper was prepared as part of an investigation conducted by the Joint Highway Research Project Engineering Experiment Station, Purdue University, in cooperation with the Indiana Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

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Publication of this paper sponsored by Committee on Transportation Programming, Planning, and Systems Evaluation.

U.S. Highway Capital Programs: Elements of Dynamics and Innovation

KANT RAO AND THOMAS D. LARSON

Methodologies for highway capital program management vary widely among state departments of transportation in the United States despite common funding sources and functional disciplines. Capital program management consists of measuring current highway physical and operating conditions, estimating future conditions, determining deficient sections, identifying cost-effective treatments, ordering projects according to established goals and policies, and developing program strategies that create and exploit opportunities for system improvement. State practices diverge to the greatest extent in the areas of establishing and implementing dynamic program strategies. The well-documented decline in infrastructure investment in the United States, coupled with various institutional changes under way, demands that the capital program management strategies become more dynamic and innovative. An overview of the changing transportation environment in the United States and how this has affected capital program management is presented. A 7-element framework to explore and understand this management process is developed. Results from an analysis of practices in eight states in the United States are described. This analysis reveals how various external factors as well as self-imposed conditions hold back or promote the dynamics of the programming process. Fifteen factors were found to be critical in this analysis. These factors ranged from obvious ones such as leadership, focus, and institutional relations to less obvious ones such as structured flow in program development, relief valves in the program structure, and real-time objective data for information analyses and program control.

Highway capital improvements have been a principal raison d'être and have provided the earliest justification for society's creation and support of highway and successor transportation agencies. Although this is now true to a lesser degree than when the highway systems were being newly built in the United States, nevertheless, the highway capital program management process remains highly visible and the delivery of high-quality, high-priority capital projects is perhaps the most readily measurable indicator of transportation agency performance.

The key activities in highway capital program management are as follows:

- Assessing current and projected highway system physical and operating conditions using quantitative measures whenever possible;
- Determining within some framework for categorization where and in what priority improvements should be effected, consistent with overall state and transportation agency strategy and goals;
- Developing a range of technically feasible options for the priority improvements sites and testing these against transportation, fiscal, political, environmental, and other impacts;
- Developing strategies that are creative to the point of being exploitive with respect to identification and application of resources to the array of ordered system improvements; and
- Budgeting, scheduling, letting to contract, and controlling these capital investments to completion.

The well-documented decline in infrastructure investment in the United States and the massive changes occurring in the transportation environment demand that the above capital program management activities become more dynamic and innovative. Analysis of several case studies reveals how various external as well as self-imposed factors can hold back or promote the dynamics in the programming process. A full description of these case studies is available in *NCHRP Synthesis of Highway Practice 151* (*1*).

An overview of the changing transportation environment and how this has affected capital program management is presented. This is followed by a conceptual view of the program management process and a discussion of the major factors affecting dynamics and innovation. Finally, some concluding observations are offered.

THE CHANGING TRANSPORTATION ENVIRONMENT

Even a casual observer may perceive significant changes in the highway transportation business during recent times. Following are some dimensions to and reasons for that change:

- The system is mature both geographically and physically. There is a growing maintenance and rehabilitation backlog as first life cycles are lived out and exceeded. The rapid early 20th century initial system construction period makes this, in economic terms, a "lumpy" phenomenon. For example, a large number of Federal-Aid primary system bridges are due or past due for replacement.
- The old institutional management and fiscal frameworks are vanishing and their replacements are only dimly perceived. For instance, the federal presence is being reduced, and the federal funding framework could change dramatically in 1991 when current legislation expires. As another example, chief administrators (at both state and federal levels) serve shorter terms, and so "institutional memory" is lost.

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• Transportation is rapidly becoming more than transportation—society is redefining what it means by infrastructure in general and transportation in particular (*2*). For example, more than just freight haulers, highway transport companies are now components of manufacturing production, competing in a global marketplace. They are responsible for accommodating just-in-time (JIT) inventory and the consequent opportunity for cost containment and quality improvement. In some states, the planning process for highways is changing, with a growing emphasis on a strategic view of transportation. With this redefinition, transportation infrastructure will come under more public and legislative scrutiny, and there will be increasing pressure for system performance. This improved performance will be gained at the margin rather than through grand increments (i.e., the Interstate system) as in the past.

• The highway program is increasingly used to achieve other societal goals. Some examples follow:

—Attract and accommodate economic development
—Enhance environmental quality
—Manage growth and land use
—Promote minority employment
—Preserve cultural heritage
—Reduce alcohol abuse
—Promote agricultural production
—Conserve energy
—Balance the federal budget

• With some localized exceptions, the U.S. highway network during most of its history has enjoyed comfortable margins of overcapacity. As a prudent society dictates narrowing these margins, the professionals, generally risk averse as a group, become increasingly uncomfortable.

• Modal variety is narrowing. Of the more than $700 billion per year private and public U.S. transportation expenditure, highway transportation accounts for more than 90 percent. When there are fewer modal options, expectations of those remaining are inevitably higher.

• The resource pool is shrinking, in part from inflation and higher standards (which cost more) but even more from national budget constraints and competition from other sectors for public funds.

• Traditional highway tax revenue sources are being eroded due to the fixed nature of the levies (which are generally not responsive to inflation, unlike sales and income taxes), through exemptions of agriculturally derived fuels, and through marked improvements in fuel efficiency for both trucks and automobiles. Meanwhile, the deficit in the federal general fund creates pressure to maintain a surplus in user fee trust funds such as those for highways.

• Private and local governments' share of highway financing is increasing with a consequent blurring of accountability and with some loss of ability to forge programmatic consensus.

• Loss of sovereign immunity and rising tort claims demand aggressive preventive measures focused on targets for these claims.

• The sophistication of instrumentation and devices for measurement, and in computer hardware and software for data management and analysis, is growing at such a rapid pace that maintaining currency is difficult and expensive, yet absolutely essential.

• There is increasing sophistication and analytical capability among congressional and state legislative members and staffers. To match this capability, departments of transportation must develop similar resources.

• The cadre of professionals brought to highway agencies by expanding programs (e.g., the Interstate system), and the attendant opportunity for personal growth, is now retiring or otherwise leaving this industry. In some states, 30 to 40 percent of the professional engineering staff is eligible to retire. A more productive use of fewer professionals must evolve.

The conclusion from this overview is that highway transportation, in all its systemic ramifications (i.e., physical extent, user mix, intergovernmental relationships, technology, etc.) is undergoing massive change in the United States. The capital program management process is at the center of this change, and thus experiences both the threats and pressures, as well as the opportunities, they represent.

7-S CONCEPTUAL FRAMEWORK

Given the complex set of functions, and the highly diverse milieu in which they are embedded, it seems intuitively correct to assume that there is no single best model or methodology for highway capital program management. The 50 states, with strong individuality, continuously seek to develop their resources and apply them to their option set, recognizing, albeit too dimly in some cases, the circularity between option identification, delivery effectiveness, and resource availability. The dynamics involved in the capital program management process can be better understood, however, by a conceptual framework of the key interacting elements of the process.

Well-executed highway capital program management represents a fine balance between art and science. This balance is necessary in listening to citizen needs and political priorities, forging a manageable consensus, and then empowering the organization to carry out the mission. The technical contributions—the science part—in this process should not be overlooked, both in objectively measuring needs (and informing the constituents thereof) and in carrying out a program of improvements; but the process is by no means completely scientific.

The 7-S framework described here is a variation of the so-called Seven S management model described by Waterman (*3*). The management concepts of the model have been modified to make the framework relevant to prevailing management practices in U.S. state transportation organizations.

Figure 1 is a schematic view of the 7-S framework as adapted to highway capital program management. The six external circles represent elements that interact in shaping the last element (the internal circle) resulting in skills and success in capital program management.

Vision, leadership—is first. What does the state, through its highway agency, through leadership, want to accomplish? The highway function is derivative. Only as highway programs serve social, economic, and political purposes will they be perceived as successful. Thus, a proper vision for capital program management is not simply of more highways and bridges; such a small vision will surely fail to garner support in an increasingly competitive environment. The vision must be to help the state and the nation in global economic competition

FIGURE 1 Seven interrelated elements.

through improved transportation. Aschauer has given substance to such a vision by noting parallel movement between indicators of infrastructure investment and productivity growth (*4*). The vision must also include worthy social and environmental goals, such as reducing carbon dioxide emissions and so the "greenhouse effect" by searching out new fuels and new propulsion systems and by reducing congestion. The vision must now offer more than getting farmers out of the mud, the catch phrase during the first half of the century. It must help them in all aspects of their enterprise, certainly providing a system of non-weight-restricted roads and bridges.

Finally, the vision must deal with equity as well as efficiency issues. Transportation professionals may indeed have a priority set that is optimal from a transportation efficiency perspective. But government will always be constrained by equity considerations. And nowhere is this more critically true than in highway transportation. In its redefined role, transportation in the United States is an essential good for social and economic reasons; a fundamental right to young and old, to rich and poor, and to urban, suburban, exurban, and rural citizens. Any vision of a highway capital improvement process less encompassing than suggested by these few thoughts will not succeed.

