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Contents

Foreword

In the papers presented in this Record, a broad range of economic analysis techniques are applied to transportation systems.

In the paper *Ranking Highway Construction Projects: Comparison of Benefit-Cost Analysis with Other Techniques*, McFarland and Memmott consider three project evaluation techniques: sufficiency ratings, priority formulas, and benefit-cost analysis. From application of the latter, the benefits obtained for a given highway budget can be maximized.

In *Analysis of the Impact of Interest Rates on Automobile Demand*, F. Mannering discusses the use of interest rate incentives on new car purchases and concludes that consumers tend to overvalue interest rates relative to their true worth.

In *Estimating the Value of Travel Time—A Speed Choice Model*, McFarland and Chui suggest that the value of travel time currently being used by highway planners is too little; it should be \$8.00 per person-hour for drivers or \$10.40 per vehicle-hour (in 1985 dollars).

After looking at differences in quality of maintenance (in the paper *Economic Efficiency Implications of Optimal Highway Maintenance Policies for Private Vs. Public Highway Owners*), Geltner and Ramaswamy conclude that a profit-maximizing maintenance policy would produce an average maintenance quality considerably lower than that provided by the public sector.

According to M. Euritt's paper *Economic Factors in Developing Fine Schedules for Overweight Vehicles in Texas*, current schedules of fines are inadequate for decreasing the numbers of overweight truck violations. Because of the low probability of being caught, current fines fail to discourage overloading of trucks, which increases profit margins for truckers but also increases wear of the highway system.

In the paper *Regional Economic Impacts of Local Transit Financing Alternatives: Input-Output Results for Portland*, Strathman and Dueker find that reduction in city economic activity is minimized with a local gasoline tax and maximized with a transit fare increase.

A planning procedure offered in the paper *Benefit Analysis for Sketch Planning of Highway Improvements*, by J. Witkowski, provides an improved method for estimating benefits due to intersection improvements through consideration of delay.

According to Eagle and Stephanedes, in the paper *Dynamic Highway Impacts on Economic Development*, increases in highway expenditures do not, in general, lead to increases in long-term regional employment. However, in counties that are regional centers, highway expenditures do have a positive long-term effect on employment.

In the paper *Measuring the Regional Economic Significance of Airports*, Butler and Kiernan demonstrate that the two main measures that may be qualified and cited as evidence of an airport's importance are its economic impacts and its transportation benefits. The primary measures of benefit are in time and cost savings to travelers.

Issues of public versus private roles in providing transportation are discussed by Loukissas and Carrara in the paper *Public/Private Partnerships in Neighborhood Transportation Planning: The Case of the Oak Lawn Area in Dallas*. A private initiative that achieved successful cooperation in developing an area transportation management plan among residents, property owners, developers, and city officials is described.

In *The Economics of Reducing the Size of the Local Rural Road System*, C. Hamlett et al. find that reducing the size of the local rural road and bridge system through the abandonment of road segments that contain no property access results in cost savings greater in value than the additional user costs imposed on the traveling public caused by rerouting of their travel.

Also on the subject of rural roads, Walker and Thiede, in the paper *Condition Assessment and Improvement Needs of Locally Maintained Arterial and Collector Highways in Wisconsin*, find that existing federal aid funding is inadequate to meet the needs of the locally maintained arterial and collector system. Local road systems have poorer geometrics and pavement conditions than state trunk highways.

Ranking Highway Construction Projects: Comparison of Benefit-Cost Analysis With Other Techniques

WILLIAM F. MCFARLAND AND JEFFERY L. MEMMOTT

Three techniques for ranking highway construction projects are compared using 1,942 added-capacity projects. This is the first comprehensive comparison of ranking techniques using a large number of actual highway projects. The three techniques, (a) sufficiency ratings, (b) priority formula based on sufficiency ratings, and (c) benefit-cost analysis, are compared according to total benefits of project rankings for a fixed budget, rank correlation coefficients, and types of projects selected. For a 10-year budget for added-capacity projects of $5.742 billion, the benefit-cost procedure selects projects that provide more than $22 billion more benefits than does the sufficiency rating ranking, and about $7.8 billion more than does the priority formula. It is concluded that explicit use of a benefit-cost analysis maximizes benefits for a given highway budget. Also, a priority formula based on sufficiency ratings is much superior to use of the sufficiency rating alone. Because some version of sufficiency ratings is used to rank construction projects in most states, a large increase in benefits would result from using a priority formula or benefit-cost analysis.

In this paper, a comparison is made among three techniques for ranking major highway construction projects: highway sufficiency ratings, a priority formula based on highway sufficiency ratings and other factors, and a benefit-cost procedure (the modified HEEM–II program). Each technique is used to rank 1,942 added-capacity projects. This study is the first comprehensive comparison of ranking techniques using a large number of actual highway projects. The projects represent the list of candidate projects that the Texas State Department of Highways and Public Transportation is considering funding in the next 20 years. The list is limited to projects that expand highway capacity mainly through increasing numbers of travel lanes or through controlling access to the highway. A more detailed comparison of the techniques, as well as a comparison of six other ranking techniques have been published previously *(1)*.

The benefit-cost procedure used is described in the first section of the paper. The next four sections contain discussions of the sufficiency rating technique and the priority formula and also the results of a sensitivity analysis that was conducted to test the structure of these formulations. The sixth section contains the comparison of rankings using the different techniques, followed by conclusions in the final section.

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BENEFIT-COST ANALYSIS

The use of economic analysis in evaluating and comparing highway projects has been limited. A 1962 survey of state highway agencies by the Highway Research Board *(2)* revealed some use of benefit-cost analysis in most states but it was generally limited. A 1974 survey *(3)* revealed that 27 out of 39 states responding to the survey were using some sort of economic analysis. From the survey results, it was estimated that there was about a 10 to 20 percent increase in the regular use of economic analysis during the period from 1962 to 1974.

In recent years, with the limited funds for highway projects, more emphasis has been placed on getting a better return on the investment in highways. Economic analysis has provided valuable tools to examine the planning and policy questions confronting highway agencies; but unfortunately, there is not yet a consensus on the specific benefits or costs to be included in the analysis and the methods or assumptions used in calculating those benefits and costs.

In an effort to standardize benefit-cost analysis for highway improvement projects in 1977, AASHTO published a manual to calculate user benefits of highway and bus transit improvements *(4)*. Because of its red cover, it has become known as the *Redbook*. This manual provides a step-by-step procedure for analyzing a proposed highway project. The procedure can be time-consuming and subject to errors because it involves looking up numbers in tables, reading numbers from graphs, and performing numerous manual calculations.

Several computer programs have been written to reduce the time and errors in making manual calculations. The FHWA developed a computer program, called the Highway Investment Analysis Package (HIAP) *(5)*, which includes a comprehensive analysis of user benefits but is limited in examining alternative routes and requires large amounts of data.

Another computer program available for analyzing highway projects is the Highway Economic Evaluation Model (HEEM), originally developed in California and adapted for use in Texas *(6)*. The revised program, called HEEM–II *(7)*, compares the existing highway corridor with the corridor if the proposed improvements are made. (A corridor consists of the highway to be improved along with up to two alternate routes. The proposed highway can also be a new location construction.)

Traffic is allocated to each corridor highway based on motorist costs of travel on each route. Motorist costs, or user costs, are calculated for each year during an analysis period, typically

20 years. User costs consist of motorist time costs of travel through the specified corridor, vehicle operating costs, and accident costs. Costs are calculated for two vehicle types—passenger cars and trucks—on a daily basis. Daily costs are summed to a yearly total. This process is repeated and costs are discounted for each year during the analysis period.

The benefits of the proposed highway project represent the reduction in user costs (user costs on the existing corridor minus the user costs of the proposed corridor). The benefit-cost ratio is the user benefits plus any change in maintenance costs divided by the project cost. The benefit-cost ratio (B/C) is determined from

$$B = \sum_{t=1}^{n} (TC_t + VOC_t + AC_t + MC_t)(1 + r)^{-t} \quad (1)$$

where

C = project cost (construction cost plus right-of-way cost),
TC_t = reduction in time costs in year t,
VOC_t = reduction in vehicle operating costs in year t,
AC_t = reduction in accident costs in year t,
MC_t = reduction in maintenance costs in year t,
n = number of years in analysis period, and
r = discount rate.

Although HEEM–II represents an improvement over other models and techniques, especially in the explicit analysis of a corridor of highways, it has some limitations. First, HEEM–II is designed principally to analyze added-capacity type projects, generally adding one or more lanes to an existing highway. The program can analyze other types of projects, but with less precision. These include new-location projects when the existing corridor is poorly defined and upgrading deficiencies, such as widening lanes or adding shoulders. Second, the program uses daily traffic as the basis of analysis, so detailed analysis of congestion during the day cannot be performed.

For this study, a computerized program to analyze many added-capacity projects with limited data was needed. The HEEM–II program, which had the basic structure and characteristics required for the study, was modified somewhat so that it could run efficiently and with less data on a large number of added-capacity projects. The same output was generated—the ratio of the expected project benefits to the project costs. The expected benefits were calculated over a 20-year analysis period and an 8 percent discount rate was used. The assumed values of time per person in passenger cars and trucks are \$7.85/hr and \$19.20/hr, respectively. These are the default assumptions in HEEM–II *(7)*.

HIGHWAY SUFFICIENCY RATINGS

Highway sufficiency ratings are used to evaluate existing highways using engineering standards. These ratings are the outgrowth of procedures developed beginning in 1933 ". . . to describe on maintenance inspection reports the condition, safety, and service features of completed Federal-aid highway improvements that had deteriorated or become obsolete to the degree that reconstruction was warranted because of unduly high maintenance costs" *(8)*. In 1946 and 1947, the Bureau of Public Roads ". . . field tested a system for numerically rating the three elements of highway condition (structural, safety, and service) which would provide greater precision and uniformity and would permit complete coverage of the rural portions of the Federal-aid primary highway system." In 1947, Region IX of the Bureau of Public Roads adopted the rating plan that by 1951 was extended to the remaining division offices in the continental United States as a part of maintenance inspection procedures.

Many state administrators faced with increased public demand for road improvements also adopted sufficiency ratings for state use. By June 1960, according to a Highway Research Board survey, 38 states used some type of sufficiency rating *(9*, p. 84).

Sufficiency ratings are an index usually consisting of three categories, each having several subunits with weights that typically sum to 100 points if the highway is totally sufficient. Highways with the lowest ratings are considered to be most in need of improvement.

The principal strengths of sufficiency ratings are that they

TABLE 1 DHPT SUFFICIENCY RATING FOR ADDED-CAPACITY PROJECTS

Category	Weights
Traffic flow conditions, present ADT volume on existing facility	
Good (LOS A-B)	0
Tolerable (LOS C-D)	7
Undesirable (LOS E-capacity)	14
Forced (1.0–2.0 × capacity)	21
Forced (more than 2.0 × capacity)	30
Traffic flow conditions, future ADT volume	
Good (LOS A-B)	0
Tolerable (LOS C-D)	6
Undesirable (LOS E-capacity)	9
Forced (1.0–2.0 × capacity)	12
Forced (more than 2.0 × capacity)	20
Present truck ADT volume per existing lane	
0–200	0
201–400	3
401–600	6
601–800	8
More than 800	12
Principal arterial system	
Off	0
On	5
Roadway functional classification	
Local or collector road or street	0
Minor arterial road or street	7
Rural principal arterials, urban connecting links of rural principal arterials, and other urban principal arterials	14
Interstate highways and other freeways	17
Gap considerations	
Does not eliminate capacity gap	0
Eliminates one-end capacity gap	9
Eliminates capacity gap on both ends or is system gap	16
Total sufficiency rating	100

are objective, easy to use, and easy to explain to the public. Sufficiency ratings have two principal weaknesses. First, because they originated from maintenance inspection reports, there has not been enough emphasis on capacity in rating highways that have deficient capacity and geometric standards. Second, the ratings are only a measure of the existing highway deficiency and do not indicate the benefit and cost associated with improvements to correct deficiencies.

Although many states have evaluated highways using sufficiency ratings, it is not clear how much these ratings have been used to set improvement priorities. Many states undoubtedly use other techniques and evaluations in addition to sufficiency ratings. The Texas Department of Highways and Public Transportation (DHPT) has not relied on sufficiency ratings as much as have other states. However, two different sufficiency rating schedules have been developed in Texas for possible use along with other evaluations in setting priorities. The Texas ratings are somewhat different from typical ratings. First, the rating schedules are set up so that the highways most in need of improvement are given higher ratings with a maximum of 100 points. Second, and more important, two different schedules have been developed, one for added-capacity projects (mainly adding lanes, providing medians, and controlling access) and one for upgrade-to-standards projects.

The Texas schedules represent a major improvement over typical schedules for purposes of setting priorities for added-capacity and upgrade-to-standards projects because they focus more on the categories of deficiency that would be affected by improvements. The added-capacity schedule emphasizes present and future capacity for the existing highway relative to present and forecasted traffic volumes. The upgrade-to-standards schedule focuses on items that cause the need for upgrading. The schedule for added-capacity projects is presented in Table 1 *(10)*. This sufficiency rating schedule gives points for deficiencies in the existing facility. Therefore, the ideal highway would receive 0 points and the most deficient possible highway would receive 100 points. Although it is more common for sufficiency ratings to go in the opposite direction—100 for the best facility and 0 for the worst—DHPT's method will be used in this paper because it is consistent with ranking techniques in which the higher the number, the higher the project priority.

In Table 1, the first two categories of traffic flow conditions are based on level of service (LOS). The table to convert average daily traffic (ADT) into LOS (presented in Table 2) is based on highway type and number of lanes. In the case of two-lane rural undivided highways, there is also a distinction for the type of terrain. The third category of truck ADT volume uses the current truck volume per lane on the existing highway instead of LOS. The next two categories are characteristics of the existing highway. The last category of gap considerations is the only category where the proposed project has any impact on the point total. The other categories are measures of the deficiencies on the existing facility.

TABLE 2 AVERAGE DAILY TRAFFIC VOLUME RANGES OF VARIOUS HIGHWAY CLASSES FOR VARIOUS QUALITIES OF FLOW

Highway Class	Range in ADT Service Volumes: Good Flow (LOS A–B)	Tolerable Flow (LOS C–D)	Undesirable Flow (LOS E–Capacity)
Urban freeways			
Four-lane	0–44,000	44,001–52,800	52,801–64,400
Six-lane	0–66,000	66,001–79,200	79,201–96,600
Eight-lane	0–88,000	88,001–105,600	105,601–128,800
Each additional lane	0–11,000	11,001–13,200	13,201–16,100
Urban divided streets[a,b]			
Four-lane	0–16,100	16,101–19,100	19,101–23,000
Six-lane	0–23,500	23,501–27,900	27,901–33,000
Eight-lane	0–29,400	29,401–34,900	34,901–42,000
Urban undivided streets[a,b]			
Two-lane	0–7,700	7,701–9,100	9,101–11,000
Four-lane	0–12,600	12,601–14,900	14,901–18,000
Six-lane	0–19,800	19,801–23,500	23,501–28,300
Rural Freeways			
Four-lane	0–20,800	20,801–31,600	31,601–42,000
Six-lane	0–31,200	31,201–47,400	47,401–63,000
Rural divided highways[a,b]			
Four-lane	0–12,000	12,001–17,500	17,501–35,000
Six-lane	0–18,000	18,001–26,200	26,201–52,500
Rural undivided highways[a,b]			
Rolling terrain, two-lane	0–2,800	2,801–4,700	4,701–14,700
Level terrain, two-lane	0–3,700	3,701–6,100	6,101–17,400
Level terrain, four-lane	0–9,500	9,501–13,000	13,001–26,000
Level terrain, six-lane	0–15,000	15,001–19,500	19,501–39,000

[a] A divided facility includes a flush or depressed median with sufficient width for storage of left turning vehicles. On undivided facilities, left turns are made from a through lane.
[b] Urban street, as opposed to rural highway, conditions prevail whenever the intensity of roadside development, speed zoning, signals, stop or yield signs, and so forth, result in interrupted flow conditions and reduced traffic speeds.