Why it will not succeed relates to all the affected constituencies. This is the subject of the second element, the *political, cultural, and economic environment*, or more simply, the *authorizing environment*. Government exists, in the United States context, by the consent of the governed. They, the governed, authorize all programs, including the highway program. For the highway system, this authorizing environment is very extensive. Indeed, it is difficult to define out any individual function, group, or institution. How does this authorizing environment speak? Concerning the need for highways, it spoke in a 1916 congressional action. It—mostly the farm society of the day—said, "Get us out of the mud and ensure regular mail delivery with a system of federally aided roads." Later, in 1944, it—then an increasingly urban population—said, "Look after some of the major urban highways in essentially the same fashion as rural highways were looked after." Still later, in 1956, again through congressional action, the authorizing environment—then a more dispersed population, one recently exposed to two world wars and facing burgeoning economic growth—said, "Connect all major economic and political centers with a national network of freeflowing, defense-supportive highways." The 1982 Surface Transportation Assistance Act said, "Let us increase spending for preservation and restoration of existing roads and bridges."

More recently, the voice of the highway authorizing environment seems, to those conditioned by previous clarion-clear calls to action, to be muted and confused. Some may say it is like viewing a rich tapestry backward and in dim light. This implies in no way, however, that the authorizing environment has gone awry. It only means that listening is more difficult, more important. A major note to be made here is to the role of leadership vis-à-vis this authorizing environment. Must highway agencies only wait for the clear voice? By no means. Pro-active listening requires knowledge, sharing of ideas, discipline, courage, and respect, respect for all the authorizing environment. These, in turn, are more likely to be found in an agency under empowering leadership.

Finally, there is *organizational capacity*. It is no good selecting, prioritizing, and promising capital programs that will not be delivered. Indeed, it is counterproductive to do so. The long-range urban planning process of the 1960s and 1970s that simultaneously raised expectations and alarms, without adequate attention to delivery, proved this point. In many regions of the country, a public exposed to undeliverable, unrealistic, threatening plans rapidly lost faith in the agency proffering them.

Organizational capacity rests in part on particular skills and numbers. But in the highway capital program arena, it rests even more on creativity, a fact noted earlier. In terms of the 7-S framework, four elements make up the organizational capacity.

Organizational goals and objectives—Organizations come to grips with something more specific than a vision. Leadership must provide manageable packages set in realistic time frames. Only then can they become part of the driving force, the empowerment for the agency.

Organizational structure, culture, and motivation—How well the internal resources are utilized is the issue here. No one structure or culture is uniquely right for capital program management. However, a "directed autonomy" is more likely to produce the necessary culture, motivation, and creativity to move the process forward and reflect the constant stream of change that is the environment. Robert Waterman in *The Renewal Factor* (*3*), says,

> "In a directed autonomy, people in every nook and cranny of the company are empowered—encouraged in fact—to do things their way . . . but this all takes place within a context of direction. The highway arena is indeed characterized by this directed autonomy."

While state program managers strive, with strong encouragement from all sides, for creative new approaches in the capital program management process, the federal government, governors, cabinet secretaries, and commissioners provide the context of direction. Using another of Waterman's terms, the frequent "renewal" from legislative input, gubernatorial change, federal program reauthorization, professional skill enhancement, and others have benefited the capital management process.

Technical and support staff capability—Along with much art, the capital program management process has strong elements of science, as already noted. People who know federal programs well, who understand political and organizational processes, who are facile in data management and analysis, and finally people who are willing to work long, very hard, and with complete integrity, these kinds of people are absolutely essential to success in this arena.

Systems for information, analyses, and control—The data volume is too great, the required analyses too extensive, and the requirements for control too pressing to operate without benefit of state-of-the-art systems. As an obvious example of element interaction, these systems must be authorized by a forward-looking leadership, one that sees improved systems as part of the overall strategy, and as further interaction, these systems become the tools whereby the support staff meets its obligation in creative ways.

The last element, the derivative element, in the 7-S framework is *skill and success* in improving and recapitalizing highway transportation systems. Lack of this success, this skill, will not be hidden. Indeed, the ability to move projects through the pipeline is perhaps the most common, most readily identifiable measure of transportation agencies' success. It relies on skill and success in all contributory elements. An important final note on this 7-S framework is that the process itself, the way in which the elements are carried out and how they interact, is important in its own right, perhaps almost as important as the product. Indeed there will not be a continuing stream of good product without a good process.

FACTORS AFFECTING DYNAMICS OF CAPITAL PROGRAM MANAGEMENT

Case studies of capital program management processes in eight states (California, Colorado, Connecticut, Florida, New York, Pennsylvania, Texas, and Washington) suggest that the 7-S framework is useful for gaining an understanding of the dynamics of the process. The case analyses revealed 15 dynamic factors or elements, factors with the potential to contribute or detract from the effectiveness of the capital management process. These factors are summarily shown in Table 1, grouped according to 7-S elements (although in some cases they could be put under more than one element) and example manifestations in state practices. The 15 factors are discussed below by 7-S element.

Vision and Leadership

In the eight states examined, three factors were observed to have a significant effect in advancing a meaningful vision for transportation. The first, an obvious one, is the nature of leadership. Strong executives can bring drama and excitement to the programming process. An example of this at the gubernatorial level is Colorado where the current governor has taken a strong role in the process, personally chairing project hearings throughout the state to build a transportation program consensus. This leadership can offset or transcend institutionalized weaknesses in the power structure resulting from constitutional separation of powers or political partisanship. A well-thought-out, goal-oriented approach also marks leadership. In Colorado, the governor's highway proposals focused on 42 critical major projects throughout the state. In New York, the department of transportation (DOT) launched its goal-oriented programming process as a way to make the agency more responsive and supportive to statewide social, economic, and transportation goals.

Another important facet of leadership is top management stability or lack thereof. Nationwide, transportation executive positions are increasingly short term and often filled from outside the agency. In contrast, the top positions in Texas are filled with people of considerable experience in the agency serving on a professional career basis. This stability is particularly important to long-term, publicly sensitive programs such as highway capital investments.

A second important factor is division of effort between or focus on building versus slicing the pie. The General Assembly of California has dealt with the resource allocation issue, north versus south, urban versus rural, by putting in place mandated distribution formulas. Due to various program limitations, this political solution is a major constraint to the program management process. The Texas Department of Highways and Public Transportation has attempted to deal with the allocation issue by using ranking indices of cost-effectiveness and accounting for equity in part through population distribution. This approach has permitted the agency to focus the attention of its constituencies on long-term goals, addressed on a statewide basis, to building and enlarging the pie. The Colorado DOT has also developed a decision tree process (called Resource Allocation and Project Prioritization or RAPP) to rationalize its allocation of road expenditures for selected programs.

A third factor is simply the time dimension of the programming process. In Pennsylvania the dimension is 12 years, divided into three 4-year segments. Projects in the first 4-year segment are approved for final design and construction; in the second segment, projects are approved for preliminary plans and clearances only; in the third segment, years 9 through 12, projects are in the distant planning stage with no dollar commitments. Texas uses a 20-year horizon for its mobility plan, with actual project development narrowing to 10 years and then differing by program in project specificity. In California, the State Transportation Improvement Program (STIP) with a 5-year horizon is specified in law with specific milestone dates in terms of program development. Until a recent legislative amendment, no funds could be expended outside the 5-year period. This time frame appears inadequate for early phase project preparation because an overall time frame of 10 years is not unusual for major projects.

Authorizing Environment

Two major factors affecting the ability to constructively work with the authorizing environment are fragmentation of authority

TABLE 1 FACTORS AFFECTING THE CAPITAL MANAGEMENT PROCESS

7-S ELEMENT	DYNAMIC FACTOR	MANIFESTATION
VISION	LEADERSHIP	*STRONG EXECUTIVES *GOAL-ORIENTED MANAGEMENT
	FOCUS ON BUILDING/ SLICING THE PIE	*MANDATED FORMULAS
	TIME DIMENSION	*SHORT TIME FRAME
AUTHORIZING ENVIRONMENT	FRAGMENTATION OF AUTHORITY	*WEAK POWER STRUCTURE *LARGE LOCAL/PRIVATE ROLE *DIFFUSED RESPONSIBILITY *LOWER VISIBILITY
	PROCESS AS TOOL FOR BUILDING CONSENSUS	*STRUCTURED INPUT *WIDE PARTICIPATION
GOALS & OBJECTIVES	DERIVATIVE CONTEXT	*LINKAGE *DISAGGREGATION
	PRIORITY SETTING/ FOCUS	*PROJECT CATEGORIES *PROGRAMMING THEMES
	STRUCTURED, MULTI-DIRECTIONAL FLOW	*JUST ENOUGH CHAOS *EXTENSIVE COMMUNICATION
STAFF	CAPACITY LIMITATIONS	*ARBITRARY CUTBACKS *CONSULTANT POLICY
	COORDINATION	*PROGRAM CENTER
STRUCTURE, CULTURE	INSTITUTIONAL RELATIONSHIPS	*INSULATION *POWER RELATIONSHIPS
	PROFESSIONAL SKILLS & VALUES	*VALUE SYSTEM *SKILLS TRAINING
	RELIEF VALVES	*DISCRETIONARY ALLOCATION *POLITICAL BALANCE
SYSTEMS	REAL-TIME OBJECTIVE DATA	*NEW TECHNOLOGY *EXPERIMENTATION
	INFORMATION MANAGEMENT	*MANAGEMENT CONTROL

and use of the programming process as a tool for building consensus.

Fragmentation of authority can occur because of too much weakness in a state's power structure, which diffuses authority between the executive and legislative branches of government, or within the executive branch among various departments. In California, the legislature established an independent California Transportation Commission, which is charged with approving and adopting the STIP, but which is without resources for implementation, which are in the hands of CalTrans (the state DOT). Furthermore, the director of CalTrans is subordinate to a cabinet officer in charge of a "Super-Cabinet" agency with oversight of transportation, commerce, and housing. This means that transportation is one layer removed from the governor. Also, in California, as in many other states including Florida and Colorado, there has developed a large local government and private sector contribution to transportation capital improvements using so-called "innovative financing methods," including public-private partnerships (*5,6*). Do these developments create checks and balances in the programming process or are they fragmenting transportation authority? Though judgment may be premature, the experience seems to point to the latter, with great effort being required to build political consensus at the statewide level for any broad improvement thrust.

In terms of building consensus, the program development process itself can be a valuable tool for transportation executives. Both Pennsylvania and Colorado, among others, use the structure of the process, coupled with statewide input, including several public hearings, to develop project priorities and support for the program. Frequent, periodic updating of the capital program provides an opportunity to build credibility with the program's constituencies.

Organization Goals and Objectives

Three key factors were observed to drive successful, goal-oriented transportation agencies. The first of these, derivative context, refers to the fact noted earlier that society is defining transportation as more than just transportation; and successful organizations, recognizing this trend, set their transportation goals in a larger context. Florida has carried this thought a step further, embedding the transportation plan in a statewide comprehensive planning process mandated of all state agencies by statute (7). In addition, Florida statutes require that the DOT's programs be driven by policies and program objectives explicitly stated in its "Work Program." There has to be disaggregation from the larger context to measurable targets.

A second dynamic factor is priority setting and focus. The Texas DOT divides its construction projects into nine categories with tailored goals, objectives, and allocation rules for each. Pennsylvania uses federal funding categories but also develops program themes of special interest: the agricultural access network (farmers), industrial and commercial access networks (industry), and priority commercial network (truckers). Projects on these networks get added preference. The Washington DOT has a tradition longer than most states in this area, rooted in a priority programming law passed in 1963. This law, with subsequent amendments, defines goals and procedures for functional classification, improvement categories and priorities, and long-term program and financial plans.

The third factor, structured and multidirectional process flow, is more elusive, but still an important source of dynamics and innovation in the program process. In successful organizations, the process of establishing goals and objectives and constantly updating them is carefully structured, with specification of roles and duties for all participants, time-phased milestones, and widespread communication. In addition, the flow is multidirectional, functioning both "top-down" and "bottom-up." Furthermore, both top executives and line officers, such as directors of regional engineering offices, get input "sideways," from legislators, media, special constituency groups, and the public. However, unless there is a carefully considered structure to the process, this can be chaotic. To maintain just enough chaos to stimulate change and innovation is an art that successful agencies have come to appreciate if not master.

Technical and Support Staff

State DOTs are by and large staffed by skilled, motivated, and professional personnel. However, two factors have notable effect on the capital programming process, capacity limitations and coordination.

Capacity limitations often take the form of arbitrary, across-the-board staff cutbacks, which result in loss of experienced personnel, difficulties in recruiting bright young replacements, and a decline in morale. Where cutbacks are a necessity due to statewide budgetary difficulties, a goal-oriented approach that distinguishes the importance of various activities is much more productive. Judicious use of consultants can augment agency capabilities in needed areas.

The importance given to coordination of capital program activities varies according to the structure of responsibilities. In centrally managed agencies, a high degree of coordination is needed. The Pennsylvania DOT uses a Program Management Committee involving all senior managers meeting weekly for full program development and control. In contrast, Florida has a highly decentralized structure. Its seven district directors report directly to the agency head (state secretary of transportation) and have authority to make most capital program decisions, subject only to certain aggregate fiscal and administrative restrictions.

Structure, Culture, and Motivation

Three important factors have strong influence on the corporate culture and internal environment within transportation agencies. The first of these, institutional relationships, refers to the manner in which agency personnel relate to external bodies, such as legislative members and local government officials. The diffusion of responsibility in California places a great importance on cooperative relationships between the agencies involved to maintain effective program development and delivery.

In Colorado, there is another manifestation of this factor, resulting from the fact that the state constitution not only provides for earmarking of highway user fee revenues to the State Highway Fund, but also makes the revenues immediately available to the agency with no appropriation needed from the legislature. The lack of "purse-string control" makes it less attractive for legislators to vote for revenue increases. In contrast, in the state of Washington, the DOT has a very close interaction with the legislature, indeed is one of the agencies most tightly controlled by the legislature. This relationship has helped in some ways to address pressing transportation concerns. For example, in 1976, Washington was an early enactor of an innovative, variable fuel tax, with a floor and a ceiling to maintain revenue stability. Since then, even more responsive measures have been considered.

The high degree of urbanization in Connecticut gives local Metropolitan Planning Organizations (MPOs) a strong voice in transportation decisions in their regions. Indeed, as a unique feature of their organizational structure and culture, the state DOT has chosen not to be represented in the MPOs. Nevertheless, Connecticut's cooperative process is such that all its major expressway improvements during the 10-year program have been endorsed by the appropriate MPOs.

A second factor affecting culture and motivation is professional skills and values. CalTrans, for example, remains a leader in many aspects of highway technology and program development, including benefit-cost analyses, because of the high professionalism and skills of its personnel. Similarly, the California Transportation Commission has developed a small but highly qualified staff, expert in transportation policy and program development. These staffs use modern information, analysis, and control systems in their highway capital improvement related work, similar to their counterparts in other leading state DOTs.

A third factor affecting delivery capability of an agency is the presence of relief valves in the programming process. Just as valves in a pipeline can provide escape when too much pressure builds up, mechanisms are needed in the capital program management process to deal with uncertainty, new or changing political preferences, unresolved equity issues, and "just enough chaos." Texas provides two relief valves: first, a group of projects identified in its long-term plan as "tentative Commission commitments." This permits real input from the small but active Texas Transportation Commission, insures their "ownership" of the program, while not permitting uncontrolled expenditure. As explicitly noted in its plan, these projects are approved for planning only, not land acquisition or construction, for which they must go through the normal ranking process. The other relief valve is a discretionary allocation to the districts to address relatively low-cost needs (traffic signal, spot safety project, etc.) for which there may be significant community clamor.

Systems for Information, Analyses, and Control

Two major factors affecting innovation in the use of information systems in transportation agencies are the desire for real-time objective data and for information management. The former is reflected in the increasing use by state DOTs (e.g. Texas) of video-imaging equipment to capture and analyze road profiles, and of pavement management systems for optimizing surface treatments.

Information management is the response to too much data, much of it often too late or not usable to management. Initial computerization efforts in state agencies often led to stand-alone automated systems. The next generation of software used linkages or integration, utilizing large data bases, and providing wide access to central office and field personnel with the need. For instance, Florida DOT's Work Program Administration (WPA) permits a "gaming" or what-if analysis approach to capital program development. The WPA also tracks performance and aids in program implementation. For example, WPA aids districts in performing allocation swaps to balance fund surpluses and shortages. As legislative and public inquiries become more sophisticated, transportation agencies will need to develop executive information systems (sometimes referred to as decision-support systems) that can extract summary data from a large pool of real-time transaction data bases.

CONCLUSION

This paper has described a framework for understanding the very creative processes used for managing capital programs in state DOTs in the United States, and the major factors observed to affect dynamics and innovation in these programs. What of the future? Clearly, the growing congestion will increase pressure on program delivery and for shorter project cycle times. At the same time, building consensus for broad programmatic initiatives may be difficult. To succeed in this competitive environment, the capital programming process must focus on broad goals, and be responsive, through better technology, analysis, and communication, to legislative and other external concerns.

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Publication of this paper sponsored by Committee on Transportation Programming, Planning, and Systems Evaluation.

Can the Community Involvement Process Be an Asset to Project Execution in Major Roadway Developments? A Case Study of a Delaware Experience

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After almost 30 years of controversy, the Delaware Division of Highways has begun construction of Delaware Route 1, the major, 47-mi component of a new north-south limited access highway system connecting Wilmington to Dover and points south. The controversy was resolved through a thorough, proactive effort to involve citizens in project planning and design. The process was structured so that the community involvement effort drove the engineering design work. It consisted of a series of cycles of thorough public discussion that commenced before any design work was completed and was repeated before each major decision point was reached. The process was interactive, incorporating stages of problem definition, conceptual solutions, multiple alternative solutions, and refined alternatives and finally selected an alternative. The process met all state and federal guidelines and regulations regarding public participation. Fast resolution of project location and design approval, about 5.5 years from commencing location study to construction, resulted from the effort. This experience suggests that a proactive approach to citizen involvement could benefit highway and transit agencies facing ever more challenging political environments. The experience also reveals a tangential problem in project review procedures of federal agencies, such as the U.S. Army Corps of Engineers and the Environmental Protection Agency, that demand detailed review of project plans after public discussion has occurred.