COST-EFFECTIVENESS TECHNIQUES BASED ON SUFFICIENCY RATINGS

Recognizing the shortcomings of sufficiency ratings for setting priorities for highway improvement, the FHWA and several states have developed other priority formulas. This type of technique is referred to here as a cost-effectiveness technique based on sufficiency ratings because the formulas represent a ratio of effectiveness to cost (or cost per highway or lane-mile). Effectiveness is measured by the change in the sufficiency rating between the existing and improved highways, multiplied by the annual ADT. The change in the sufficiency rating represents the effectiveness of the proposed highway improvement per vehicle mile and is weighted by vehicle miles to obtain total effectiveness. There are several variations of this general procedure, for example, the technique used by Minnesota *(11)*, the PRIPRO formula developed by FHWA *(12)*, and the cost-effectiveness procedure used in the Highway Performance Monitoring System *(13)*.

In this study, a similar technique was developed for testing in Texas. This technique is called the Texas priority formula because it is based on the Texas sufficiency rating and has features that distinguish it from formulations used elsewhere. The priority formula has two variations—one for added-capacity projects and one for upgrade-to-standards projects. The general equation for this priority formula is

$$PF = (SR_E - SR_P)(1 + P/100)(2CADT/3 + FADT/3)(LTH)/CST \quad (2)$$

where

- PF = priority formula rating,
- SR_E = sufficiency rating for existing facility,
- SR_P = sufficiency rating for proposed facility,
- P = sufficiency points for categories that do not change with improvement,
- $CADT$ = current annual average ADT,
- $FADT$ = forecasted, typically 20 years in the future, annual average *ADT*,
- LTH = project length (mi), and
- CST = initial highway construction and right-of-way cost ($ thousands).

The first factor in the priority formula represents the change in the sufficiency points as a result of the improvement. Because the Texas sufficiency ratings give higher point totals to more deficient highways, this change is obtained by subtracting the sufficiency rating for the proposed highway from the sufficiency rating for the existing highway. This change can be viewed as a proxy for the benefits of the project per vehicle. The second factor is an adjustment for those categories in the sufficiency rating that do not change as a result of the improvement and are, therefore, not reflected in the first term. In Table 1, these are shown as Categories 4, 5, and 6. The third factor is a weighted average of the current and future ADT. If the first two terms are viewed as adjusted benefits per vehicle, then multiplying by the total vehicles gives a measure of total benefits. The weighting of current and future ADT represents both the increasing number of vehicles over time and the lower present value of future benefits through discounting. The formula is then multiplied by project length and divided by project cost to produce a measure of the desirability of a project.

The Texas priority formula is not a benefit-cost ratio because the benefits are not measured in dollars. It is a cost-effectiveness index measuring the amount of benefits (or effectiveness) per dollar of construction cost. Each variation of the sufficiency rating presented in the next section can be used in the priority formula so there is a separate priority formula ranking associated with each sufficiency ranking.

ALTERNATIVE FORMULATIONS OF THE SUFFICIENCY RATING AND THE PRIORITY FORMULA

One weakness of an easy-to-use manual method of calculating a sufficiency rating, such as the Texas rating schedule presented in Table 1, is the limited number of different characteristics that receive points within each category. If a large number of projects is being ranked, many projects receive the same score. In a computerized version of the Texas sufficiency rating for added-capacity projects, the first three categories can easily be modified so the points are calculated directly using ADT. The points P_{ADT} for each of the first two categories in traffic flow conditions in Table 1 can be approximated using the following formula:

$$P_{ADT} = [(TRF - T1)/A1]^{A2}, \text{ if } T1 < TRF \leq T4 \quad (3)$$

where

- $A1$ = $\exp[\ln(T4 - T1) - \ln(S4)/A2]$,
- $A2$ = $[\ln(S4) - \ln(S2)]/[\ln(T4 - T1) - \ln(0.5T1 + 0.5T2)]$,
- TRF = ADT volume per lane on existing facility (either current ADT or future ADT),
- $T1$ = ADT/lane for upper limit on LOS A–B,
- $T2$ = ADT/lane for upper limit on LOS C–D,
- $T3$ = ADT/lane for capacity volume,
- $T4$ = ADT/lane for volume two times capacity,
- $S1$ = points for tolerable conditions,
- $S2$ = points for undesirable conditions, and
- $S4$ = points for forced flow greater than two times capacity.

Texas sufficiency rating points for ADT on urban freeways, along with the continuous approximations of those points using Equation 1 are shown in Figure 1. Each curve starts where the first points are awarded, intersects the midpoint of the second step, and stops at two times capacity where maximum points are awarded.

The points P_{TRK} for the truck ADT volume can be approximated using a simple linear equation.

$$P_{TRK} = 4.0 + 0.02(TK), \text{ if } TK > 200 \quad (4)$$

where TK equals current ADT truck volume per existing lane.

As shown in Figure 1, DHPT's sufficiency points for traffic flow conditions are given in such a fashion that the approxima-

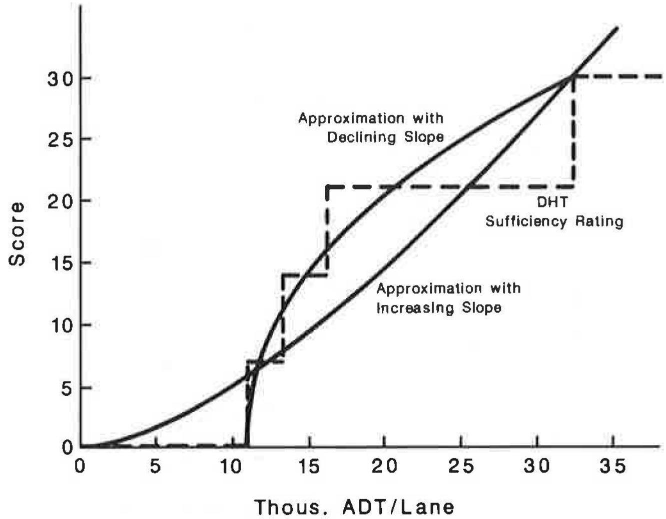

FIGURE 1 Continuous approximation of sufficiency rating scores for traffic flow condition categories as a function of average daily traffic per lane.

tion has a decreasing slope and the curve becomes flatter as ADT increases. If the points awarded are considered as proxy for the user costs generated by increased traffic volumes and congestion, the curve should have an increasing slope, with the curve becoming steeper as ADT increases. Therefore, a second modification was developed to approximate the points for both current and future ADT using the following equation.

$$P_{ADT} = [(TRF/A1)^{A2}], \text{ if } TRF \le T4 \qquad (5)$$

where

$A1$ = $\exp[\ln(T4) - \ln(S4)/A2]$, and
$A2$ = $[\ln(S4) - \ln(S1)]/[\ln(T4) - \ln(0.5T1 + 0.5T2)]$.

This equation starts at zero, goes through the midpoint of the first step in Figure 1, and stops at the maximum point at two times capacity.

An advantage of a sufficiency rating is that it is capped on both ends. In this case, points can only vary between 0 and 100. This limitation allows for an easy comparison of projects because each project can be compared with the best situation (0 points) and the most deficient situation (100 points). However, this system penalizes those projects that have conditions worse than the conditions necessary for maximum points in a category. In the case of ADT, existing facilities that have current or future ADT greater than two times capacity receive no additional points. As a result, the priority formula is also tested with no cap on points for those projects that have ADT values exceeding two times capacity.

SENSITIVITY ANALYSIS OF SUFFICIENCY RATING AND PRIORITY FORMULA

A pilot study of 102 proposed added-capacity projects throughout Texas was used to test and compare the variations of the Texas sufficiency rating and the Texas priority formula described in the previous section. Eight rankings were analyzed: the Texas sufficiency rating and three variations of it, and four priority formula rankings corresponding to each of the sufficiency ratings.

The various project rankings are first compared with each other using Spearman's rank correlation coefficient, which measures the degree of correlation between two sets of rankings. A coefficient of 1.00 indicates the rankings are the same, whereas a coefficient of −1.00 indicates they are the opposite. A coefficient of 0.00 indicates the rankings are not correlated at all. The correlation coefficient is calculated using the following formula, which includes an adjustment for ties *(14)*.

$$r = [M - (\Sigma D^2 + T_x + T_y)]/[(M - 2T_x)(M - 2T_y)]^{1/2}, \quad \text{with } -1 \le r \le 1 \qquad (6)$$

where

r = Spearman's rank correlation coefficient,
M = $(n^3 - n)/6$,
D = difference in the pair of rankings,
n = number of projects,
T_x = $\Sigma(t_x^3 - t_x)/12$,
T_y = $\Sigma(t_y^3 - t_y)/12$,
t_x = number of ties in consecutive groups of the x series, and
t_y = number of ties in consecutive groups of the y series.

The comparisons of rankings using Spearman's rank correlation coefficient are presented in Table 3. The positive coefficients in the table indicate that all the variations produce rankings that are positively correlated, and the positive correlations are all statistically significant. Although no rankings are

TABLE 3 SPEARMAN'S RANK CORRELATION COEFFICIENTS FOR RANKING OF SAMPLE PROJECTS

	Code for Ranking Techniques						
	2	3	4	5	6	7	8
1	0.972	0.967	0.959	0.403	0.494	0.478	0.620
2		0.987	0.974	0.365	0.533	0.517	0.655
3			0.963	0.352	0.515	0.513	0.638
4				0.334	0.482	0.480	0.660
5					0.805	0.769	0.729
6						0.971	0.916
7							0.926

NOTE: All coefficients are statistically significant at the 1 percent level. The code for ranking techniques is defined as follows:

1. Texas sufficiency rating.
2. Texas sufficiency rating with continuous approximation for ADT and truck points.
3. Texas sufficiency rating with continuously increasing slope curves for ADT points.
4. Texas sufficiency rating with continuously increasing slope no cap on points.
5. Texas priority formula.
6. Texas priority formula with continuous approximation for ADT and truck points.
7. Texas priority formula with continuously increasing slope curves for ADT points.
8. Texas priority formula with continuously increasing slopes, no cap on points.

exactly the same (a coefficient of 1.00), the highest correlations are for rankings using modifications of the same technique between the sufficiency ratings and between the priority formulas. The Texas sufficiency rating (No. 1) and the three versions of it (Nos. 2, 3, and 4) have correlation coefficients greater than 0.96. The correlation between the priority formulas is generally not quite so high, with the correlation of the priority formula (No. 5) with the variations (Nos. 6, 7, and 8) ranging from 0.805 to 0.729, correspondingly.The correlations between Numbers 6, 7, and 8 are higher, ranging from 0.971 to 0.916, correspondingly.

The results of the pilot study rankings comparisons using the correlation coefficient indicate that the particular version of the Texas sufficiency rating used does not make much difference in project rankings. But that is not the case with the priority formula. Therefore, the original Texas sufficiency rating (No. 1) along with the last version of the priority formula (No. 8) were selected for further analysis on the complete set of added-capacity projects in DHPT's 20-year plan. The version of the priority formula with continuously increasing slopes and no cap on points, was chosen because it comes closest to representing the benefits generated by making an added-capacity improvement, which can then be compared with the cost of the project in making comparisons among projects.

COMPARISON OF PRIORITY RANKINGS

The three techniques discussed in preceding sections were used to rank a large number (1,942) of actual added-capacity projects that are being considered in Texas for possible funding in the next 20 years. These rankings are compared in three ways. First, the total highway user benefits obtained at different budget levels, or levels of cumulative initial cost, are compared for the three techniques; the improvement relative to random selection also is discussed. Second, a comparison is made of the rankings from different techniques to determine the extent to which the rankings are similar, using rank correlation coefficients. Third, a comparison of project rankings is made by deciles of cumulative initial cost to determine the location of projects being chosen (rural, urban, or suburban) and the average size of project selected.

Comparison of Benefits at Different Budget Levels

One of the principal criteria used to compare project rankings for the three techniques is the level of benefits provided by each technique's ranking. Two different sets of rankings were compared on this basis. First, a pilot study was conducted of rankings for 102 added-capacity projects, as reported in the preceding section. The complete test reported in this section involved ranking the full set of 1,942 added-capacity projects being considered for planned funding in Texas in the next 20 years. These 1,942 projects were ranked from first to last using each of the three techniques. The cumulative benefits were calculated using the modified HEEM–II computer program for the rankings using each technique. The results of this exercise are shown in Figure 2. Each technique's cumulative benefits are plotted versus the cumulative cost for that technique's rankings. In addition to showing the cumulative benefit curve for each of the three techniques, Figure 2 shows the cumulative benefits that would result from random selection (represented by the straight dashed line). The random selection line shows the benefits, at different levels of cumulative cost, that would be expected to result if projects were chosen randomly; the slope of this curve is determined by dividing the total benefits for all 1,942 projects by the total cost for all 1,942 projects, or $89.062 billion divided by $21.228 billion.

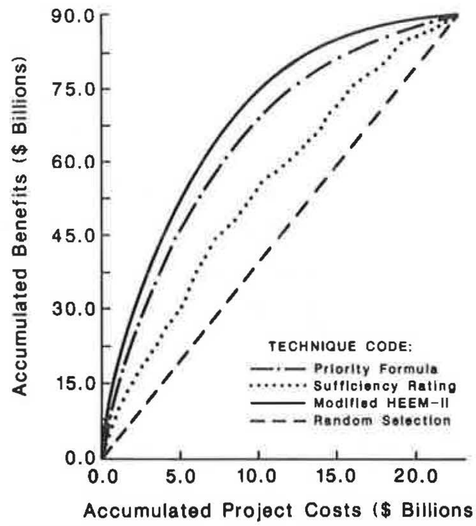

FIGURE 2 Cumulative benefits versus cumulative costs for rankings by different techniques.

All three ranking techniques show an improvement over random selection, with the HEEM–II benefit-cost technique having the highest cumulative benefit curve, followed by the priority formula and the highway sufficiency rating technique. All four curves eventually converge at the upper-right corner of the graph, representing the cumulative benefits and costs for all projects. A more precise comparison can be made, however, by comparing the benefits from each technique at lower budget levels. The data in Table 4 show such a comparison at budget levels representing funds that are expected to be available for budget levels for 1-year, 5-year, and 10-year construction programs. At the 1-year budget level of $0.785 billion, random selection of projects would entail selection of projects that

TABLE 4 CUMULATIVE BENEFITS AT SELECTED BUDGET LEVELS, BY TECHNIQUE

	Cumulative Benefits for Cumulative Cost		
Ranking Technique	$0.785 billion in 1-Year Program ($ billions)	$3.551 billion in 5-Year Program ($ billions)	$5.742 billion in 10-Year Program ($ billions)
Texas sufficiency rating	7.316	24.610	36.512
Texas priority formula	12.980	39.034	51.618
Modified HEEM–II	16.780	45.723	59.202
Random selection	3.293	14.898	24.091

provide $3.293 billion in benefits as compared with $16.780 billion for HEEM–II, $12.980 billion for the priority formula, and $7.316 billion for the sufficiency rating.

Perhaps more instructive is the benefit comparison at a 10-year budget level of $5.742 billion. The percentage improvement over random selection at this budget level is shown for each technique in Table 5. The HEEM–II benefit-cost program

TABLE 5 TOTAL BENEFITS AND PERCENT IMPROVEMENT OVER RANDOM SELECTION FOR DIFFERENT TECHNIQUES FOR THE 10-YEAR PROGRAM (costing $5.742 billion) OF ADDED-CAPACITY PROJECTS

Ranking Technique	Benefits for 10-Year Program ($ billions)	Improvement Over Random Selection (%)
Texas sufficiency rating	36.5	51.5
Texas priority formula	51.6	114.1
Modified HEEM–II	59.2	145.6
Random selection	24.1	0.0

selects projects that give 145.6 percent more benefits than does random selection. HEEM–II ranked projects for the 10-year budget are expected to give $22.7 billion more than the sufficiency rating ranking and $7.6 billion more than the priority formula ranking. It is not surprising that the HEEM–II technique gives the best ranking because these benefits are calculated using the HEEM–II estimates of savings in travel time costs, vehicle operating costs, and accident costs that are expected from these added-capacity projects. Nevertheless, the magnitude of the improvement is impressive. It should be noted that these benefits are calculated in terms of present values over a 20-year analysis period, assuming the projects are constructed immediately. Because the projects would be constructed over about a 10-year period, the assumption that they are constructed immediately has a tendency to overstate benefits. This overstatement would probably be more than offset by future traffic growth and benefits from the improvements, which are generated over a period greater than 20 years. Future research should include more precise calculations with phasing of the projects over time, allowing for traffic growth before the improvement is completed, and discounting future benefits from the time the projects are completed to the date considered. As noted, however, the estimated difference between techniques probably would increase from the consideration of the budget over time.