The principal north-south highway in Delaware and the DelMarva Peninsula is US-13 extending from north of Wilmington to the Chesapeake Bay Bridge Tunnel in Virginia on the south. A high percentage of the state's north-south truck, commuter, and recreational traffic now uses US-13 because it is the only dualized highway from Wilmington to south of Dover. The highway is generally four-lane, having essentially uncontrolled access along its outer edges and frequent left turn openings through the median. It was largely completed in its present form in 1952. Figure 1 illustrates the project area.

Many attempts have been made to improve the vehicular capacity of the corridor. Early efforts to improve capacity were concentrated in the Dover area. In 1958 a study sponsored by the Delaware Department of Transportation Division of Highways (DelDOT) resulted in the development of three alternative preliminary designs for a Dover Bypass. DelDOT took no action, principally because the necessary authority to condemn and construct controlled access facilities in Delaware was not in effect at that time. (The absence of this authority has a long and interesting history, dating to T. Coleman DuPont's decision to construct the highway in 1911 as an economic development project in which roadway edge leases/sales would help finance the highway.) It is widely believed that this authority was not granted by the legislature because its denial was useful as a mechanism to block the bypass project.

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In 1964 the Delaware State Planning Office prepared the Dover Area State Planning Study recommending construction of a limited access bypass west of the city. This location was believed to best meet expected growth in the Dover area. In 1966 the first public hearing on the Dover Bypass was conducted by DelDOT. Strong opposition was voiced. This opposition to the project consisted of three types. First, farmers objected because the route crossed much active farmland. Second, there was a host of complaints about the proposed alignment from property owners and nearby residents. Third, opposition emerged from retail business owners located on the existing highway who feared a traffic bypass would reduce sales volumes.

An economic study commissioned as a response concluded that the bypass location was appropriate and raised two arguments in favor of the project. To the farmers, the study suggested that increases in land values near the project promised substantial profits (from the ultimate sale and development of their land) for owners of adjacent properties. To the business community, the study argued that the bypass would support continued growth in the Dover area, thereby broadening the market base. This study was not well received.

In 1967, DelDOT commissioned another study to review all previously developed alternatives, refine the preliminary designs, and select several for engineering design development. Thirty-eight alternatives were reviewed. A western bypass was again recommended because it was less expensive, had the highest "user benefit ratio," would best relieve traffic on existing roads, and traversed less prime farmland. The user benefit concept and other aspects of this analysis represented the evaluation system in use prior to the National Environmental Policy Act (NEPA) of 1969. An update of the 1967 economic study drew the same conclusions, that is, that the

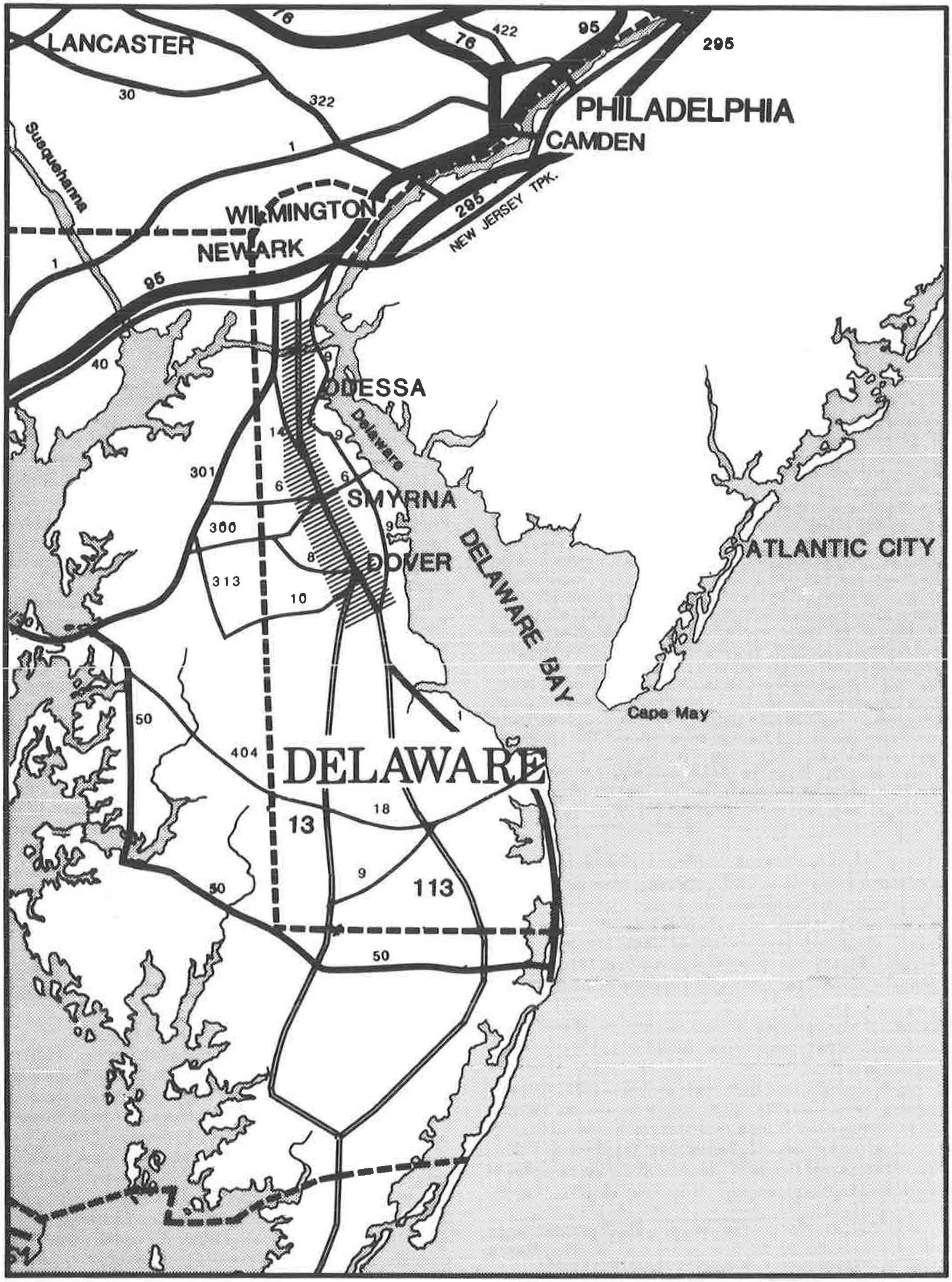

FIGURE 1 The US-13 Corridor Location Study focused on the shaded area extending from south of Wilmington to south of Dover, Delaware.

benefits of the west bypass were optimal. Meanwhile, DelDOT sought the approval of local authorities, and in 1969 both the Dover City Planning Commission and the Dover City Council passed resolutions endorsing the west bypass. DelDOT then held a public hearing.

At the public hearing on the proposed west Dover bypass in the fall of 1969, serious and organized opposition again surfaced. The opposition consisted of farmers, area residents, and business leaders. The farmers, led by a number of agricultural organizations, argued for investigating alternatives that would take little prime farmland and optimize traffic flow on the existing route. They argued vehemently that consideration of such alternatives had been inadequate and that they had not been permitted to participate in the design and evaluation process. Similarly, residents offered detailed complaints about the location of the line. Another contentious point was the projected traffic volumes and distribution. The instinctive reaction of the witnesses was that these forecasts were wrong. As a result of the public hearing, DelDOT launched another study.

In 1970 another engineering firm was awarded a contract to evaluate all studies, reports, alternative alignments, and recommendations made to date. The direction to the consultants had two characteristics. First, improvements were to be made to the designs of 1967. Second, several "new" alignments (i.e., alignments discarded when the 38 alternatives were under consideration) were to be fully evaluated. A refined west bypass, generally closer to Dover than the original, known as the Near West Alternative, was recommended.

By 1970 the problem of north-south highway service in central Delaware had taken on larger dimensions. An internal study by DelDOT systems planners, called the Delaware State North-South Corridor Study, revisited the Dover Bypass and raised the larger issue of improving service in the entire corridor to Wilmington.

In a parallel effort, new north-south highway corridors were developed in internal studies initiating what became known as the Peninsular Thruway Concept. These addressed the issue of a limited access connection from I-95 to Norfolk via the Chesapeake Bay Bridge Tunnel. In 1971 another engineering firm was asked to identify alternative routings for a highway connecting the planned Dover Bypass with I-95. Seven alignments were considered. The preferred one was largely on the west of the existing US-13, as was the planned Dover Bypass. Also in 1971 the first Kent County Master Plan adopted the Dover Bypass as county policy. No action was taken.

By 1974 interest in a fully integrated north-south system had increased and another study was begun. The 1974 study encompassed a comparative review, similar in form to current NEPA documentation, of four alternatives. It recommended construction of a new north-south highway entirely west of US-13 as a toll facility. Considerable, even more formidable documentation of the need for the project and the appropriateness of the selected route was prepared. When the study was completed, DelDOT held a series of public meetings.

Again, considerable opposition was present. However, this time the most frequent theme was the complaint that the public had not been permitted to participate in the design development. This theme was echoed by all project opponents including farmers, residents, and business owners. The state took no further action.

One more effort was made to bring this repetitive saga up to the present. Governor Pierre DuPont formed a study committee consisting of business, agricultural, and community leaders to review the work to date and make recommendations. The committee report, submitted in 1981, recommended the development of a new north-south freeway from I-95 to south of Dover. DelDOT did not act until 1983, when it once again advertised for a route location study for what had been renamed the North-South Relief Route.