Rank Correlation Coefficients

Spearman's rank correlation coefficients were calculated for different pairs of rankings. The calculation technique used is similar to that in the pilot test discussed earlier, the only difference being that the full 20-year set of 1,942 added-capacity projects is used instead of the 102 projects in the pilot test.

Spearman's rank correlation coefficients between pairs of ranking techniques for rankings of 1,942 added-capacity projects are presented in the following table:

Ranking Techniques	*HEEM–II*	*Priority Formula*
Sufficiency rating	0.467	0.673
HEEM–II		0.806

These values can be tested to determine if the pairs of rankings are positively correlated. A rank correlation coefficient of only 0.053 is needed to reject the null hypothesis of no correlation or negative correlation at the 0.01 level of significance and of only 0.108 at the extreme 0.000001 test level. Because the smallest value in the table is 0.467, the hypothesis that the pairs of rankings are randomly related or negatively related is rejected and the hypothesis that the pairs of rankings are positively related is accepted.

Analysis of Location and Size of Projects Selected by Deciles of Cost

To further investigate the characteristics of projects being ranked highest by each technique, the rankings for each technique were divided into 10 groups (deciles) of roughly equal cost. To determine the projects in the first decile for a specific technique, the procedure used entailed going down the ranked list of projects until the next (marginal) project would cause cumulative cost to exceed one-tenth of the total cost of all projects. The second decile includes that marginal project plus all other projects down the list until the next project would exceed two-tenths of the total cost of all projects, and so forth. There are some small differences between the costs of each decile because of projects that do not add precisely to one-tenth. Also, in the case of sufficiency ratings, there are some project ties in the ranking. All of the ties are put in the same decile so there is more irregularity in the decile costs for sufficiency ratings than for the other techniques.

Within each decile, for each ranking technique, several characteristics are evaluated. The characteristics of all 1,942 added-capacity projects are summarized in Table 6. Less than

TABLE 6 CHARACTERISTICS OF 1,942 ADDED-CAPACITY PROJECTS CONSIDERED AS POSSIBILITIES FOR FUTURE CONSTRUCTION

	Type of Area			
Characteristic	Urban	Urban-Rural	Rural	Total
Number of projects	605	402	935	1,942
Percent of all projects	31.2	20.7	48.1	100.0
Cost of projects ($ millions)	10,542	2,934	7,752	21,228
Percent of all cost	49.7	13.8	36.5	100.0
Average cost per project ($ millions)	17.4	7.3	8.3	10.9

one-third of all projects are in urban areas but these projects represent almost 50 percent of all project costs. The urban-rural fringe area projects represent 20.7 percent of all projects and only 13.8 percent of all costs. Rural projects represent 48.1 percent of all projects but only 36.5 percent of all costs.

TABLE 7 TOTAL COST OF URBAN PROJECTS SELECTED BY EACH TECHNIQUE BY DECILE OF TOTAL COST

	Decile of Total Cost ($ millions)										Total
Technique	1	2	3	4	5	6	7	8	9	10	($ millions)
Sufficiency rating	1,726	1,670	1,258	1,312	1,263	1,345	699	659	496	114	10,542
Priority formula	1,249	1,338	1,382	1,220	1,228	968	1,134	792	671	559	10,542
Modified HEEM–II	972	870	1,083	1,147	841	694	1,277	1,316	1,080	1,261	10,542
Average	1,314	1,293	1,241	1,226	1,111	1,002	1,037	2,767	749	645	10,542

TABLE 8 TOTAL COST OF URBAN-RURAL FRINGE PROJECTS SELECTED BY EACH TECHNIQUE BY DECILE OF TOTAL COST

	Decile of Total Cost ($ millions)										Total
Technique	1	2	3	4	5	6	7	8	9	10	($ millions)
Sufficiency rating	257	373	403	425	83	172	342	315	206	358	2,934
Priority formula	538	540	294	284	295	124	182	253	150	275	2,934
Modified HEEM–II	589	671	338	359	235	208	183	94	210	45	2,934
Average	461	528	345	356	204	168	236	221	189	226	2,934

TABLE 9 TOTAL COST OF RURAL PROJECTS SELECTED BY EACH TECHNIQUE BY DECILE OF TOTAL COST

	Decile of Total Cost ($ millions)										Total
Technique	1	2	3	4	5	6	7	8	9	10	($ millions)
Sufficiency rating	107	108	463	378	674	694	1,085	1,167	1,426	1,650	7,752
Priority formula	330	251	288	733	631	1,027	829	1,072	1,300	1,291	7,752
Modified HEEM–II	517	612	679	642	1,031	1,204	707	677	864	819	7,752
Average	318	324	477	584	779	975	874	972	1,197	1,253	7,752

The data in Tables 7 through 9 present the costs of projects selected by each technique by deciles of total cost for urban areas, urban-rural fringe areas, and rural areas, respectively. The sufficiency rating tends to select large urban projects in the top deciles but distributes urban-rural fringe projects more evenly over deciles. Large urban projects tend to be ranked high because they have large traffic volumes and, thus, large sufficiency ratings, and the sufficiency rating does not adjust this for larger construction costs in urban areas. This effect carries over somewhat into the priority formula. The modified HEEM–II tends to provide a more uniform distribution across deciles. The priority formula and HEEM–II tend to favor urban-rural fringe area projects much more than does the sufficiency rating.

The data in Table 10 show the percentage of project costs summed over the first three deciles in Tables 7 through 9. These top three deciles cover a total project cost of about $6.368 billion, or slightly more than is anticipated will be available for these types of projects in the next 10 years, so these three deciles cover the projects that are of most interest in developing a 10-year plan.

The sufficiency rating and priority formula both allocate a large percentage of the total budget (for the first three deciles) to urban projects, with 73.1 and 63.9 percent, respectively, as compared with HEEM–II's 46.2 percent. The priority formula and HEEM–II both allocate a relatively high percent to suburban (urban-rural) projects, with 22.1 and 25.2 percent, respectively, as compared with an average of 13.8 percent for this type of project for all projects. All three techniques allocate a smaller percent than the overall average to rural projects, but the sufficiency rating and priority formula are especially low with 10.7 percent and 14.0 percent, as compared with 36.5 percent for all projects. HEEM–II is much closer to the overall average with 28.6 percent of all costs allocated to rural projects.

CONCLUSIONS

The priority formula ranking for the 10-year budget provides considerably more total benefits than does the sufficiency rat-

TABLE 10 PERCENTAGE DISTRIBUTION OF NUMBER OF PROJECTS IN TOP THREE DECILES BY TYPE OF AREA, BY TECHNIQUE

	Percentage Distribution of Number of Projects in Top Three Deciles by Type of Area			
Technique	Urban	Urban-Rural	Rural	Total
Sufficiency rating	64.0	20.2	15.7	99.9
Priority formula	52.4	24.9	22.7	100.0
Modified HEEM–II	35.6	27.2	37.2	100.0
Average	50.7	24.1	25.2	100.0
Average (all deciles)	31.2	20.7	48.1	100.0

ing ranking. For a 10-year expenditure program, the priority formula gives 114 percent more benefits than does random selection and 41 percent more benefits than does the sufficiency rating. This finding indicates that the priority formula, by considering the change in the sufficiency rating, by weighting the change in rating by vehicle-miles of travel, and by dividing effectiveness by project cost, transforms the sufficiency rating into a greatly improved rating method. This implies that the Texas sufficiency rating schedule does a good job of measuring the factors that affect benefits, but that the schedule must be used properly in a priority formula to become a good ranking technique.

The benefit-cost analysis is superior to both the sufficiency rating and the priority formula in maximizing motorist benefits. For the 10-year construction program, the benefit-cost analysis gives 62 percent more benefits than the sufficiency rating and 15 percent more benefits than the priority formula. This represents an increase in benefits of $22 billion relative to the sufficiency rating and $7 billion relative to the priority formula.

Because some version of sufficiency ratings is used to rank construction projects in most states, it is concluded that a large increase in benefits would result from using a priority formula or benefit-cost analysis.

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Analysis of the Impact of Interest Rates on Automobile Demand

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The popularity of interest rate incentive programs as a means of boosting new car sales has been puzzling to many industry analysts. In this paper, an econometric analysis is undertaken to determine how consumers value interest rates in their new car choice decisions. The findings suggest that consumers tend to overvalue interest rates relative to their true worth, thus explaining the surprising success of interest rate incentive programs. Moreover, estimation results indicate that domestic manufacturers can reap greater benefits from interest rate overvaluation than can their Japanese competitors.

Since the early 1980s, American automobile manufacturers have increasingly relied on rebate and interest rate incentives to boost sales of new automobiles. These sales incentives have been offered with the primary objective of reducing inventory, and their success in achieving this objective has been undeniable *(1)*. However, the ever-increasing reliance of manufacturers on new car sales incentives has given rise to an inadvertent market impact. This impact stems from recent sales figures that appear to suggest that consumers may have become so accustomed to sales incentives that they are willing to forego vehicle purchases until sufficiently attractive incentives are offered. Such behavior represents an important alteration of consumer expectations and makes it extremely important, from an industry perspective, that the relative impact of various incentive programs on new car demand be well understood.

In recent years, a variety of interest rate programs have virtually replaced the cash rebate programs that enjoyed widespread popularity at the beginning of the decade. Automobile manufacturers have apparently found interest rate incentives to be more attractive to consumers than other previously implemented programs. However, the precise impact of interest rates on new car sales remains somewhat of a mystery.

The purpose of this paper is to empirically analyze the impact of interest rate incentives on new car sales. In particular, the following questions will be addressed: How much are consumers willing to pay (in terms of increased vehicle capital costs) for a reduction in interest rates? How sensitive are consumers to changes in automobile interest rates? In terms of 1986 model offerings, which automobile manufacturer is likely to benefit the most from interest rate incentives? Answers to these questions will provide valuable insight into the interest rate/automobile demand relationship and the potential impacts of future incentive programs.

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Although research on automobile demand has made significant progress in the past few years *(2–6)*, previous efforts have not explicitly addressed the effects of buyer incentive programs. This situation is due largely to the lack of data on such programs and the reliance of most previous work on the actual revealed preferences of the automobile consumer. In this paper, carefully constructed hypothetical choices are presented to a sample of potential automobile consumers, thus enabling a careful and explicit examination of interest rate incentive programs. The use of such hypothetical choices follows the efforts of Calfee *(7)*, which address the potential market penetration of electric vehicles, and Mannering and Chu Te *(8)*, who consider the effects of manufacturer sourcing.

The paper begins with a discussion of the econometric approach and a description of the survey and resulting data sample. Next, estimation results are presented and their significance is assessed, followed by a discussion of policy implications and, finally, conclusions and directions for future work.

ECONOMETRIC APPROACH

To arrive at an estimable econometric model, it will be assumed that individuals exhibit utility maximizing behavior. The utility provided by each vehicle alternative is defined to be a linear function,

$$U_i = \sum_k \beta_{ki} \cdot x_{ki} \qquad (1)$$

where

U_i = indirect utility provided by vehicle i,
x_{ki} = value of attribute k on vehicle i, and
β_{ki} = estimable parameters.

If a disturbance term is added to Equation 1 such that $V_i = U_i + \varepsilon_i$ and these terms are distributed with a generalized extreme vague (GEV) distribution, it can be shown *(9)* that the vehicle choice probabilities are given by the standard multinomial logit model,

$$P(i \mid s) = \frac{e^{U_i}}{\sum_i e^{U_i}} \qquad (2)$$

where $P(i \mid s)$ equals the probability of selecting vehicle i from the set of vehicles s, and U_i equals the utility provided by vehicle i as specified in Equation 1.

Multinomial logit models are typically estimated on the basis of revealed preferences with a single choice made by each respondent in the sample. Under these conditions, the disturbance term, ε, accounts for the taste variation from one decision maker to the next. In contrast to the revealed preference approach, recent studies *(7–8)* have presented decisionmakers with repeated hypothetical choice sets from which individuals select a utility maximizing alternative. Under these conditions, a logit model can be estimated for each individual as opposed to the single model estimated in the traditional revealed preference approach. With repeated hypothetical choices the disturbance term, ε, accounts for a single individual's taste variation from one choice to another, as opposed to taste variations between individuals *(7, 10)*.

To evaluate the impact of interest rate incentives on new car demand, sets of repeated hypothetical choice situations are presented to each survey participant. The use of such hypothetical choices permits a wide range of choice set variation particularly with respect to interest rates. Such variation is simply not available in known revealed preference data [Information on typical automobile-related revealed preference data is described by Mannering and Train *(11)* and Hensher *(12)*.]. These repeated choice observations will be used to estimate individual logit models (one for each individual) as well as a single overall logit model that will treat choice observations as if they were all made by different respondents.

The estimation of a single overall logit model with repeated observations for each respondent gives rise to an obvious correlation of disturbances because the unobserved influences affecting a specific individual's choice are likely to be correlated from one of his selections to the next. Explicitly accounting for such individual effects in the context of discrete choice models in general, and the multinomial logit model in particular, can be an extremely difficult task *(13)*. In this paper, the possible correlation of error terms is not explicitly accounted for in the overall logit model and hence the results must be viewed with some caution *(14–16)*.

One correctable outgrowth of repeated observations on individual respondents is the estimated standard errors of model coefficients, which will be understated by standard estimation packages. A valid conservative correction for package-reported standard errors is to multiply them by the square root of the number of repeated observations used from each respondent. This correction procedure has been successfully applied in studies of this type *(17)*. All of the overall logit model standard errors presented in this paper are corrected by this procedure.

SURVEY DESIGN AND SAMPLE DESCRIPTION

The survey form consisted of four distinct parts. The first part provided extensive information for participants, including the choice environment they were to imagine themselves to be in (i.e., considering the purchase of a new car) and the vehicle attributes that they were to consider in their choices. The second part collected general information relating to the participant's household income, age, current vehicle ownership, and so on. The third part consisted of the hypothetical vehicle choice sets. The survey form concluded with a detailed debriefer in which the comments and suggestions of participants were collected.

The information included in the hypothetical choice sets consisted of vehicle make (Chevrolet, Chrysler, Ford, Honda, Mazda, Nissan, Toyota, Subaru), purchase price, fuel efficiency (in miles per gallon), reliability index (scaled from 1 to 5), and the annual loan interest rate. A typical choice set is given in Table 1. Each participant was given 30 such new vehicle choice sets, all of which contained 3 vehicles. The participant was then asked to select one of the 3 vehicles for each of the 30 choice sets. Amortization tables were provided to permit participants to make monthly payment calculations. The survey's objective was to ensure that all participants carefully and meticulously consider their vehicle choices. Because survey completion times generally ranged from 25 to 45 minutes, it can be assumed that the survey instrument achieved this objective.

TABLE 1 SAMPLE VEHICLE CHOICE SET

Attribute	Choice A	Choice B	Choice C
Vehicle make	Chevrolet	Ford	Nissan
Price ($)	6,000	8,400	10,700
Miles per gallon	27	17	31
Reliability index (1 = poor, 3 = average, 5 = excellent)	1	2	3
Annual loan interest rate (%)	7.6	9.5	10.0

The 30 hypothetical choice sets were carefully constructed to be realistic and at the same time provide for a reasonable variation in vehicle attributes. Although participants were not provided with information as to the actual vehicle model (e.g., Camry, Thunderbird) all choice sets were based on the attributes of currently offered (spring 1986) vehicle models. A summary of the choice set statistics is given in Table 2.

TABLE 2 SUMMARY STATISTICS FOR HYPOTHETICAL CHOICE SETS

Choice Set	Summary Statistics
Percent foreign make/domestic make	48/52
Price ($)	8,760
Fuel efficiency (mpg)	25.6
Reliability index (1 = poor, 5 = excellent)	3.4
Annual loan interest rate (%)	9.5

NOTE: Averages unless otherwise noted.

The survey was undertaken in the spring of 1986 and was administered to 36 individuals living in New York, N.Y.; Pittsburgh, Pennsylvania; and State College, Pennsylvania. The summary statistics for participants and their associated households are given in Table 3. The figures given in this table reflect values that are reasonably close in national averages with the exception of higher income, higher percentage of males, and lower average age when compared with typical new car buyers.

ESTIMATION RESULTS

The first model estimated is the overall logit model, which treats each participant's response as a separate observation.

TABLE 3 SAMPLE SUMMARY STATISTICS

Participant Attributes	Summary Statistics
Persons in household	2.61
Workers in household	1.58
Household income ($)	31,250
Number of cars in household	1.56
Age of household cars (years)	4.24
Sex (% male/female)	54/36
Age	32.3

NOTE: Averages unless otherwise noted.

This gives a total of 1,080 observations (i.e., 36 respondents each making 30 choices). The estimation results of this model are given in Table 4.

The data in Table 4 indicate that all variables are of plausible sign and reasonable magnitude. The foreign make indicator variable reflects a slight preference among respondents for foreign cars; this finding is consistent with other studies that have focused on new car purchase decisions *(18)*. Presumably this preference is capturing notions of fit and finish and other perceptions of workmanship, which are not explicitly accounted for in the model.

The reliability index was found to have a strong positive influence on the probability of selecting a new automobile. In fact, a large percentage of the respondents indicated in the survey debriefer that the vehicle's reliability was the primary concern in their selection process. An interesting aspect of reliability is that it was found to be valued more in domestic automobiles than in their foreign counterparts. This result reflects the relatively low reliability of current domestic offerings (i.e., room for significant improvement) and supports the earlier new vehicle choice findings *(19)*.

Vehicle price, as expected, had a strong negative effect on vehicle selection probabilities. The model also indicates that female respondents tended to be slightly more sensitive to price considerations than males, but this difference is not large or statistically significant. It was also found that fuel efficiency (measured in miles per gallon) was valued more by younger participants than older ones. This is likely to be an outgrowth of the fact that younger owners tend to drive more and therefore seek lower vehicle operating costs. Finally, it was found that increasing interest rates have a strong negative effect on the vehicle selection probability.

TABLE 4 VEHICLE CHOICE MODEL ESTIMATION RESULTS

	Estimate	Standard Error
Foreign make indicator (1 if foreign, 0 otherwise)	1.652	2.18
Reliability index if domestic make	.967	.383
Reliability index if foreign make	.598	.487
Vehicle price if male	−.000279	.00011
Vehicle price if female	−.000332	.000131
Miles per gallon if participant older than 40 years	.0855	.068
Miles per gallon if participant 40 years old or less	.0962	.027
Interest rate	−.0213	.0117
Number of observations	1080	
Log likelihood at zero	−1153.50	
Log likelihood at convergence	−934.26	

NOTE: Standard errors obtained by multiplying actual estimates by $\sqrt{30}$ (see text).

The relative importance of various vehicle attributes to the vehicle selection process is reflected in the choice elasticities given in Table 5. The data in this table indicate that all variables, with the exception of the foreign make indicator, are elastic. It is interesting to compare the price and interest rate elasticities. Although price elasticities are more elastic than interest rate elasticities, it must be realized that it is much less costly for manufacturers to effect a significant percentage change in interest rates than it is to effect an equivalent percentage change in vehicle price. For example, at sample means (see Table 2), a 50 percent reduction in vehicle price would cost manufacturers $4,380, whereas a 50 percent reduction in interest rates (from 9.7 percent to 4.85 percent) would cost considerably less at typical automobile loan payoff periods of 3 to 5 years. This indicates that participants will be much more receptive to interest rate changes than equivalent vehicle price rebates. This finding will be borne out in the marginal rate of substitution calculations undertaken next. As a final point, however, it must be realized that interest rate reductions have an inherent value limitation in that the rate is unlikely to venture below zero percent. The limitation has been recognized by manufacturers with the recent use of zero percent automobile financing.

TABLE 5 VEHICLE CHOICE MODEL ELASTICITY ESTIMATES

Elasticity Factor	Estimate
Foreign make	.878
Reliability index if domestic make	1.82
Reliability index if foreign make	1.20
Vehicle price if male	−1.61
Vehicle price if female	−1.93
mpg if participant older than 40 years	1.43
mpg if participant 40 years old or less	1.60
Loan interest rates	−1.37

NOTE: Elasticities defined as $\partial P_i/\partial k \cdot k/P_i$, where P_i is the probability of selecting vehicle i and k is an explanatory variable.

CONSUMERS' VALUATION OF INTEREST RATES

With the coefficients given in Table 4, it is possible to arrive at the marginal rate of substitution between vehicle prices and interest rates, that is, the amount participants are willing to pay in terms of increased vehicle purchase price for a 1 percent reduction in the annual loan interest rate. The coefficient estimates indicate that male participants are willing to pay $764.37 for a 1 percent reduction and female participants are willing to pay $642.35. The true value of a 1 percent reduction in interest rates for an $8,000 loan ($8,760 mean price with roughly 10

TABLE 6 ACTUAL SAVINGS RESULTING FROM INTEREST RATE REDUCTIONS FOR AN $8,000 LOAN (in current dollars)

Reduction in Interest Rate (%)	Length of Loan in Years		
	3	4	5
10.5 to 9.5	135.36	184.32	236.4
9.5 to 8.5	133.92	182.4	232.8

percent down payment; see Table 2) around the mean interest rate of 9.5 percent is given in Table 6 for various lengths of loan. Note that the values in this table are not discounted for the time value of money. Hence the present worth of a 1 percent reduction is significantly less than these values at any reasonable discount level.

The data in the table suggest that participants are indeed overvaluing interest rates. However, the extent of this overvaluation must be assessed in light of the confidence intervals of the marginal rates of substitution. The standard errors of these estimates are $566.20 for males and $458.80 for females. These relatively wide confidence intervals make it difficult to develop definitive statements on interest rate overvaluation. Therefore, the results of individual logit models (one model for each respondent) are also considered.

Of the 36 models estimated, 12 respondents' models indicated highly significant marginal rates of substitution (t statistics exceeding 2.0). The respondent number, marginal rate of substitution, and sex is given in Table 7. The marginal rates of substitution calculated from these individual logit models range from $359.23 to $1,743.44 with an average of $798.96, which is well in excess of the true value indicated in Table 6. For the 24 participants with less significant marginal rates of substitution (t statistics less than 2.0), values ranged from $44.21 to $928.17 with an average of $456.28. In terms of demographics, in comparing the 12 participants with highly significant marginal rates of substitution with the 24 participants who did not have significant rates, no particular distinction between the two groups was noticeable. It is speculated that these groups differ as a result of past vehicle ownership and loan payment experiences (information that was not collected in the survey).

The results of both the overall logit model and the individual logit models indicate that consumers in general are overvaluing interest rates and some by a very large margin. This finding goes a long way to explain the success of interest rate incentive programs and the near demise of cash rebate programs. It appears as though low interest rates are just another sales ploy available to automobile dealers.

TABLE 7 INDIVIDUAL LOGIT MODEL RESULTS FOR PARTICIPANTS WITH HIGHLY SIGNIFICANT MARGINAL RATES OF SUBSTITUTION (t values exceeding 2.0)

Respondent No.	Marginal Rate of Substitution[a]	Sex
4	877.77	Male
6	746.61	Male
9	436.68	Female
10	1,743.44	Male
16	821.25	Male
18	811.13	Male
19	811.89	Male
23	820.78	Male
28	763.78	Female
29	677.79	Female
31	717.16	Male
34	359.23	Female

NOTE: Models include the following variables: make indicator (1 if foreign, 0 otherwise), price, miles per gallon, reliability index, and interest rate.

[a]Price (in dollars) willing to pay in increased purchase price for a 1 percent reduction in loan interest rate.

MANUFACTURER IMPLICATIONS

Given the apparent importance of interest rates on new car sales, it would be interesting to determine which manufacturers could benefit most from interest rate incentive programs. To do this, interest rate elasticities are calculated for individual vehicle makes as opposed to the overall interest rate elasticity value given in Table 5. The result of these calculations is given in Table 8.

TABLE 8 INTEREST ELASTICITIES BY VEHICLE MAKE

Make	Value	Make	Value
Chevrolet	−1.413	Mazda	−1.161
Chrysler	−1.587	Nissan	−1.248
Ford	−1.460	Toyota	−1.166
Honda	−0.934	Subaru	−1.067

NOTE: Elasticities defined as $\partial P_i/\partial k \cdot k/P_i$, where P_i is the probability of selecting vehicle i and k is an explanatory variable.

The data in this table indicate that Chrysler could benefit the most from incentive programs (i.e., most elastic), followed by Ford and Chevrolet. In general, Japanese producers offer vehicles that are much less sensitive to interest rates. This finding could be one explanation for why domestic manufacturers have chosen to offer interest rate incentive programs, that is, to gain some degree of competitiveness with Japanese firms whose cars traditionally have dominated in most vehicle attribute areas.

As a final point, it must be recognized that the elasticity estimates given in Table 8 are a direct function of the types (models) of vehicles currently offered by the manufacturers. Therefore, the time stability of these elasticity estimates has to be viewed with caution.

SUMMARY AND CONCLUSIONS

The purpose of this paper is to provide some insight into the relationship between interest rate incentive programs and the demand for automobiles. Econometric choice models were developed and estimated with a sample of 36 respondents, each of whom made selections from 30 different new vehicle choice sets.

The findings from the overall logit model (i.e., treating each choice as a unique observation) and individual logit models suggest that participants overvalue interest rates relative to their actual worth. Although the extent of this overvaluation varies across the sample population (as reflected in the individual logit model estimates), it is clear that automobile manufacturers could easily exploit this overvaluation to boost new car sales. Based on the extensive interest rate incentive campaigns undertaken by the industry in recent years, it is apparent that manufacturers and dealers have long recognized consumer overvaluation of interest rates.

In terms of individual manufacturers' ability to exploit interest rate overvaluation, the findings indicate that domestic firms have a greater potential benefit than their Japanese counterparts. This disparity is an outgrowth of current automobile model offerings and their associated attributes. Barring a shift in consumer preferences, the domestic industry is in a position to benefit from interest rate incentive programs and use such programs as a legitimate weapon in their battle against Japanese imports.

As a final word of caution relating to the findings of this research, it is important to note that the issue of the change in interest rate valuation over time is not addressed. Presumably continued exposure to interest rate incentive programs will result in a more knowledgeable consumer who is less likely to overvalue interest rate deductions. This "exposure" notion may explain in part the demise of the cash rebate programs that enjoyed widespread popularity before the introduction of interest rate incentives. An important direction for future research would be to examine the time stability of interest rate valuation.

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The Value of Travel Time: New Elements Developed Using a Speed Choice Model

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In benefit-cost analysis, travel time saving represents a major determinant of the benefits from highway improvements. Current values of time adopted by the Texas Highway Evaluation Model as well as those recommended by AASHTO's manual for calculating benefits of highway and bus transit improvements are outdated and new estimates are needed. In this study, the value of time was derived from a telephone survey by adopting a speed choice model in which each driver chooses speeds that minimize the total driving costs for each trip. Driving costs include vehicle operating costs, time costs, accident costs, and traffic violation costs. The value of time for each individual is proportional to the square of the individual's chosen speed, the reciprocal of the distance traveled, and the sum of the first derivatives with respect to speed of the driver's accident costs, vehicle operating cost, and speeding ticket costs. Among the driving cost components, fatal accident cost plays an important role in the determination of the value of time. Individuals' fatal accident costs directly relate to their values of life, which were derived using a foregone labor earnings approach. Different weights were considered and applied to arrive at weighted average values of time. The resulting value of time for a driver was $8.03/hr, and for a passenger car $10.44/hr, in 1985 dollars.

Benefits resulting from travel time savings represent a major portion of the total benefits in benefit-cost analysis used by highway planners and officials for evaluating highway improvement projects. To translate benefits from travel time savings between alternative projects to monetary terms, the unit value of time is needed. Many estimates of the value of time have been performed over the last 20 years. The methods most commonly used involve binary choices of transport modes or routes. The modal choice method is relevant mainly in areas that offer transit alternatives such as bus, subway, and train; the route choice method in areas that have toll roads. Therefore, in states or areas where transit alternatives or toll roads, or both, are few, or where alternate free roads are unavailable, these methods are not as readily applicable.

Another method used in estimating the value of time is based on the speed choice model *(1)* in which drivers are assumed to drive at speeds that minimize total trip costs. In rural areas of Texas for which this study was performed, few transit alternatives are available and toll roads are practically nonexistent. For estimating the value of travel time on rural highways in Texas, the speed choice model is more appropriate than either the modal choice or route choice model and hence was chosen for adoption for this study.

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The speed choice model was introduced in 1965 in a study by Mohring *(2)*, who roughly estimated a value of time of $2.80 for a driver on a rural highway driving at his or her desired speed, with vehicle operating cost as the only trip cost considered. In 1975, Ghosh et al. *(3)* equated the marginal benefits of speed to the marginal costs of speed and obtained a set of optimal speeds for the British motorways using different combinations of the value of time and the cost per fatality. More recently, Jondrow et al. *(4)* used a similar approach but distinguished between the private optimum speed and the social optimum speed. Optimum speeds were calculated for different combinations of value of time and value of life. The speed choice model also has been used in several German studies *(5)*.

A major shortcoming of previous speed choice models for use in estimating a value of time is that they use average values for motorist cost curves and speeds. This shortcoming may be overcome by estimating specific cost curves for each individual in the sample and by using each individual's desired speed in different cost situations.

MODEL

In the speed choice model for evaluating the value of time, it is assumed that a rational driver chooses a speed at which the driver's total trip cost is minimized. In this study, the total trip cost is assumed to include time costs, vehicle operating costs, accident costs, and traffic violation costs. Each of these cost components is related to speed and the relationship differs not only in magnitude among cost components but also in direction. Hence, when a driver attempts to decrease one of the costs, other cost components may increase, resulting in a higher total trip cost. For instance, by increasing travel speed, travel time is reduced and consequently, time costs are lowered. However, at higher speeds, other costs may increase, offsetting the lower time costs and resulting in a higher total trip cost. A rational driver who minimizes total cost (Point A in Figure 1) chooses the optimal speeds.

The total trip cost (TTC_i) for individual i traveling a distance of d (mi) at speed s_i (mph) is calculated as

$$TTC_i = TMC_i + VOC_i + ACC_i + TKC_i \tag{1}$$

where TMC_i, VOC_i, ACC_i, and TKC_i represent individual i's time costs, vehicle operating costs, accident costs, and traffic ticket costs, respectively.

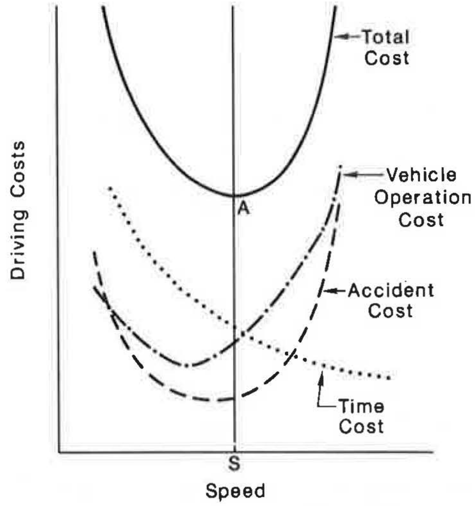

FIGURE 1 An individual's driving costs.

Individual i's total trip cost is minimized by differentiating Equation 1 with respect to speed s_i and setting the resulting equation to zero. Thus

$$D_{s_i}(TMC_i) + D_{s_i}(VOC_i) + D_{s_i}(ACC_i) + D_{s_i}(TKC_i) = 0 \quad (2)$$

where D_{s_i} is the derivative with respect to speed of individual i. Time cost TMC_i of individual i is defined as

$$TMC_i = VT_i \times T_i \quad (3)$$

where VT_i represents the individual i's value of time and T_i is individual i's travel time needed to travel distance d at speed s_i.

$$T_i = d/s_i \quad (4)$$

Equation 3 can be rewritten as

$$TMC_i = VT_i \times d/s_i \quad (5)$$

Differentiating Equation 5 with respect to s_i gives

$$D_{s_i}(TMC_i) = -VT_i \times d/s_i^2 \quad (6)$$

By substituting Equation 6 into Equation 2 and solving for VT, the value of VT_i is obtained:

$$VT_i = (\hat{s}_i^2/d) \times [D_{\hat{s}_i}(VOC_i) + D_{\hat{s}_i}(ACC_i) + D_{\hat{s}_i}(TKC_i)] \quad (7)$$

where $\hat{s}_i$ represents the optimal speed for individual i and the speed derivatives are all evaluated for $s_i = \hat{s}_i$.