DEVELOPMENT OF A PROCESS

DelDOT was very concerned that the north-south highway location issue be resolved. Contributing factors included worsening traffic conditions, rapid development of potential right-of-way areas, and escalating costs. Past experience had demonstrated that having a well-documented project need and competent engineering design were not enough to resolve the problem. The conventional process of alternatives development based on traffic study and engineering design followed by public review had failed three times, in 1958, 1967, and 1974. The delay in resolving the corridor location had resulted in a much more expensive and politically challenging project. It was critical to approach the subject through a process that would build a public consensus for a specific solution.

Several aspects of the past efforts appear to have contributed to their failure, based on reviews of the public hearing testimony and subsequent legislative discussions. First, the public objected that it had not been consulted in any depth in the development of alternatives. This perception transcended the merits of the engineering designs; many witnesses did not care about the specific designs but focused on the fact that they had "fallen out of the sky" at the public hearing. The learning curve required for the public to become conversant with the project and therefore to be able to comment accurately about it was simply too steep. The presentations were overwhelming.

Second, the need for the project was not well understood. The underlying all-year-round traffic growth was confused with summer traffic conditions during which heavy traffic (bound for the beaches from Rehoboth, Delaware, to Ocean City, Maryland) affected US-13. Relatively subtle issues, such as the loss of capacity in the existing corridor because of uncontrolled edge conditions (largely highway retail) and the rapid increase in the number of intersections requiring signalization, were little understood. Many respondents objected to building the road "so people could get to the beach."

Third, many people had alternative alignment solutions which they believed had not been adequately considered. There were advocates for "widening" the existing road and for alternatives in other locations. The fact that many of these issues had been addressed in the engineering studies was invisible, and arguments by DelDOT that these possibilities had been tested and rejected were not accepted. Citizens did not believe that adequate effort had been made to integrate their ideas.

Fourth, substantive criticism came from the agricultural community. Farmers basically believed that the project—the western alignments developed in 1974—put the heaviest burden on agriculture. This perception was based on fact. As engineering proceeded, locations on higher, well-drained land were selected because these conditions are superior for road construction. They are also superior for farming. Farmers especially objected to the pervasive idea that farmland was "vacant land." A second objection was raised regarding secondary land use impacts. Agricultural leaders argued that the road would create a new development corridor west of the current urbanized areas along US-13. They feared that residential, commercial, and other nonagricultural land uses would spread around the new corridor. Farmers rejected the argument that they would be well paid for their land. They noted that a reduction in the number of farms would affect the overall stability of all farms because of the loss of suppliers, loss of the efficiencies of shared labor and equipment, and a rise in the inevitable conflicts between farmers and homeowners. Agricultural leaders wanted the existing highway upgraded or an alignment very close to the existing developed corridor.

Finally, there remained objections from the business community rooted in the fear that traffic diversion would hurt business volume for highway merchants. The previous economic impact analysis focused on broad community growth issues such as employment levels, housing production, and population levels. The specific issues of the effects on highway-related and highway-dependent businesses, such as gas stations and restaurants, and the effects on non-highway-dependent businesses located on the highway (whose owners attributed a portion of their business to location) were not addressed. Arguments that broad growth in the communities would assure continued overall success were not persuasive.

Several themes from this review provided guidance in the formulation of the process for the relief route study. These can be characterized as follows:

- Early and genuine involvement in project planning by the general public and by active special interests has considerable value in its own right. The fact that engineering and planning professionals may be able to accomplish quality design work without this involvement and that they can do so expeditiously is not sufficient justification to approach the work that way.
- Public input at the problem definition stage of project development is vital to achieving acceptance of a particular solution later.
- Sincere examination of the suggestions and concerns of affected people is necessary even if in some cases project professionals would otherwise have dismissed these ideas as unworkable. The reasons to adopt or reject suggestions or alternatives must be made clear in an ongoing dialogue. A clearly announced willingness to examine concerns as they are raised is crucial.
- Time should be invested in explaining broad project issues such as traffic service, economic growth, agriculture, wetlands (and other environmental issues), historic resources, and community impacts so the public can converse about these sometimes-conflicting demands. The public's understanding can and should go beyond the immediate concerns of effects near a particular property.

These themes led to the formulation of a process for the location study in which public involvement would drive the planning and engineering effort, rather than the reverse. The process unfolded in the following broad phases:

Phase 1—planning: While baseline environmental, socioeconomic, and traffic engineering data were being assembled, senior project staff called on dozens of groups and communities to open the dialogue and solicit ideas about how they would like to participate. This initial effort was followed by the first series of public exhibits at which the problems were reviewed (e.g., traffic growth, loss of capacities on the existing roadway, community growth, etc.) and environmental resources data and conceptual solutions were presented. These conceptual solutions were not alignments, but generic improvement types exploring the significance of various designs (e.g., limited access) and the ways in which these interact with their surroundings. These were presented as fragments, not project plans, to provide the participants with an image of the physical tools available to resolve the traffic problems. At this first project exhibit, participants began to sketch the alignment on their own and provide location and design suggestions. Several of these suggestions were carried into Phase 2.

The principal goals during the first phase were to achieve consensus on the definition of the problem, share the design concepts that would address the problem, share the environmental concerns that designers were obligated to respect, and, most importantly, to make participants aware of the full range of issues [i.e., to heighten town people's awareness of agricultural issues, farmers' awareness of wetland issues, highway business people's awareness of the character of upgrade limited access designs (free of driveways), etc.]. Figure 2 illustrates the work flow through the first and second public exhibits. Note the rounds of smaller meetings before each exhibit, the points at which newsletters were sent, and the relationship to the technical studies.

Internal to the study group, a team system was employed in which diverse professionals (engineers, planners, historians, agricultural specialists, and biologists) worked closely together in both the development of project design and the interpretation of public and resource agency comments.

Phase 2—preliminary alternatives: Employing the traffic engineering and environmental and community data developed by the project team and ideas and comments from the public, an array of alternative corridors was developed. The eight corridors are illustrated in Figure 3. Two of these, the "State Line Alternative" (Route A) and the "Route 9 Alternative" (Route G), were suggested by people attending the first exhibit series. The former was judged unlikely to meet traffic needs and the latter required extensive acquisition and filling of estuarine wetlands, which appeared to the project team to be unreasonable given that alternatives with less impact were available. In addition, a full "upgrade" alternative, converting the existing highway to a limited access design with service roads, was developed to test the alternative most attractive to the agricultural community. All three were physically feasible. If the project team wished to drop any of them, the team needed to demonstrate its disadvantages to its advocates. The eight alternatives developed were taken to presentations in the affected towns, to business and agricultural groups, and finally to a second series of public exhibits, as shown in Figure 2.

At the exhibits, a comparative display of the impacts of each alternative (developed using fast and inexpensive linear measurement methods) gave proportionate differences among the direct effects on all key resources. From this display, the