DATA

Both primary and secondary data were used in this study.

Primary Data Source

A telephone survey was conducted to elicit Texas motorists' driving habits on rural highways as related to some personal characteristics. Questions on driving habits included speeds during daytime and nighttime on four-lane divided and two-lane rural highways; use of seat belts; model, make, body style, and model year of an in-town vehicle and an out-of-town vehicle, if a different vehicle is used; and annual mileage. Personal characteristics elicited were age, sex, race, education level, and hourly wage.

A sample of 500 people ages 18 and older was randomly selected to participate in the telephone survey. Answers to each question were tested by following a procedure *(6)* to determine the existence of outlier data. Outliers were discarded because they were believed to belong to a population other than the one being studied.

The personal characteristics of the sample group were as follows: the average age was 36.5, 41.2 percent were male, 58.8 percent female, 7.8 percent Black, 79.8 percent Anglo, and 11.4 percent Hispanic. Further, 16.2 percent had less than a high school education, 31.4 percent finished high school, 27.6 percent had done some college work, 24.2 percent graduated from college or did graduate work, and the remaining 0.6 percent did not respond. The average hourly wage was $10.05, slightly higher than the hourly wage of $9.47 for the state. Compared with the 1980 census population of age 18 years and older in Texas, the sample group was younger and had a higher percentage of females. In 1980, the average age of adults in the state was 41.7 years and the female population was 51.6 percent of the total adult population.

To obtain data on various precincts' traffic ticket costs, a questionnaire was sent to 75 justices of the peace who represent Texas precincts.

Secondary Data Sources

Data on vehicle operating costs and on accident rates for three types of accidents—fatal, injury, and property damage only (PDO)—were obtained from literature sources. Although Zaniewski et al. *(7)* provided the most updated vehicle operating costs related to driving speed by vehicle size, Solomon's 1962 accident study *(8)* provided the only available accident rates related to speed. Numbers of current accidents and vehicle-miles traveled on different highway classifications came from the Texas Department of Public Safety, the Department of Highways and Public Transportation (DHPT), and the Highway Performance Monitoring System (HPMS) for Texas.

RELEVANT VARIABLES

The value of time (Equation 7) includes relevant variables of vehicle operating costs, accident costs, traffic ticket costs, and travel speed. Further, accident costs comprise two important variables: the value of life and accident rates.

Vehicle Operating Costs

Based on 1982 data *(7)*, vehicle operating costs of large, medium, and small passenger cars and of pickup trucks traveling at different speeds on grade 0 and at service index *(SI)* of 3.5

are regressed against powers of the traveling speed. The estimated equations for the four vehicle types are as follows:

$$VOC_L = 197.879 - 3.45626(s) + .043516(s^2) \quad (8)$$

$$VOC_M = 194.973 - 3.73728(s) + .046126(s^2) \quad (9)$$

$$VOC_S = 217.440 - 4.89824(s) + .051209(s^2) \quad (10)$$

$$VOC_P = 167.368 - 3.13530(s) + .045907(s^2) \quad (11)$$

where

VOC_L = vehicle operating costs of large passenger cars ($/1,000 mi),
VOC_M = vehicle operating costs of medium passenger cars ($/1,000 mi),
VOC_S = vehicle operating costs of small passenger cars ($/1,000 mi),
VOC_P = vehicle operating costs of pickups ($/1,000 mi), and
s = traveling speed (mph).

The multiple correlation coefficients of determination for Equations 8–11 are R^2 = 0.9540, 0.9703, 0.9721, and 0.9480, respectively.

No updating on vehicle operating costs was performed because it was believed that current gasoline prices, the major component of vehicle operating costs, have been stable since 1982. Figure 2 shows the estimated vehicle operating costs of the four vehicle sizes, each as a function of speed. Small passenger cars actually have the highest operating costs among all four sizes at speeds below 15 mph (24 km/hr) and higher operating costs than pickup trucks below 30 mph (48 km/hr). Small cars cost the least to operate at speeds over 30 mph (48 km/hr). Pickup trucks have the lowest operating costs among all vehicle sizes at speeds below 30 mph (48 km/hr) but are the most costly to operate over 65 mph (104 km/hr). A comparison of the minimum points of the four cost versus speed curves reveals that both large and medium passenger cars are least expensive to operate at about 40 mph (64 km/hr), whereas costs of operating a small car bottom out at about 48 mph (77 km/hr) and pickup trucks reach their minimum operating costs at 34 mph (54.5 km/hr), before all other vehicle sizes do. At a speed range of 47 to 70 mph (75.2 to 112 km/hr), the operating costs of the large, medium, and small vehicles perform as expected, with the large cars costing the most to operate and the small cars the least, whereas operating costs for pickup trucks lie between those of large and medium cars in most parts of this speed range.

After identifying the size of each individual's vehicle or vehicles from information on vehicles obtained from the survey, the individual's vehicle operating cost curve can be obtained using one of the estimated equations, whichever is appropriate for the person's vehicle size. When the choice situation involves trips on rural highways, the cost curve for the out-of-town vehicles is used if it differs from the in-town vehicle. In the sample, the vehicle fleet driven is made up of nearly 28 percent of each of the three sizes of passenger cars, with the remaining 17 percent being pickup trucks.

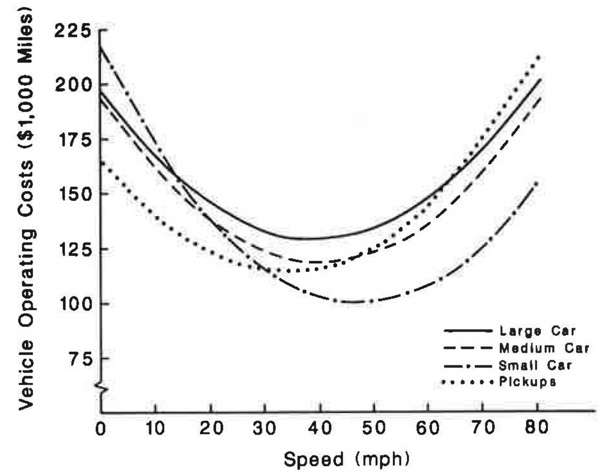

FIGURE 2 Vehicle operating costs by vehicle size.

Accident Rates

Data on accidents occurring at various travel speeds are practically nonexistent, except those reported by Solomon *(8)* in 1964. Some concern was raised as to the validity of using old speed data because of the differences in speed limits and vehicle operating conditions *(9)*. However, an examination of Solomon's data set and the 1984 Texas accident data reveals their similarity in both fatal and injury accident rates. Fatal accident rates on four-lane divided rural highways and two-lane rural highways estimated from Solomon's data were 0.0153 and 0.0263 fatalities per million vehicle-miles (MVM), respectively, whereas the 1984 Texas fatal accident rates on Interstate highways and on minor arterials were 0.0191 and 0.0325 fatalities per MVM, respectively. The injury rates between the two data sets present an even narrower gap. Table 1 gives the 1984 numbers of fatal and injury accidents and vehicle-miles traveled on rural Texas highways and Table 2 gives the comparison of rural fatal and injury accident rates between 1984 Texas accident record and the Solomon data.

Based on Solomon's accident data, two sets of accident rate equations expressed as functions of speed were estimated, one for four-lane divided rural highways and one for two-lane rural highways. Each set comprises three equations, one each for fatal accidents, injury accidents, and property damage accidents. The estimated equations in log-linear form are as follows:

TABLE 1 1984 ACCIDENTS AND VEHICLE MILES TRAVELED ON RURAL HIGHWAYS IN TEXAS

Functional Classification	Accidents[a]		Distance Traveled[b]
	Fatalities	Injuries	(veh-mi, thousands)
Interstate	193	4,007	10,087,505
Two-lane[c]	202	3,840	6,212,300

[a]Accident data were calculated from accident data tapes from the Texas Department of Public Safety and the Texas State Department of Highways and Public Transportation.
[b]From Texas data in the Highway Performance Monitoring System (HPMS).
[c]Minor arterials are represented in this category.

TABLE 2 COMPARISON OF RURAL ACCIDENT RATES BETWEEN 1984 TEXAS ACCIDENTS AND SOLOMON'S ACCIDENT DATA

	1984 Texas Accidents[a]		Solomon's Accident Data[b]	
Functional Classification	Fatalities ($/MVM)	Injuries ($/MVM)	Fatalities ($/MVM)	Injuries ($/MVM)
Four-lane divided (Interstate)	0.0191	0.3972	0.0153	0.3155
Two-lane (minor arterials)	0.0325	0.6181	0.0263	0.5572

[a]Texas accident data were made available by the Texas Department of Public Safety and the Texas State Department of Highways and Public Transportation.
[b]Figures represent the estimated daytime accident rates at 55 mph from Equations 12, 13, 15, and 16.

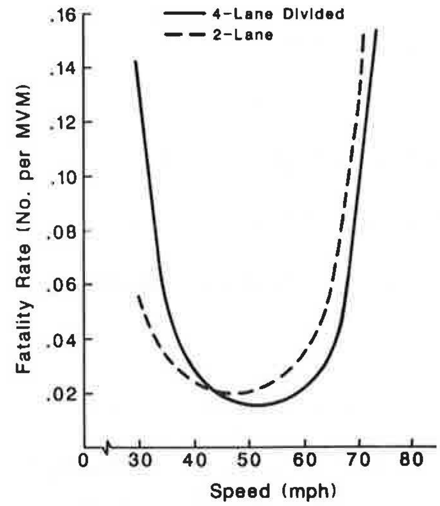

FIGURE 3 Daytime fatality rate by road type versus speed.

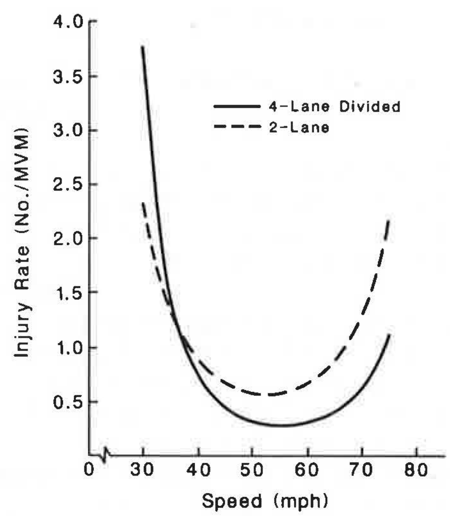

FIGURE 4 Daytime injury rate by road type versus speed.

Four-Lane Divided Rural Highways

$$\ln (FATAL) = 9.2299 - 0.4859(s) + 0.0047(s^2) - 0.8352(Q) \quad (12)$$

$$\ln (INJUR) = 11.6802 - 0.4264(s) + 0.0038(s^2) - 0.9827(Q) \quad (13)$$

$$\ln (PDO) = 18.2155 - 0.3992(s) + 0.0034(s^2) - 0.9520(Q) \quad (14)$$

Two-Lane Rural Highways

$$\ln (FATAL) = 5.0515 - 0.3206(s) + 0.0034(s^2) - 1.4074(D) \quad (15)$$

$$\ln (INJUR) = 7.8000 - 0.2846(s) + 0.0027(s^2) - 0.8484(D) \quad (16)$$

$$\ln (PDO) = 14.6954 - 0.2854(s) + 0.0026(s^2) - 0.7773(D) \quad (17)$$

where

$FATAL$ = number of fatalities per MVM,
$INJUR$ = number of injuries per MVM,
PDO = dollars (1958) of property damage per MVM,
s = traveling speed (mph), and
Q = dummy variable for daytime and nighttime travel,
= 1 if daytime, and
= 0 if nighttime.

The multiple correlation coefficients of determination for Equations 12–14 are 0.9280, 0.9412, and 0.9568, respectively.

Figures 3 and 4 show the estimated fatality and injury rates, respectively, as functions of speed on four-lane divided rural highways and on two-lane rural highways. On four-lane divided rural highways, the safest speeds for avoiding fatal, injury, and PDO accidents are 51.9, 55.7, and 59.2 mph (83, 89, 95 km/hr), respectively, while on two-lane rural highways, the safest speeds for the corresponding accident types are 46.9, 55.7, and 54.7 mph (75, 89, and 87.5 km/hr).

The PDO figures obtained from the equations are expressed in 1958 dollars and are updated to the current level using consumer price indexes (CPI) to represent the 1984 PDO costs.

Accident rates also vary according to road type and to the use of seat belts. From Solomon's data, nighttime driving has a higher accident rate. There are 429 traffic accidents per MVM at night as compared with 215 traffic accidents per MVM during the day. Also, four-lane rural highways are safer than two-lane highways. The four-lane highway had an accident rate of 212 accidents per MVM whereas the two-lane highway had 300 accidents per MVM.

Studies have shown that drivers who use seat belts are 50 percent safer than those who do not. Seat belts are reported to be responsible for reducing the number of fatalities and injuries by 30 percent *(9)*. Because the seat belt law in Texas went into effect only recently, these percentages may be invalid. However, because the survey was carried out before the law took effect, the percentages were considered valid and were therefore used in this study. Four groups of drivers are identified from the sample: daytime belted, daytime unbelted, nighttime belted, and nighttime unbelted. Using the accident statistics related to seat belt use and the ratios of belted and unbelted drivers in the sample, adjustment factors were developed separately for Interstate and for two-lane rural highways. These factors are to be used for adjusting the accident rate equations (Equations 12–17) for each of the four groups of drivers using these two road types (see Table 3). A general functional form of the adjusted accident rate (AAR) of accident type j on highway type H for driver group (T,B), where T is for time of day and B is for seat belt use, is as follows:

$$(AAR_{j,H})_{T,B} = (a_j)_{T,B} \times (AR_{j,H})_T \qquad (18)$$

where a_j represents the adjustment factor from Table 3 and AR_j one of the estimated accident rates. In this study, these adjusted accident rate curves are assumed to be applicable to everyone within the same driver group on the same highway type at the same time of day.

TABLE 3 ADJUSTMENT FACTORS OF ACCIDENT RATES BY DRIVER TYPE AND BY TIME OF DAY

	Fatal and Injury by Driver Type		Property Damage Only by Driver Type	
Time of Day	Belted	Unbelted	Belted	Unbelted
Day	0.53	1.52	0.68	1.35
Night	0.55	1.56	0.69	1.38

Value of Life

The cost of a fatality represents the value of an individual's life. In the foregone earnings approach, which is used to estimate the value of an individual's life, human wealth is measured by the present value of expected future labor earnings determined by age, sex, race, education, and past earnings. Ordinarily, earnings increase with age, peak around middle age, and remain stable until retirement. Levels of earnings are higher and peak at a later age the higher the educational level. Blomquist *(10)* was able to derive a set of age-earnings equations for seven different education levels, as given in Table 4. An individual's foregone earnings (EARN) represent the summation from the current age up to age 70 of the individual's expected annual discounted labor earnings multiplied by the appropriate age-, sex-, and race-dependent probability of survival. EARN is expressed as follows:

$$(EARN_{b,c,e})_a = \sum_{j=a+1}^{70} (E_e)_j \times 1/(1+i)^{j-a} \prod_{k=a}^{j-1} (P_{b,c})_a \qquad (19)$$

TABLE 4 AGE-EARNINGS PROFILES BY GRADE LEVEL *(10)*

Grade Level	Age-Earnings Profiles
0–4	$E = c + 497.9(A) - 4.46(A)^2 + 0.0581(A)^3$
5–8	$E = c + 653.3(A) - 11.65(A)^2 + 0.0662(A)^3$
9–11	$E = c + 264.7(A) - 2.62(A)^2$
12	$E = c + 929.2(A) - 16.92(A)^2 + 0.1008(A)^3$
13–15	$E = c + 1036.1(A) - 15.74(A)^2 + 0.0708(A)^3$
16	$E = c + 1145.9(A) - 15.77(A)^2 + 0.0623(A)^3$
17+	$E = c + 238.9(A) - 38.98(A)^2 + 0.2055(A)^3$

NOTE: E is earnings, A is age, and c is calculated by substituting into the appropriate equation the current annual earnings and current age.

where

a = current age,
b = race,
c = sex,
e = education level,
i = annual discount rate,
$(E_e)_j$ = predicted annual labor earnings at education level e in year j, and
P = annual probability of survival.

In this study, an annual discount rate of 4 percent is used. The probability of survival $(P_{b,c})_a$ by age, sex, and race is calculated from the following formula, using the 1980 mortality data supplied by the Texas Department of Health:

$$(P_{b,c})_a = 1 - (M_{b,c})_a/(pop_{b,c})_a \qquad (20)$$

where

a = age,
b = race,
c = sex,
P = probability of survival,
M = number of deaths, and
pop = population.

Information on wage and population characteristics is obtained from the survey.

Findings from Blomquist's value of life study determined the average value of life to be 2.5 times the amount of the average foregone earnings. In other studies of the value of life, the ratio of value of life to foregone earnings was found to range from as low as 1.3 to as high as 107 *(11)*. The inconsistency of the results and the complexity of the problem warrant further investigation. In this study, the ratio of value of life to average foregone earnings is assumed to be 2.5.

Accident Costs

Costs for accidents other than the cost per fatality are based on a recent Texas study *(12)* that estimated detailed injury and property damage costs for each accident type for different types of rural highways.

Depending on the group (daytime belted, nighttime belted, daytime unbelted, or nighttime unbelted) an individual belongs to, the injury and PDO cost functions are different between the highway types but are assumed to be alike for all people within a group. However, fatal cost functions are unique. Each individual has a unique fatal cost function because the individual's value of life is used as the unit fatal accident cost.

Traffic Ticket Cost

Fifty-one of the 75 questionnaires sent to justices of the peace in various Texas precincts were returned, and all indicated that traffic ticket cost increases with driving speed. The relationship is estimated using ordinary least squares regression technique. The estimated equation is as follows:

$$\ln (TK) = 1.01889 + 0.03991s \quad (21)$$

where TK equals cost per speeding ticket fine for ticketed speed s, and s equals travel speed (mph). The correlation coefficient of fit for Equation 21 is 0.7296.

The frequency of getting a traffic ticket is calculated by dividing the number of traffic tickets by the total mileage traveled. In 1984, 45,189.555 million mi were traveled on rural Texas state highways and 940,640 traffic tickets were given on these highways. The frequency of getting a traffic ticket is thus 0.021 tickets per 1,000 mi of travel on rural state highways, and the traffic ticket cost (TKC) per 1,000 mi is this rate multiplied by the cost per ticket:

$$TKC = 0.021 \times e^{1.01889+0.03991s} \quad (22)$$

Speed

Respondents were asked to indicate their daytime and nighttime driving speeds under the current speed limit of 55 mph (88 km/hr) on a four-lane divided Interstate rural highway and on a two-lane rural highway. The speed given for each of the four situations (daytime Interstate, daytime two lane, nighttime Interstate, and nighttime two-lane) by a respondent represents the optimal speed at which the respondent perceives that total driving costs are minimized for the specific situation. As indicated in the value of time equation (Equation 7) discussed earlier, the optimal speed of a respondent is needed in the evaluation of the respondent's value of time.

In this sample, the average speeds driven during the day on a four-lane divided rural highway and on a two-lane rural highway are 57.5 and 53.2 mph (92 and 85 km/hr), respectively, whereas average speeds for nighttime driving on the same two road types are 54 and 49 mph (86 and 74 km/hr), respectively. This finding is consistent with the hypothesis that people tend to drive more slowly at night because they perceive a higher accident cost for night driving.

RESULTS

Four values of speed—at night and during the day on four-lane and two-lane roads—were calculated for each respondent for whom complete data were available. Because speeds on four-lane roads are less affected by physical restraints, it is surmised that these values probably are the best estimates, although the overall weighted averages for the two types of road were similar.

The estimated values of time using desired speeds of travel on four-lane highways are given in Table 5 by sex, time of day,

TABLE 5 VALUES OF TIME BY SEX, TIME OF DAY, AND SEAT BELT USAGE

	1984 $/hr			
	Belted		Unbelted	
Time of Day	Male	Female	Male	Female
Day	14.84	6.93	16.21	9.99
Night	12.77	6.66	17.01	11.70

and seat belt usage. The values of time for male drivers are consistently greater than those for female drivers. This difference results mainly from males' driving at higher speeds and having higher average earnings (and, thus, higher assumed fatality costs). Average values of time also tend to be higher for unbelted drivers. This finding could be the result of unbelted drivers actually having higher values of time or an error in the cost curves that are used to represent drivers' perceived costs. The average values of time tend to be fairly close between night and day for any given subgroup of male–female and belted–unbelted. Weighted across male–female and belted–unbelted, the average value of time using day speeds is $11.84/hr and using night speeds is $11.71/hr.

These values are not weighted to account for the amount of driving per year. In a benefit-cost analysis, the value of time needs to represent the average driver using a highway. To derive this type of value, the values in Table 5 were weighted by the estimated number of hours per year that each driver spent driving. The weights that were used to derive the weighted averages are given in Table 6. These hours per year

TABLE 6 WEIGHTS USED IN WEIGHTING VALUE OF TIME

Condition	Day	Night
Driver type		
Belted	0.52	0.55
Unbelted	0.48	0.45
Time of day	0.75	0.25

were estimated by dividing each person's estimated miles per year by the average speed, both of which were items in the questionnaire. Because the ratio of males to females in the completed questionnaire was significantly less than statewide estimates, values of time were calculated separately for males and females and the statewide population estimates were used as weights. Average values of time not weighted by hours of travel are given in the top half of Table 7, and values weighted by hours of travel are given in the bottom half. As these results show, persons with higher values of time tended to indicate that they drove less hours per year, so the unweighted average value of time is $11.81/hr and the weighted value of time is only

Economic Efficiency Implications of Optimal Highway Maintenance Policies for Private Versus Public Highway Owners

DAVID GELTNER AND ROHIT RAMASWAMY

The idea of transport infrastructure privatization has been receiving increased attention recently from researchers and policy makers. In both Britain and the United States, as well as in some developing countries such as India, the idea of highway ownership privatization is being seriously considered and in some cases is being implemented. Most research to date has focused on the technical or financial feasibility of highway privatization or of using tolls to finance roads. This paper is motivated, rather, by the question of the economic efficiency of highway ownership privatization. The paper focuses on in-depth analysis in an effort to quantify what may be the main issue in the question of the economic efficiency of privately owned highways—the problem of suboptimal highway physical quality, which could result over the long run from highway maintenance policies that seek to maximize immediate private profit rather than overall economic welfare. The paper shows that for a typical representative highway the profit-maximizing maintenance policy would produce poor highway quality that over the long run would be considerably poorer than the welfare-maximizing quality. However, the paper concludes with a benefit-cost discussion, which indicates that it still could be economically beneficial to privatize the ownership of some highways.

The idea of transport infrastructure privatization has been receiving increased attention among researchers and policy makers. The English Channel Tunnel and the British Airports Authority are examples of privatization in practice in Britain. In the United States, where more nonhighway transport infrastructure is already in private or semiprivate ownership, interest is growing in the idea of expanding the role of the private sector in public infrastructure provision and finance, in particular, in the fields of highway and mass transit facilities. In a particularly striking example, a group of private investors in Denver has announced a project to develop a 180-mi, $800-billion, 80-mph turnpike in Colorado. A private development consortium has also proposed to build, own, and operate a 30-mi extension of the Dulles Airport Tollway in the Washington, D.C., area of Northern Virginia.

Much of the attention in the discussion of infrastructure privatization has to date been focused on the question of its financial feasibility and its capability for obtaining additional revenues to pay for infrastructure without recourse to taxation and the government budget. Relatively little attention has been focused on the question of the economic efficiency of transport infrastructure privatization. Key questions in this regard are (a) Would private infrastructure owners charge an economically efficient price to the users of the infrastructure? and (b) Would private infrastructure suppliers provide efficient levels of quantity and quality of product or service over the long run?

This paper focuses on a specific aspect of the second question. In particular, a hypothetical privately owned toll highway is considered. The profit-maximizing highway pavement quality maintenance policy for this highway is compared with the socially optimal or economically efficient policy. Methodologically, this paper contains an extension and application of other work previously presented to the TRB *(1, 2)*.

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DEVELOPMENT AND IMPLEMENTATION OF THE ANALYTICAL MODEL

In this section the assumptions and mathematical model used in the analysis are presented.

Economic Background and Definitions

A highway market is defined as the supply of and demand for highway facilities between two geographic points. The highway supply in such a market is characterized by its quantity or capacity (e.g., number of lanes); its quality, such as pavement surface quality; and its use price, or toll. The highway market is said to be inefficient in the allocational sense if the supply characteristics (quantity, quality, and price) could be altered so that potentially everybody affected by the market could be made better off. For example, if the toll is set too high, some people who otherwise value the use of the highway at more than what it costs society for them to use it will be priced off the road, resulting in a net loss of welfare for society. In such a case, society would be allocating too few resources to the use of the highway with the too-high toll, and perhaps allocating too many resources to the use of other alternatives.

Most highway markets exhibit imperfections or market failure that cause the profit-maximizing supply characteristics of the highway to differ from the efficient (or socially optimal or welfare-maximizing) levels. If toll roads only are addressed, there are two major imperfections or sources of market failure in such markets: (a) economies of scale or indivisibilities in production, as well as sunk costs involved in market entry, all of which lead to some degree of natural monopoly or incontestability (market power); and (b) external benefits and costs,

TABLE 7 VALUES OF TIME, WEIGHTED AND UNWEIGHTED, BY TIME OF DAY AND SEAT BELT USAGE

Time of Day	1984 $/hr Belted	Unbelted	Average
Unweighted by Hours of Travel			
Day	10.76	13.00	11.84
Night	9.61	14.27	11.71
All	10.47	13.32	11.81
Weighted by Hours of Travel			
Day	6.67	8.72	7.65
Night	5.71	10.91	8.05
All	6.43	9.67	7.75

TABLE 8 VALUE OF TIME

	1984 $/hr			
	Four-Lane		Two-Lane	
Condition	Belted	Unbelted	Belted	Unbelted
Day	6.67	8.72	4.71	8.56
Night	5.71	10.91	7.18	18.73
Overall weighted value of time	7.75		8.01	

$7.75/hr. For comparative purposes, Table 8 gives the values of time derived for using desired speeds (and costs) on four-lane and two-lane highways. Although there is considerable variation between subgroup values, the overall average is similar for the two road types. It is recommended that the value of $7.75/hr be used for benefit-cost analysis.

CONCLUSIONS AND RECOMMENDATIONS

The speed choice model was chosen for estimating values of time because it can be applied across a representative statewide sample of Texas motorists. Two other methods judged to be good theoretical approaches—the choice of mode (especially bus versus automobile) and the choice of route (especially toll road versus alternate free route) methods—cannot be used as effectively because many Texans seldom, if ever, ride buses (especially not for rural trips) and few situations are available in Texas where choices involving toll roads are made. The speed choice model has been criticized by some researchers as having the weakness of assuming that motorists know the expected costs of different road types as related to travel speed. This criticism, however, can also be applied to the other techniques. For example, in the bus-automobile modal choice situation, it is assumed that the driver knows his out-of-pocket vehicle operating costs, even though the trip usually involves several different highway types, intersections, and so forth, not to mention widely varying traffic volumes and other operating conditions. In addition, expected accident costs as perceived by the motorist must be estimated to use this approach in a valid way. Similar calculations must be made of operating costs and accident costs on toll roads versus alternate free routes to use the route-choice models. Therefore, in this study, it is concluded that the speed choice model is at least as valid theoretically as the other techniques and has the definite advantage of being applicable to a statewide cross section of Texas motorists.

Previous researchers in Great Britain and the United States have used the speed choice model to calculate the trade-off between time and accident costs at different average speeds and for different average costs. This study represents an improvement over previous studies in that specific speed decisions and cost curves are used for each individual in the study, instead of using average speeds and average cost functions.

The principal data problem in using the speed choice model involves the estimation procedure for the cost of fatalities. To estimate this cost, the study adopted the foregone earnings approach. Depending on hourly wage, age, race, sex, and education level, each individual's value of life was estimated. The value of time for a driver of a passenger car after being weighted by annual travel time spent by individuals, by seat belt use, and by the time of day, is found to be $7.75 in 1984 dollars, or $8.03/hr after being updated to 1985 using the consumer price index. Assuming an occupancy rate of 1.3 persons per car, the recommended 1985 value of time for passenger vehicles is $10.44/veh-hr. This is the value recommended to be used in benefit-cost analysis in Texas.

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which cause either the highway provider or the user to be unable to experience all of the benefits and costs of the highway and its use. As a result of imperfections or market failure, the highway user cannot usually have available a perfect substitute for any given highway. This situation causes the highway provider to face a downward sloping demand curve for the road, enabling the provider to increase profits only by increasing the toll or by providing less quantity or quality of product, or both, up to a point. Partly as a result, the extra cost to the users caused by deterioration of road quality (vehicle wear and tear, extra travel time, and discomfort) will to some extent remain an external cost to the highway provider (i.e., a cost the provider does not fully experience).

Thus, assuming an objective of profit maximization, one would expect a privately owned toll highway to provide less than the socially optimal level of quality maintenance over time, at least in the absence of any intervention or control by a government body *(2)*.

In the remainder of this paper, attempts are made to explore quantitatively the question of how bad or serious this problem of suboptimal private highway quality might be. This analysis is pursued by taking the case of a hypothetical highway representative of the type that might be a likely candidate for privatization as a toll road—a high-traffic-density, large-scale urban or suburban expressway or beltway. Privatization would be most likely to be financially feasible for such a road.

It is assumed that the highway is privatized as a new or newly reconstructed (hence, high-quality) facility. Next, the profit-maximizing versus welfare-maximizing pavement maintenance policies are modeled over time, observing the resultant difference in the highway pavement quality profile over time, and the difference in net welfare that results from profit maximization as opposed to welfare maximization. It is assumed that the same toll would be charged in both cases, for example, a level of toll fixed by the government.

The General Analytical Model and Assumptions

A general mathematical model of the optimal highway quality maintenance policy over time is presented. The model is described under two possible alternative objectives—net welfare maximization and highway owner's profit maximization. No matter what the objective, the problem is formulated mathematically as a dynamic optimization problem. In other words, the unique highway quality maintenance policy over time represented by the annual maintenance expenditure profile over time that maximizes the present value of the objective (either net social welfare or owner's profit, whichever the case) is determined.

Consider an infinitely long-lived highway with a pavement life cycle that repeats itself every T years. Let $v(t)$ be the highway maintenance expenditure per unit of time, at time t, where t is less than T. Let $Q(t)$ be the traffic volume demand on the highway in equivalent standard axle loads (ESALs) per unit of time, at time t. Let $S(t)$, represented by some index, such as the average pavement serviceability index (PSI) of AASHTO, be the physical quality of the highway at time t. The state differential equation that describes the change in the condition of the pavement with time can be written

$$\dot{S}(t) = g\,[v(t), Q(t), S(t)] \qquad (1)$$

where $\dot{S}(t)$ equals dS/dt at time t.

The maintenance expenditure $v(t)$ is a proxy for the physical level of maintenance effort performed on the pavement during the time increment from t to $t + dt$. Within the highway pavement cycle, it is assumed that only routine maintenance is performed on the pavement. The role of routine maintenance applied at any time t is to slow the instantaneous rate of deterioration $\dot{S}(t)$ but not to cause any positive improvement in the condition of the pavement. In Equation 1, therefore,

$$\dot{S} \leq 0,\ \dot{S}'(v) = \partial\dot{S}/\partial v \geq 0,\ \partial\dot{S}/\partial Q \leq 0$$

At the end of the T-year pavement life cycle, reconstruction or rehabilitation is performed on the highway at a cost of R. This reconstruction cost is assumed to be a decreasing function of the terminal pavement quality $S(T)$.

$$R(T) = R[S(T)] \qquad (2)$$

Thus, there are two reasons for the highway owner to spend money on maintenance. One is to keep the highway use cost down during the life cycle. The other is to reduce the required reconstruction cost at the end of the life cycle or to prolong the life cycle, pushing back the date when the road must be reconstructed, thereby reducing the present value of the reconstruction cost.