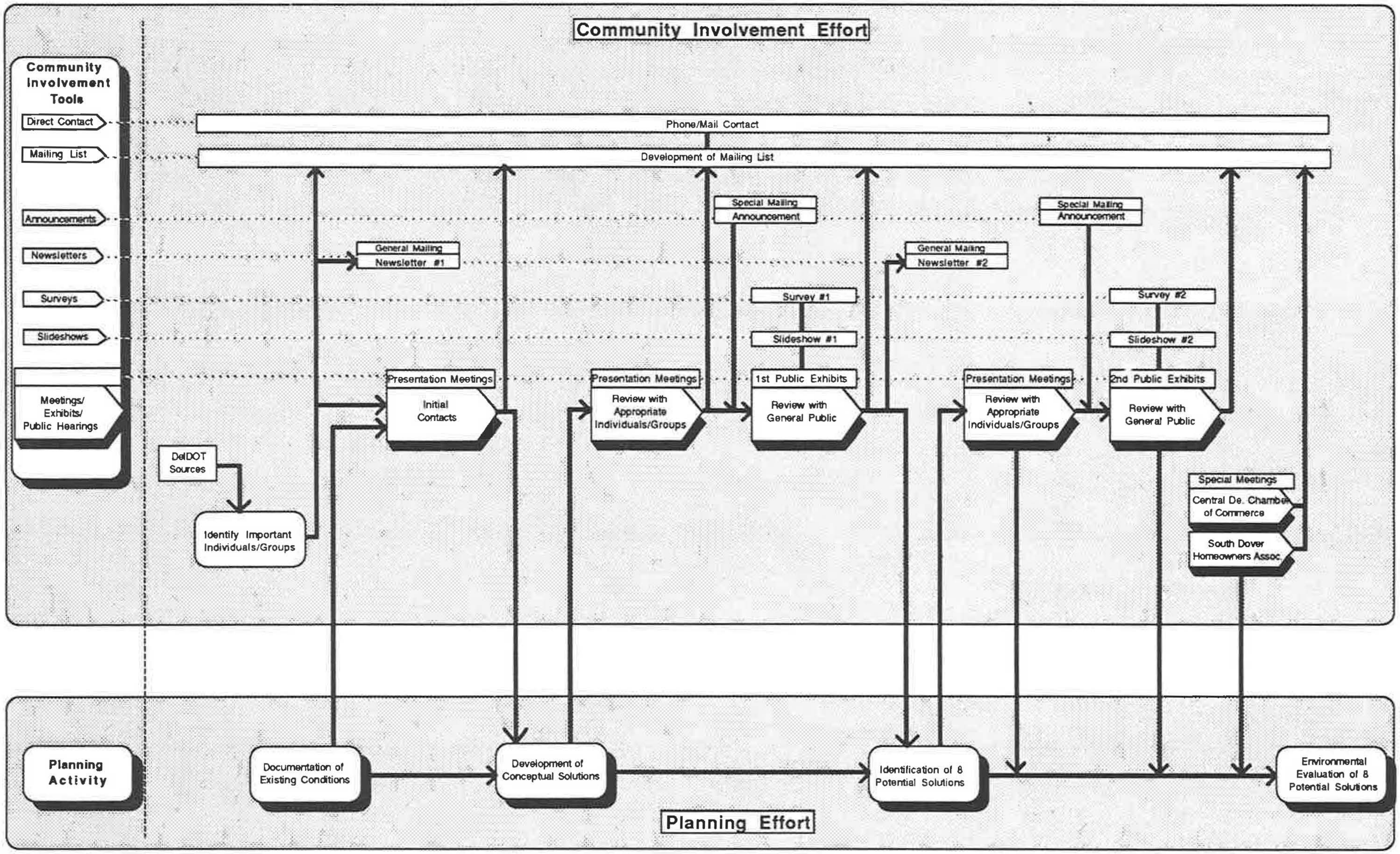

FIGURE 2 Flow of activities in Phases I and II of the project. The flow of meetings in the center of the diagram shows how smaller outreach meetings preceded major public meetings.

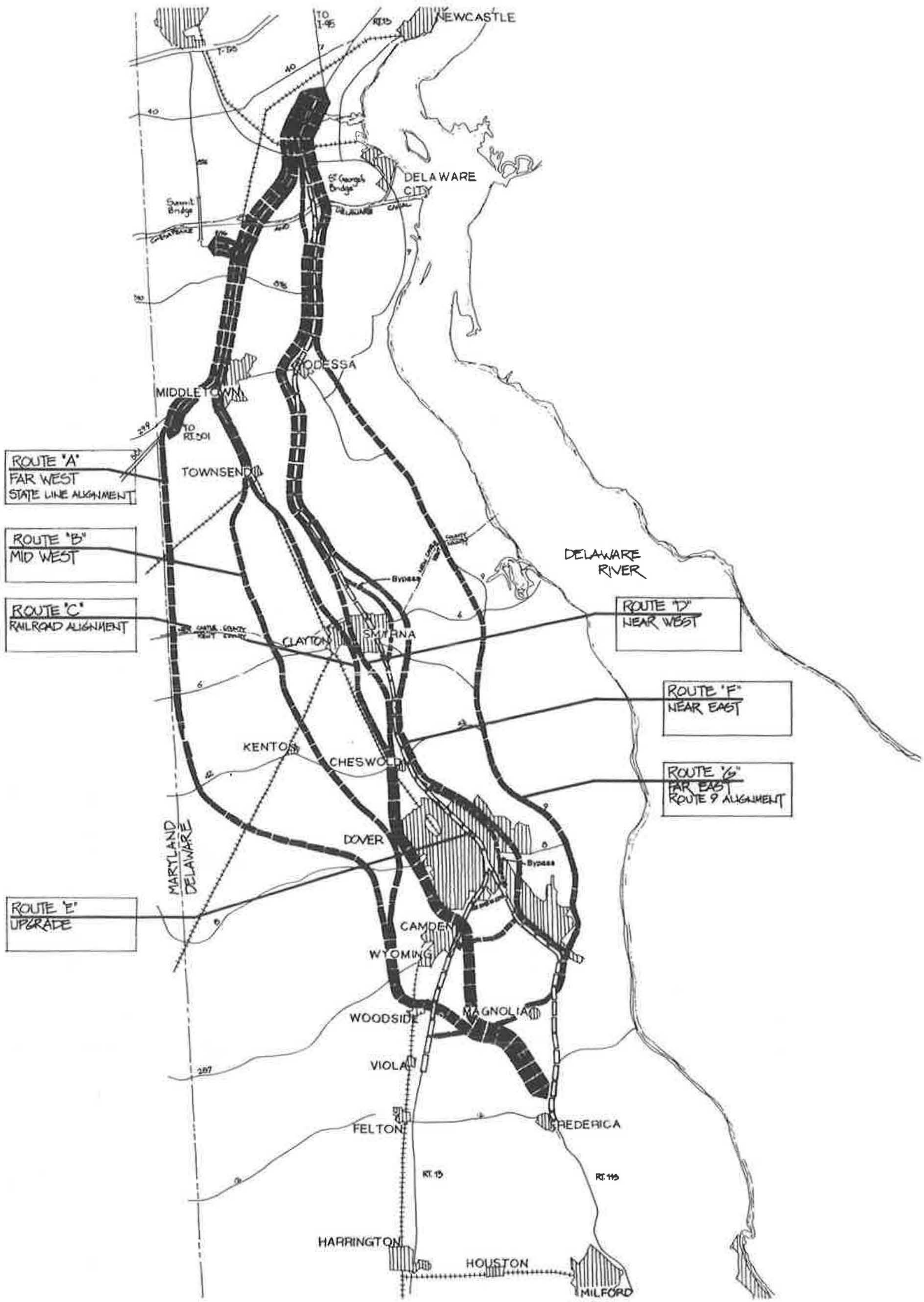

FIGURE 3 The eight corridors developed in Phase II of the study. Two of these alternatives, Routes G and A, were developed in response to requests from participants.

public could readily make key comparisons; for example, the Route 9 Alternative (G, Figure 3) had low relocation and low agricultural impacts but very high wetland impacts, whereas the Upgrade Alternative (E) had very high relocation impacts. The team members made it clear, in hundreds of individual discussions, that their goal would be to balance impacts and thereby respect all the major resources. This concept of balancing impacts became a theme in future discussions and was well received.

Following this second round of meetings and exhibits the team selected three alternatives for full analysis in the Draft Environmental Impact Statement (DEIS).

Phase 3—selected alternatives, DEIS: In order to refine the three DEIS alternatives and review the rationale for their selection, a third round of meetings was held with interested groups, complete with public exhibits. Two of the alternatives were largely new alignments, one east and one west of the existing highway, both relatively close to the urbanized area. Both the new alignment concepts had significant agricultural impacts, but they had more relocation and less agricultural impacts, especially secondary impacts, than alternatives farther from the existing highway. The third alternative was the upgrade alternative which, despite extensive relocation and associated high acquisition costs, was retained because of relatively broad support. It was clear to the project team that if upgrade designs were to be ultimately rejected, a detailed justification based on full preliminary engineering designs, to be prepared for the DEIS, would be needed. Instincts and professional judgment were not enough.

Some months later, when the DEIS environmental documentation was largely assembled and the preliminary engineering refined to reflect the comments received at the start of Phase 3, another round of meetings was held. During this round, the project team was able to display the extensive list of problems that had arisen during the analysis. For instance, the upgrade alternative, because it followed the existing corridor, had potential impacts on properties eligible for or on the National Register of Historic Places. These resources, protected under Section 4(f) of the Department of Transportation Act of 1967, had to be avoided if possible, obligating the team to consider significant off-alignment segments as part of the upgrade concept. These off-alignment sections tended to blur the distinction between "upgrade" and "new alignment" in several key areas. Once illustrated and discussed, most participants accepted the changes resulting from these and numerous other findings of the detailed studies. This public contact effort closed the DEIS phase and preceded by a short period the first formal public hearings on the project. The Phase 3 work flow is illustrated in Figure 4.

Phase 4—location hearing—selection of alternative: This step began with the Location Public Hearings which, like previous project exhibits, were held at three locations on consecutive nights. At this point in the process, the project mailing list exceeded 4,000 participants and not less than 200 individual owners were affected by each alternative. Fifty-five witnesses appeared and approximately 80 written comments were reviewed. Of the witnesses, only two favored the "no build" alternative, approximately 30 wished to express their support for (or opposition to) particular alternatives, and the balance had specific concerns (e.g., access to property, effects of proposed property acquisition) plus other comments (such as suggesting toll financing for the project). Similar concerns prevailed in the written comments. The public hearing participants were largely a focused group that had immediate concerns about particular alternatives or particular circulation problems associated with them. No participants complained about being uninformed or surprised.

After the hearing, an alternative was recommended by the team to the Secretary of Transportation, Kermit H. Justice, who accepted the recommendation and announced its selection to the legislature three months after the public hearing. The total elapsed time from project inception in late January 1984 to announcement of a selected alternative in February 1986 was just over two years.

The third year's effort focused on further refinement of the selected alternative and preparation of a Final Environmental Impact Statement (FEIS). As is typical of any location study process, the specificity of the concerns increased as plans became more definite. New participants emerged who apparently had not been persuaded that the project was "real." They required and received extensive background information about the origins of the project and the work that had been completed. This step backward in the process was addressed directly and assertions that they were "too late" were avoided.

The workload during the period in which the FEIS was prepared was dominated by negotiations for the various agreements needed from the state and federal review agencies. As several complex issues were involved, including wetland mitigation and archaeological and historic resource mitigation, the FEIS was not approved by the Federal Highway Administration until June 1987.

The high level of engineering detail carried forward from the DEIS allowed DelDOT to receive location approval in August 1987 and set Design Public Hearings for the first section—17 miles from Dover to Smyrna—for September 1987. At the Dover-Smyrna Design Public Hearing, a pattern similar to the Location Public Hearing developed. At the Design Public Hearing, preliminary engineering at a larger scale was displayed to permit accurate judgments about relationships to property lines and distances between roadways and buildings. Forty-seven witnesses testified, and of these more than 30 were concerned that the roadway be moved more to the east over a stretch south of Smyrna. It was possible to make this shift and accommodate these concerns. Only one witness spoke against the project. Design approval was granted by FHWA to DelDOT in early 1988.

REACHING THE PUBLIC

The US-13 Relief Route community involvement effort had several main purposes. First, it was to provide input to the planning team and assist in its attempt to deliver the best design possible. To accomplish this, the team needed to understand the specific ways in which communities, farmers, business people, and individuals functioned in the project area. Second was to ensure that affected people had ample opportunity to be fully informed. It was crucial that there be as few surprised people as possible because such experiences tend to be harmful to major projects. The third purpose was to educate the public about the often-obscured factors affect-

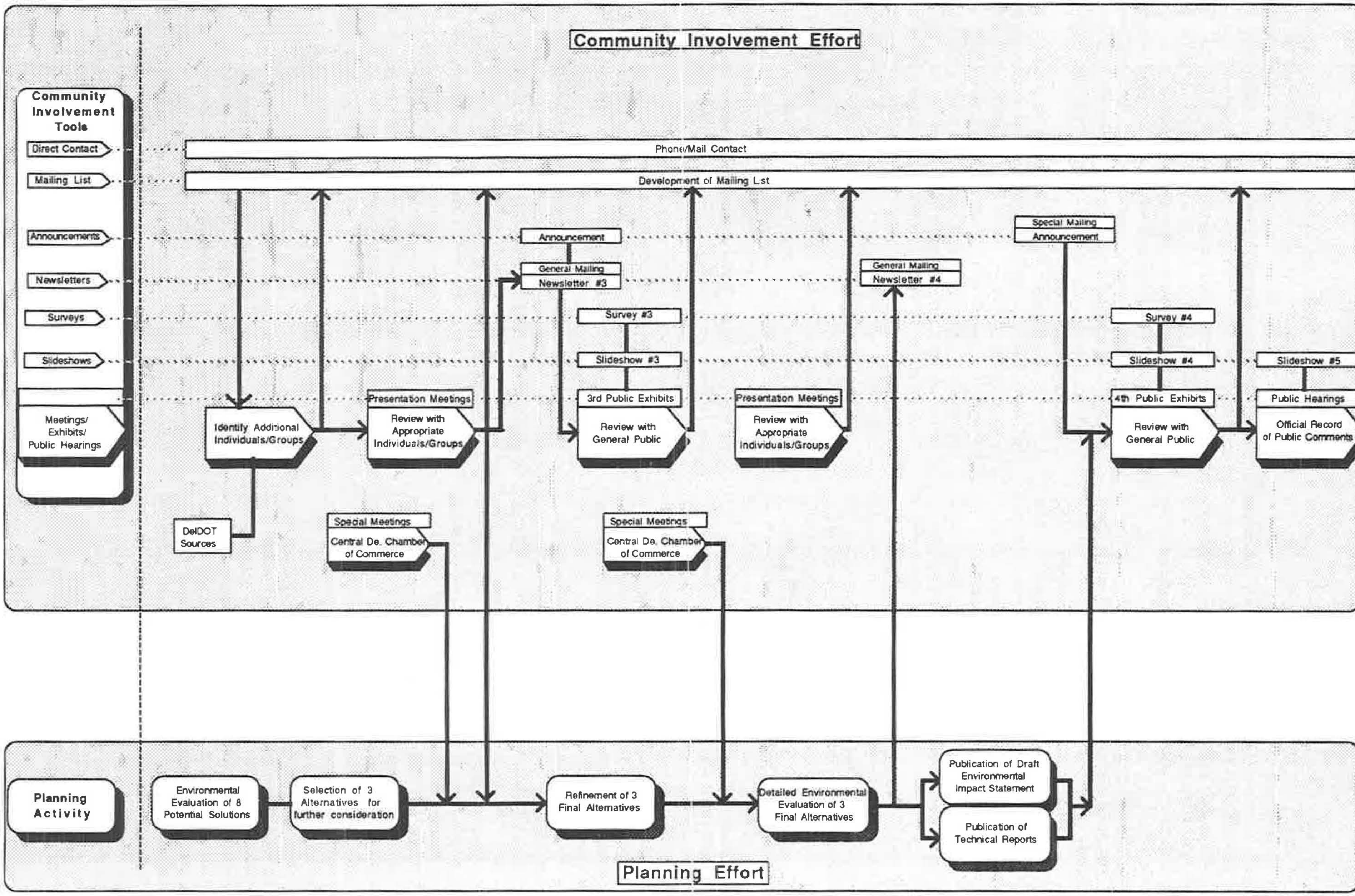

FIGURE 4 Flow of activities from the initiation of Phase III, which commenced with selection of alternatives for full DEIS review, through the Location Public Hearing. A similar flow was carried into Phase IV when the FEIS was completed.

ing project location and design, such as engineering issues and environmental constraints, so that participants could fully understand the results of the effort.

The techniques were not individually unique. Their application, however, was intense because thoroughness was crucial to its success. The principal elements were as follows:

- Outreach meetings: The team made regular presentations to local governments, businesses, and farm organizations as well as other groups such as Rotary, Ruritans, and chamber of commerce. This effort was proactive; the project team sought them out early in the process, before alignments had been drawn, and continued to seek audiences with them in the periods prior to each public exhibit. As these meetings progressed, the displays of project materials—project need and approaches, early alignments, and DEIS alignments—became the subjects of the presentations. Through these smaller meetings, a base of participants was developed who became part of the larger public exhibit audiences. In this way, the project team minimized problems arising from being perceived as strangers, gained invaluable insight into local concerns, and provided local leaders with the background information needed to answer constituents' questions. Broadly speaking, the policy was to meet with virtually anyone who wanted to meet with the project team.
- Public exhibits: The focal point of each phase of the planning effort was its public exhibit. They were scheduled on three successive nights in Dover, Smyrna, and Odessa, towns central to major segments of the project area. They were in an open house format, similar to a "plans view" or workshop meeting, from 4 p.m. to 8 p.m. Each event typically attracted 300 to 500 persons, for a total average of 1,100 persons per exhibit. The label "exhibit" was useful because it did not predispose visitors to expect either a formal presentation (i.e., speaker and audience) or a "workshop" where a small group would sit around a table. Presentations (slides and individual discussions) did occur on an ongoing basis during the event and workshops were conducted with groups and individuals having issues to review within the format.

The exhibits were always held before major decision points. The first was held before the development of the multiple alternatives; the second was held after the first set of alternatives was developed but before a short list was selected for full environmental study; the third was held before full evaluation of the DEIS alternatives and led to their refinement; the fourth was held when the DEIS was complete, but before the Location Public Hearing, to review results and solicit comments on a preferred alternative; and the fifth and last exhibit series was held on the selected alternative while the FEIS was being prepared and also led to a series of refinements. This timing was crucial because the process was based on the commitment to discuss the project with the public before decisions were made. Public officials and the press were always briefed prior to each exhibit series.

The exhibits were laid out as a series of stations. The first was a reception area where people signed in and newsletters and surveys were distributed. From the sign-in area, each person or family was directed to a 6- to 8-min slide show. Displays included background on the project activities to date (traffic issues displays were retained until very late in the process), a diagram of the project work flow illustrating the present point in the larger process, a poster-sized list of what will happen next, and lastly, an array of that particular exhibit's primary subject panels. Tables provided not only places to fill out surveys but also places to put copies of alternatives plans on which both staff and visitors could work. These were often used with trace overlays to create accurate notes about issues pertaining to particular properties with the concerned individual. Figure 5 is a photograph of an exhibit underway.

The exhibits were heavily staffed. DelDOT personnel, including the project management team, community relations staff, right-of-way specialists, and consultants were always present, providing a total of 16 to 18 professionals. The staff was stationed throughout the room and offered explanations of each display, identified individual concerns, and directed people to the best displays and staff to discuss these concerns. The goal was to have a conversation (usually more than one) with every visitor. Elected officials often attended as well. Frequently a legislator introduced a constituent to team members and then stayed as he or she expressed the problem or concern. This pattern reflected the fact that the team had repeatedly stated that the work would be done openly "in a fish bowl" and that there would be no "back door" to project influence. As a result, the Secretary of Transportation and the Director of Highways had very few special meeting requests, despite the large size of the project, and the "special service" was limited to setting up a meeting with the team.

The only objection raised to the exhibit format was the quietly expressed concern of some elected officials that there was no forum from which they could make statements to the crowd. On balance, the team believes the absence of such a forum was an asset.

- Slide shows: To overcome the chronic problem of sharing basic background information on the project, a series of short slide shows was prepared. A small room seating 12 to 20 people was set aside and a staff member restarted the program every 8 to 10 min. The slide shows consisted of 60 to 75 slides controlled by a synchronized sound track lasting 6 to 8 min.

FIGURE 5 At the second public exhibit series, numerous sketches were developed to record specific comments.