The traffic volume demand on the highway per unit of time at time t, $Q(t)$, is given by the demand function

$$Q(t) = D[P(t)] \qquad (3)$$

where P is the average variable composite price users of the highway pay per unit of use (i.e., per ESAL-mi). Thus, P includes time and inconvenience or discomfort value as well as direct and indirect monetary outlays sensitive to travel on this highway.

The inverse of the demand function is the marginal social value MSV function that represents society's willingness to pay for each increment of aggregate use of this highway. The function is expressed as

$$MSV = P(Q) = D^{-1}(Q)$$

This definition amounts to assuming that there are no major external benefits associated with marginal use of this highway. Thus, the total instantaneous net user benefit NUB of quality level S at time t on the highway is given by the integral of the demand function as

$$NUB[S(t)] = \int_{P[S(t)]}^{\infty} D[P(S)]dP(S) \qquad (4)$$

The average variable composite user price P includes some monetary payments (e.g., tolls and gasoline taxes) that represent intrasocietal transfers to the government or to the highway owner rather than deadweight losses to society. These transfer payments are therefore not social costs or economic costs in the sense that they involve no loss of aggregate net social welfare (one person's loss is another's gain within the society). Therefore, the average variable social cost of highway use (net welfare loss, as distinct from user price) per unit of use (apart from the highway maintenance expense, which is considered separately) is given by

$$C = P - (\tau + f) \quad (5)$$

where τ is the toll and f is the use-sensitive nontoll user fees, such as gasoline taxes, both measured per ESAL-mi.

The average highway user social cost C is in general a function of many things, including Q itself if the highway is congested. But in order to focus on the main issue and to keep our problem tractable, it is assumed that C is independent of Q. For clarity of presentation, it is also assumed that all exogenous influences on C are constant over time so that the instantaneous user cost at time t, $C(t)$, can be expressed as a function only of $S(t)$, the pavement condition at time t, as follows:

$$C = C(S) \quad (6)$$

However, the assumption that exogenous influences on C are constant is not necessary for the analytical tractability of the model.

Based on the foregoing definitions, the aggregate net welfare W obtained by society from the highway per unit of time at time t is given as

$$W(t) = NUB[S(t)] + (\tau + f)Q\{P[S(t)]\} - v(t) \quad (7)$$

where $P(S)$ equals $C(S) + (\tau + f)$.

On the other hand, the profit per unit of time, π, obtained by the private highway owner at time t is given by

$$\pi(t) = \tau Q\{P[S(t)]\} - v(t) \quad (8)$$

Here corporate income taxes are ignored to simplify the analysis and because the government could make highway companies tax exempt (just as the current toll highway owners, state and local government agencies, are tax exempt). Also, it is assumed that the toll τ is constant, although this assumption is not necessary and is made only for simplicity.

Figure 1 shows graphically the difference between Equations 7 and 8. The shaded area in the left-hand graph represents $W + v$, which is seen to consist of the large net user benefit triangle plus the small rectangular area of the intrasocietal transfers. The shaded area in the right-hand graph represents $\pi + v$, which consists only of a part of the intrasocietal transfer rectangle. Clearly, the private owner's profit represents only a small subset of the total social welfare from highway use prior to consideration of the level of maintenance outlays v. Of course, v, which is not explicitly shown, may not be the same in the two graphs (it would be smaller in the right-hand graph, to maximize profits). This difference is the focus of the analysis.

Let r_w and r_p be the social and the private owner's discount rates, respectively, applicable to money-valued future returns on cash investments. Then the welfare maximization objective is given by the present discounted value of the future net welfare flows, including consideration of the reconstruction cost at the end of the cycle,

$$\max_{v(t)} \int_0^T \exp(-r_w t)\, W(t)dt - R[S(T)] \exp(-r_w T) \quad (9)$$

where $W(t)$ is given by Equation 7.

The private owner's objective function is given by

$$\max_{v(t)} \int_0^T \exp(-r_p t)\, \pi(t)dt - R[S(T)] \exp(-r_p T) \quad (10)$$

where $\pi(t)$ is given by Equation 8.

Equations 9 and 10 represent the objectives of finding among all the possible profiles of maintenance outlays over time $v(t)$ that one, call it $v^*(t)$, which is optimal in the sense that it maximizes either the present discounted value of net welfare (Equation 9) or of the private highway owner's profits (Equation 10).

The state equation governing the rate of deterioration of the highway quality over time represents the physical and tech-

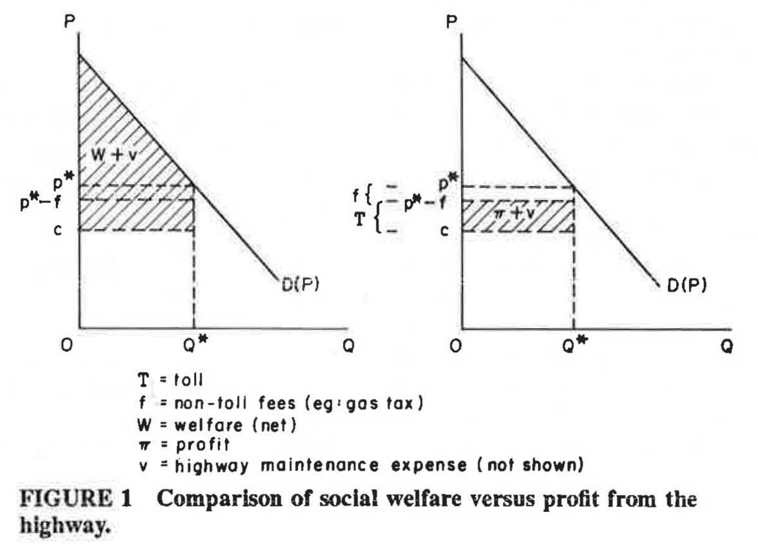

FIGURE 1 Comparison of social welfare versus profit from the highway.

nological constraints within which the maximization problem must be solved. This state equation is the same (Equation 1) no matter which objective motivates the highway maintenance policy decision.

In addition to the objective function and to the state equation, to fully characterize the optimal highway maintenance and reconstruction policy for the T-year life cycle, the boundary condition must be specified as

$$S(nT) = S_0 = 4.5 \text{ (PSI) for } n = 0, 1, 2, \ldots \quad (11)$$

and the nonnegativity constraint as

$$v(t) \geq 0, \text{ for each } t \quad (12)$$

The boundary condition (Equation 11) is derived by hypothesis because the highway is assumed to be like new at the initial time of privatization. (New highways have the maximum possible PSI of 4.5.) Note also that in the standard optimal control formulation of this problem there is a second boundary condition at the terminal time T of the cycle, specified by the reconstruction cost function. Thus, the dynamic optimization problem that must be solved is a two-point boundary value problem, with an inequality constraint on the control variable. Such problems can be solved by a variety of techniques to find the optimal $v^*(t)$ path and the resultant optimal highway quality profile over time $S^*(t)$. This solution can then be evaluated according to the objective function (Equation 9 or 10) for a range of different cycle terminal times T. The optimal cycle duration T^* can then be selected as that which maximizes the objective function.

Specific Quantitative Assumptions

Specific assumptions about functional forms and parameter values are required for application of the general model. To begin, the example highway is characterized as a six-lane urban tollway experiencing approximately 40,000 veh/day or 3 million ESALs/year at the assumed toll. The toll is assumed in the base case to be 20 cents/ESAL-mi, a level similar to that charged on several existing urban tollways (e.g., the Massachusetts Turnpike Extension in Boston). The nontoll use fees (parameter f in the previous subsection) are assumed to be 8 cents/ESAL-mi, or about 2.5 cents/veh-mi for the average vehicle. (Three to four veh-mi to the ESAL-mi is assumed.)

For simplicity, it is assumed that demand is linear. Thus, Equation 3 obtains the form

$$Q = Q_0 - bP \quad (13)$$

It is also assumed for simplicity and clarity of presentation that the intercept and slope, Q_0 and b, respectively, are constant, which amounts to assuming that the socioeconomic or other exogenous determinants of highway demand are stationary over time. The parameters Q_0 and b are specified so as to give a point elasticity, at the initial user price, of approximately unity (in the base case). While this elasticity value assumption may at first seem high—for example, an often-employed rule of thumb for transit demand is that the fare elasticity is about one third, and empirical studies of highway demand for urban travel show highway demand to be insensitive to money cost—it must be remembered that the concern here is with a total composite price elasticity, where the price P includes both travel time value and money costs. Thus, because value of time makes up a substantial portion of the total composite price, a total elasticity of unity (the base-case assumption) would not be inconsistent with an out-of-pocket direct money price elasticity of considerably less than one-half. This value would appear to be consistent with typical empirical findings *(3–6)*.

Also, bear in mind that the relevant elasticity here is the elasticity of demand for the highway or route alternative owned by the private highway owner, not the elasticity of demand for all automobile travel in the given market (provided there are other alternative routes between the origins and destinations served by the highway).

As noted, the user average variable social cost function $C(S)$ as given by Equation 6 consists of value of travel time, cost of fuel, cost of vehicle wear-and-tear, cost of accidents, and so on. This cost is a function of the highway quality. Experiments and empirical studies have shown that user costs as a function of pavement quality can be represented by an exponential function similar to that presented as follows and shown in Figure 2 *(7–10)*.

$$C(S) = C_0 + C_1 \exp(-C_2 S) \quad (14)$$

where C_0 represents the cost component that is independent of pavement quality (e.g., price of fuel), and $C_0 + C_1$ represents the maximum possible cost when the pavement is in a completely deteriorated condition (PSI = 0). The parameters C_0, C_1, and C_2 need not be constant over time although in the analysis, they have been so assumed for simplicity. The parameter values that have been assumed and that are shown in Figure 2 are

C_0 = \$1.00/ESAL-mi,
C_1 = \$15.00/ESAL-mi, and
C_2 = 1.8.

These values assume a user cost of about 30 cents/veh-mi up to a PSI of approximately 2.0, after which user costs begin to rise rapidly.

The state equation has been expressed as a negative exponential function, reflecting decreasing returns to scale in the application of maintenance effort on the highway at any time.

$$\dot{S}(t) = \alpha(t) \exp[-v(t)\mu(t)] \quad (15)$$

where α is a positive constant and μ is a parameter of maintenance effectiveness.

Note that by Equation 15, as increasing amount is spent on maintenance at any time [$v(t) \rightarrow \infty$], the highway deterioration rate approaches zero. On the other hand, in the absence of any maintenance, the highway would deteriorate linearly at the rate of $\alpha Q(t)$ (PSI) per unit of time. In the analysis, α is selected so that if the initial traffic $Q(0)$ were maintained on the highway in the absence of any maintenance, the highway would deteriorate completely from PSI of 4.5 to 0 in 30 years. This period is assumed to equal the pavement design lifetime.

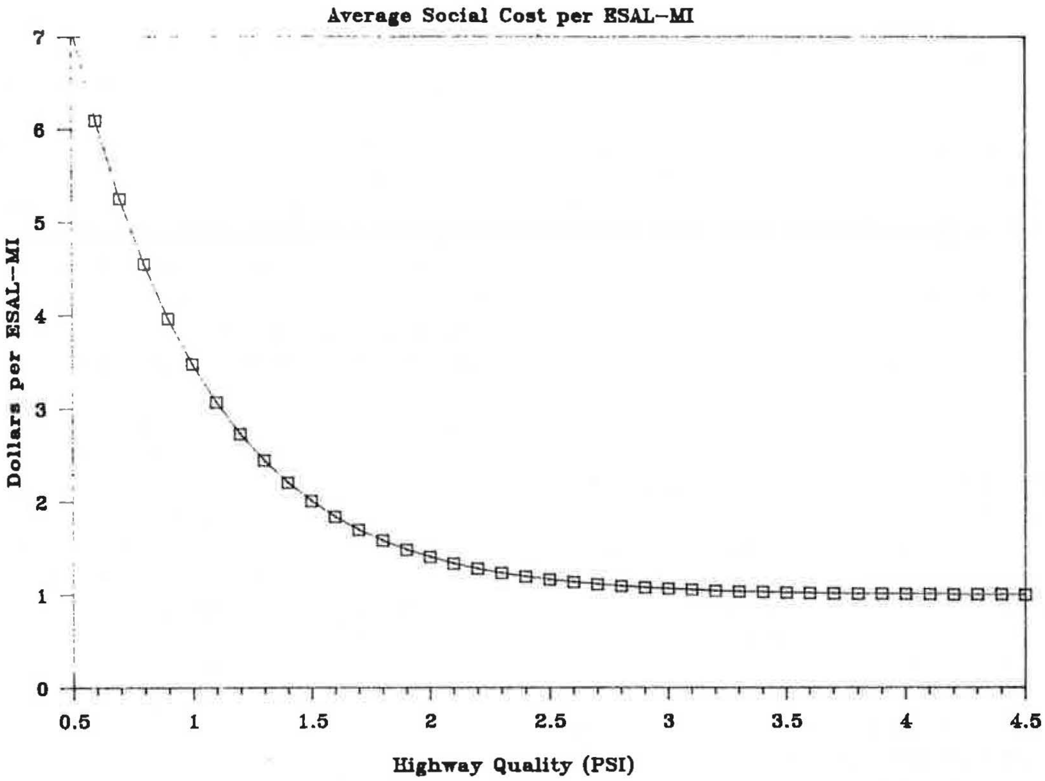

FIGURE 2 Plot of highway user cost function.

In the analysis, T is assumed to be 30 years. In fact, the optimal cycle duration T^* was determined, but in the simple model neither highway profits nor social welfare was sensitive to the cycle duration and the optimal duration tended to be about the same under either of the two objective functions.

In the state equation, highway maintenance, as represented by the expenditures $v(t)$, is viewed to have an instantaneous effect in slowing down the rate of highway quality deterioration. Thus, the larger μ is, the more effective is 1 unit of maintenance effort. Specifically, μ represents the percentage reduction in the highway quality deterioration rate caused by a 1-unit increase in maintenance expenditure, as follows:

$$\mu = [\partial \dot{S}(v)/\partial v]/\dot{S}$$

Intuition and engineering judgment suggest that μ is a function of the existing pavement quality S and that this function should be shaped roughly like that shown in Figure 3. Maintenance is most effective over a broad region of moderate quality pavement. When the pavement is badly deteriorated, routine maintenance (as opposed to rehabilitation or reconstruction) is not effective because the existing pavement and possibly support structures are too weak to allow maintenance to have much effect. When the existing pavement quality is good, it is impossible for maintenance to cause much additional improvement.

In fact, the argument that μ as a function of S is shaped generally as shown in Figure 3 has been supported by a recent empirical study *(11)*. The specific functional form that has been assumed for $\mu(S)$ is

$$\mu = A\ [1 - \exp(-\theta_2 S)]/\{1 + \exp[\theta_1(S - a)]\} \qquad (16)$$

Because data are not available to statistically estimate the parameters of Equation 16, the following values in the base case have been assumed, based on engineering judgment and consistent with the evidence found in *(11)*.

$\theta_1 = \theta_2 = 2.5$
$a = 4.0$
$A = 1/775{,}000$

The curve drawn in Figure 3 is a plot of μ/A as a function of S with these parameter assumptions.

Note that the state equation (Equation 15) can also be interpreted as a kind of maintenance production function, with the output of maintenance being viewed as reductions in the rate of deterioration of the highway. As noted, Equation 15 is such that this production function will exhibit declining returns to scale. However, the degree of scale diseconomies can be manipulated by altering the parameter A in Equation 16, without changing the basic shape of the maintenance effectiveness as a function of pavement quality as depicted in Figure 3. This procedure allows sensitivity analysis to be applied with respect to the nature of the maintenance technology in terms of its effectiveness and degree of scale diseconomies.