The show carried the participant through the problem, the process, the current state of the effort, and what was at issue at that exhibit. By using a "canned" introduction, it was possible for the staff at the exhibits to move individual discussions into much more detail. Questions concerning what the effort was about, why it was occurring, what had transpired thus far, and what could be expected at that exhibit had already been answered. Overall, the amount of time spent on basic project facts was sharply reduced.

- Project newsletters: Newsletters were issued at regular intervals throughout the planning and early design phases. They were sent in the periods between major public meetings and provided reports on previous exhibits, progress of the study, and special issues. The newsletters were used as a bridge between major decision points in the process. Subsequent newsletters were mailed during the FEIS phase to describe the selected alternative, note various changes made to it during the period, and apprise the public of the process of final design, property acquisition, and construction. The newsletters have been continued into final design and construction.
- Surveys: At each public exhibit, a two-page survey was distributed and collected. It served several purposes. First, it gave the team a detailed, reliable view of what the attendees thought of the ideas under discussion. Second, it served to reinforce the project issues by restating them and engaging participants in the questions at hand. Finally, each survey contained a question regarding the experience of the individual at the exhibit. These surveys were scored and the results reviewed at the team work sessions that followed.
- Mailing lists: A mailing list of all participants was assembled. After each exhibit, the list was culled to avoid duplicate mailings and establish the number of new participants. This culling process proved valuable because the staff managing the list was able to ascertain the locations of homes and businesses of new participants. Typically, neighbors of participants who had learned that their areas might be affected would appear at the subsequent exhibit, usually the next night. This reinforced the team's belief that it was critical to constantly restate the background and process of the work. These new participants needed to have a complete understanding of the project.
- Special studies: Issues arose around which the team conducted special studies in response to both planning and design concerns. These usually focused on a particular subgroup of the public. One issue illustrates this process and how it was reflected in project engineering.

As has been noted, many highway retail business owners feared that the loss of traffic would affect their business volumes. In order to quantify these effects, a summer survey of patrons was taken. The methodology took into account off-highway and on-highway business locations and met accepted statistical standards. It was developed closely with a special committee organized by the Central Delaware Chamber of Commerce and involved interviewing managers and customers both on weekdays and weekends at more than 80 businesses. By using a system that identified local-to-local, nonlocal-to-local, and nonlocal-to-nonlocal trip types among customers, it was possible to develop assessments of the potential loss of business due to a bypass. The outcome, in summary, was that business loss from new alignment alternatives would occur for service stations, fast food establishments, and restaurants, but that the loss would be sharply lower than owners estimated. Other business types having a local customer base, such as hardware and clothing stores, were estimated to be largely unaffected or perhaps aided by new alignments because local customers would have better access as a result of the reduction in through traffic.

Protecting the viability of existing businesses was carried into project engineering design. It was apparent that the most successful design concepts were relatively close to the existing highway. This presented an opportunity to create a system of easy exit and reentry to and from the limited access roadway at locations north and south of the towns. As a result, a commitment was made to avoid creation of full interchanges with local roads but instead to make all interchanges directly with the existing highway. This is intended to prevent the creation of new business locations at interchanges, protecting the status of the existing locations. Interestingly this led to a substantial agreement between business and agricultural leaders about the positive effects of alignments very close to the existing highway.

Other special studies were incorporated, including an agricultural impacts evaluation system that gave considerable weight to secondary land use effects, and a number of design studies to reduce roadway impacts in specific locations. Each special study contributed to the quality of the selected alternative and the credibility of the project effort.

ACHIEVING CLOSURE

The outcome of the US-13 Relief Route study process is that in the fall of 1989 construction began. This time span, of 5.5 years, is reasonably fast for a major new highway project. It was not only necessary to determine and resolve the public's concerns but also to maintain an aggressive pace in project engineering. This allowed the public process leading to the Design Public Hearings to maintain momentum from the location study.

The outreach effort is being sustained through the final phases of design and bid letting and will continue through construction. Issues arising from final design and construction must continually be addressed, and issues relating to later phases of construction must now be resolved. The intensity of the outreach effort compared to the level during design development can now be reduced, but there will always be new people and issues. The DelDOT Division of Highways believes it would be an error to stop communications regarding the project now that construction has begun.

RELATIONSHIP TO ESTABLISHED PROCEDURES

The US-13 Relief Route planning process conformed completely to both NEPA and FHWA regulations and guidelines. What distinguished the process from earlier studies on this project was the thoroughness of the effort and the commitment to obtain community input prior to each major project decision. To illustrate its conformance with established regulations and procedures, a brief review of the October 1982 FHWA memorandum "Guidance Material on Public Hearings and Other Public Involvement" from the Director, Office of Environmental Policy, to Regional Federal Highway Administrators is appropriate. This memorandum represents a compilation of both regulations and recommended policy.

On the purpose of public involvement the memorandum says the following:

- "An SHA's actions can merit public confidence as well as assist in expediting the highway development process through early identification and resolution of issues."
- "To be effective, public involvement needs to be an integral part of the highway project development process, beginning at the earliest stage and ensuring adequate opportunity for citizen input and an exchange of views through project development."

This section goes on to say that other necessary elements of an effective public involvement program include provision of sufficient agency resources to use the views expressed, impart sufficient knowledge, and use appropriate techniques. Clearly this fundamental objective can best be met through a system providing for public input at regular intervals from before project plans are formulated through the decision sequence.

The memorandum encourages active participation by local government and goes on to support alternative involvement procedures that should

- "Be comprehensive with coverage throughout project development,"
- "Be consistent with . . . all applicable FHWA regulations,"
- "Correlate public involvement activities other than hearings with the environmental process (e.g., public meetings at the time environmental studies on alternatives are available for review),"
- "Provide the opportunity for informal interaction," and
- "Provide adequate information and sufficient time for citizens and other agencies to familiarize themselves with a proposal prior to a meeting or hearing."

The Relief Route process fully reflects these recommended procedures. It was comprehensive, extending throughout the effort; it was consistent with regulations; it very closely correlated public review with the actual study process; it provided extensive opportunity for informal interaction; and it provided complete access to virtually all the information affecting the decisions on a timely basis. Similar parallels can be drawn with recommended public hearing procedures, public notices, public meeting forms, recommended workshop type settings, newsletters, mailing lists, maps, and right-of-way information as described in the guidance memorandum.

REPLICATING THIS PROCESS

The close linkage maintained between the public input and project development involved a very high level of effort compared with past experience in Delaware. The willingness to devote staff and other resources to maintaining this process and defining the project in terms of the sequence of public involvement rather than in terms of the engineering development process were vital to the effort's success.

This is a repeatable process. It is possible to involve the public in the project definition phase of work, the alternatives development phase, the environmental review phase, and in the selection of a preferred alternative. The effect, in the case of the Relief Route process, was a relatively short project development time and a substantial public consensus for the project. Several features of this effort warrant consideration:

- The Secretary of Transportation of Delaware, Kermit H. Justice, at his announcement of the study to the legislature in January 1984, said, "I have instructed the team to ask questions first and draw lines later." This characterization, and subsequent support for the process from FHWA, was very valuable. There was a visible commitment to give community concerns a lead role in developing the project.
- There was a commitment to spend more dollars and staff time to meet the needs of the process. While unquantifiable, it is possible that, by resolving what will be done fairly quickly, overall project costs were reduced.
- The effort was proactive. Time was sought on the agendas of many official bodies, special interest groups, and even some social organizations. The effectiveness of the discussion is clearly enhanced by seeking these audiences rather than waiting until some concern arises and an invitation is made. Similarly, when difficult groups or special problems arose, the team sought and conducted appropriate sessions.
- There were many discussions of broader transportation, land use, environmental, and economic issues. The context of the project is important.

PROBLEMS AND WEAKNESSES

The US-13 Relief Route community involvement process was not free of problems. The most vexing was the emergence of serious issues late in the study process. For example, the South Route 13 Business Coalition came into existence as a result of serious objections to the upgrade-type design selected for the western segment of the project south of Dover. Despite the extensive outreach effort made during the design phases, the specific concerns and their seriousness did not surface until after the DEIS was completed and a selected alternative identified. The team assumed that the selected design was the most desirable to these business owners because, generally, this had been the view of highway business people during design development. Such assumptions, though usually correct, are not always. These problems could have been avoided by a still-more energetic effort to gather comments.

Another area of difficulty was the interaction between review agencies, such as the Environmental Protection Agency, and the project. EPA had no stake in the process of project design and focused only on its mandated concerns. In this case, these were largely wetland impacts. EPA raised the question of making significant alignment changes, which in some instances would have led to changes to carefully negotiated project elements. It was not sufficient for EPA purposes that the agency had been involved from project inception, that wetlands received considerable attention in the process of design development, and that a comprehensive mitigation program had been developed. The process could have been improved by even greater EPA involvement earlier in the effort. This would require a significant revision in U.S. Army Corps of Engineers' procedures that now provide for substantive review (for Section 404 permits) to occur only when a specific proposal has been fully detailed. The current procedure involves a sequence in which engineering, wetland delineation, and mitigation plans are fully prepared before meaningful review takes place. The public cannot consistently distinguish among these agencies (i.e., it's all part of the "government") and is likely to view major project changes coming late in the process as part of an effort to subvert the carefully developed plan. Such late changes can be devastating to credibility.

Publication of this paper sponsored by Committee on Citizen Participation in Transportation.