Finally, the assumption regarding pavement rehabilitation costs at the end of the life cycle (Equation 2) was that these costs would be a linear function of the terminal pavement quality. Specifically, the following function for R was assumed:

$$R = \$225{,}000 - \$50{,}000\ [S(T)] \qquad (17)$$

RESULTS OF THE ANALYSIS

Using the foregoing specific quantitative assumptions, the optimal maintenance and reconstruction problem described was

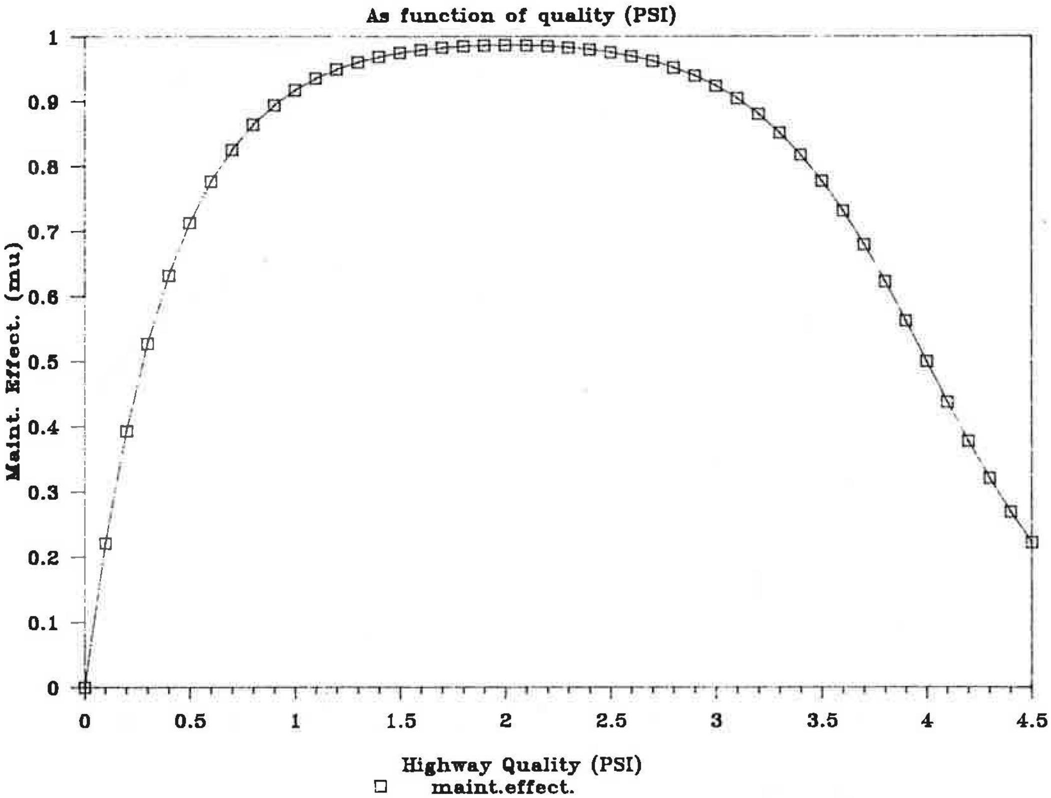

FIGURE 3 Plot of maintenance effectiveness.

solved using a first-order gradient method *(12)*. The results of this solution are shown in Figures 4 and 5, assuming $r_w = 8$ percent and $r_p = 10$ percent.

Figure 4 shows the optimal maintenance expenditure profile over the 30-year life cycle under the base case assumptions. The higher curve is optimal for maximizing net aggregate social welfare from the highway according to the objective function of Equation 9, whereas the lower curve is optimal for maximizing the profits according to the objective function of Equation 10. As one would expect, the profit-maximizing maintenance expenditures are considerably less than the welfare-maximizing expenditures, and they start later in the cycle.

Figure 5 shows the resulting optimal highway quality profile over time. The highest quality profile is, of course, the welfare-maximizing or efficient quality. The middle line is the profit-maximizing quality. The lowest line indicates the do-nothing profile of highway quality that would result if nothing at all were ever spent on maintenance and the traffic using the highway decreased accordingly. Note that the profit-maximizing quality level is closer to the efficient level than to the do-nothing level throughout most of the life cycle.

More important, note that the average level of pavement quality over time under the profit-maximizing objective (about PSI 3.6) compares favorably with what is achieved in practice by many government agencies managing the Interstate highway system. Indeed, the profit-maximizing terminal quality at the end of the 30-year cycle is about PSI 2.7 in the base case, which compares favorably with the life cycle terminal quality of 2.5 PSI that is often taken to represent the standard practice on the Interstate highway system (when funding allows). The implication is that a private profit-maximizing highway owner would maintain the example highway no worse than, and perhaps better than, the current typical standard government practice. This result may not be generalizable across all government agencies because of the wide variety of methods of analysis and the different indexes for the measurement of pavement condition used by different authorities.

Sensitivity analysis has been conducted on the previously described results with respect to four key parameters—the demand elasticity, the discount rates, the toll, and the maintenance effectiveness—or scale diseconomy parameter A in Equation 16. Summaries of these sensitivity analysis results are given in Table 1. The description of the various scenarios is given in Table 2. Each scenario was run under both the welfare-maximizing and profit-maximizing policies, with the results as indicated. The overall result of the sensitivity analysis appears to confirm the foregoing general conclusions.

The last column in Table 1 presents the terminal quality of the highway, that is, the PSI after 30 years. Because the optimal quality profile over time is roughly linear (as shown in Figure 5), and the quality starts out at PSI 4.5, this terminal quality is a good relative index of the average highway quality over time. Note that one would expect the optimal terminal quality to be less for a highway with less traffic density than for the example, so the optimal terminal qualities found in the analysis are not necessarily general indictments of the current standard of 2.5 PSI.

The first column in Table 1 gives the value of the social objective function for the scenario and policy in question (from Equation 9, the present discounted value of the net welfare provided by the highway, per mile of highway). The second column presents the per-mile present discounted value of the

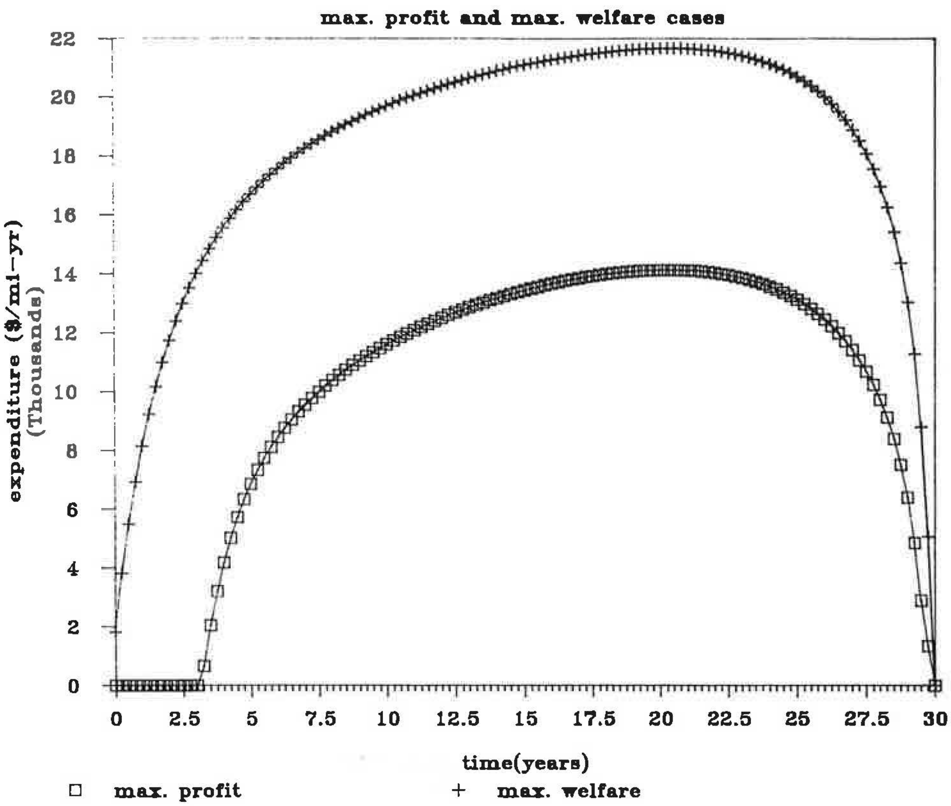

FIGURE 4 Maintenance expenditure versus time.

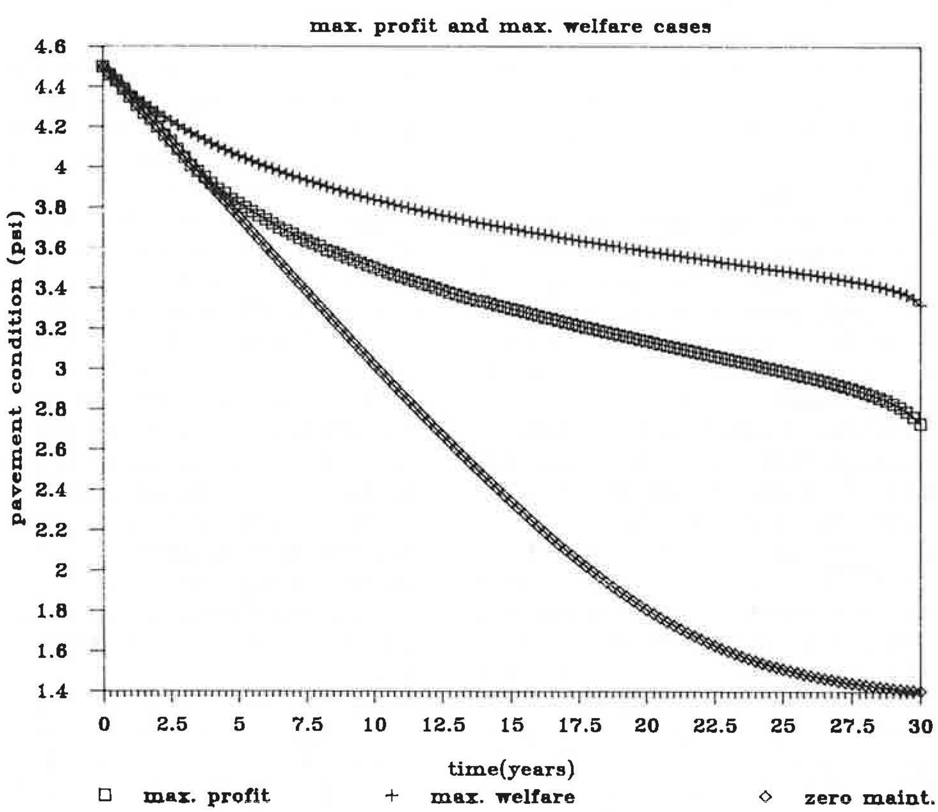

FIGURE 5 Pavement condition versus time.

TABLE 1 SENSITIVITY ANALYSIS OF RESULTS

Scenario Number (Policy)	Economic Benefits[a]	Profits[a]	Potential Cost[a]	Terminal Quality (PSI)
1. (W-max)[b]	34.195	5.834		3.32
(D-max)[b]	33.723	5.871	0.472	2.73
2. (W-max)	54.498	5.870		3.31
(D-max)	53.946	5.927	0.552	2.60
3. (W-max)	22.008	5.789		3.38
(D-max)	21.597	5.798	0.411	2.89
4. (W-max)	22.807	4.178		3.28
(D-max)	22.451	4.211	0.348	2.58
5. (W-max)	68.082	9.680		3.35
(D-wax)	66.743	9.719	1.339	2.73
6. (W-max)	34.842	3.063		3.30
(D-max)	33.760	3.127	1.082	2.38
7. (W-max)	33.256	8.138		3.35
(D-max)	32.952	8.161	0.304	2.89
8. (W-max)	33.927	5.740		3.14
(D-max)	33.091	5.812	0.836	2.45
9. (W-max)	34.388	5.899		3.51
(D-max)	33.934	5.916	0.454	2.91

[a]Figures are capitalized values per mile of highway in $millions.
[b]W-max = welfare maximization; D-max = profit maximization.

TABLE 2 SCENARIO DEFINITIONS

Scenario Number	Demand Elasticity	Discount Rates r_w, r_p (%)	Toll ($0.00)	Maintenance Effectiveness Parameter A
1 (base)	1.0	8, 10	0.20	1/775000
2	0.5	8, 10	0.20	1/775000
3	2.0	8, 10	0.20	1/775000
4	1.0	12, 14	0.20	1/775000
5	1.0	4, 6	0.20	1/775000
6	1.0	8, 10	0.10	1/775000
7	1.0	8, 10	0.30	1/775000
8	1.0	8, 10	0.20	1/1550000
9	1.0	8, 10	0.20	2/775000

profits generated by the highway under each maintenance and reconstruction scenario (Equation 10). Profits are discounted using r_p for both policies.

The third column presents the difference in present discounted net welfare between the socially optimal versus the profit-maximizing policies for each scenario as taken from Column 1, which uses a discount rate of r_w for both policies. These differences range between roughly $0.5 million per mile of highway in the base case, down to $0.3 million per mile of highway in Scenario 7, and up to $1.3 million per mile of highway in Scenario 5.

CONCLUSIONS AND POLICY IMPLICATIONS

The results in the previous section give some idea of the quantitative difference between the profit-maximizing and the welfare-maximizing highway quality for a representative typical case. It is clear that there is a potentially important physical difference in the average quality of a highway maintained to maximize profits versus social welfare. But to draw any substantive conclusions from this analysis, it is suggested that the figures in the third column of Table 1 are more relevant. The figures quantify the dollar value of this physical difference in terms of aggregate social welfare.

As noted, this difference in social value ranges from about $0.3 million to about $1.3 million in capitalized value per mile of highway, depending on the scenario of the sensitivity analysis. To see the significance or use of this type of quantitative finding regarding the policy question of whether a highway like the hypothetical example should be privatized, it is necessary to return to the economic points raised previously and to consider how the highway would be privatized and subsequently regulated by the government. Recall that their are three major characteristics of the highway supply, quantity, quality, and price, which determine the efficiency of the highway market. It is not hard to imagine how the government might privatize either new or existing highway facilities and still easily maintain control over both the quantity (e.g., number of lanes available in a given market) and price (i.e., toll) of the highway supply in the market *(2)*.

It is less easy to see how the government could maintain control over the quality of privately owned roads. Thus, of the three characteristics determining the efficiency of the privatized highway market, quality poses the main problem.

It is therefore tempting to think of quality as the main potential economic cost of a policy of highway privatization. The preceding analysis was motivated by a desire to try to put a quantitative upper limit on what that cost might be. In the example, $1.3 million would appear to be a good approximation of what that limit might be, in present, capitalized value per mile.

If quality might be the major potential economic cost of highway privatization, what would be the major economic benefit? Some might argue that the major benefit would be to obtain more funding for highway construction to get more highways built sooner than they otherwise would be. However, any highway that could be successfully privatized without government subsidy would be by necessity self-financing, and therefore could be built by the government without recourse to tax revenues or the government budget. The government can borrow money at least as cheaply as private developers can. The timing advantage of privatization therefore would, in theory, only exist if the relevant government agency lacks sufficient borrowing authority. Highways that would require government subsidy to be privatized due to capitalized toll profits being insufficient to cover construction costs might not have any timing advantage over government ownership, because government funds would have to be used or committed to get the project started.

Rather, it would seem that the main potential economic benefit from highway privatization might be to improve the production efficiency as opposed to allocational efficiency with which highway quantity and quality are produced. Going back to the hypothetical example, suppose the highway does not yet exist or does exist but is badly deteriorated and in need of reconstruction. The government plans to construct or reconstruct the highway. Now suppose that a private developer could construct or reconstruct the highway 10 percent more efficiently than the government could due to greater production efficiency or greater management flexibility and profit incentive. But the private developer would subsequently maintain the highway so as to maximize its profits rather than to maximize the economic welfare of the society, whereas the government would maintain the highway to maximize welfare.

If the government's estimated cost for the highway construction or reconstruction project is greater than $13 million/mi, the savings in more efficient highway production by a profit-maximizing private highway owner would more than offset the economic loss of the subsequent less efficient highway quality maintenance, even assuming the government would pursue a welfare-maximizing highway maintenance policy. The construction cost savings would exceed 10 percent of $13 million, whereas the capitalized cost of the difference between profit-maximizing versus welfare-maximizing highway quality maintenance would be estimated at only $1.3 million or less (indeed, only $0.5 million in the base case).

Considering the magnitude of the highway that was studied in the numerical example (six lanes, 40,000 veh/day), it appears likely that construction costs could exceed this upper limit threshold of $13 million/mi, although for a reconstruction project it is more questionable whether the cutoff point would be exceeded. Of course these benefit-cost numbers are illustrative, depending on the assumption that private producers would be 10 percent more efficient than government producers and considering only the concern for highway pavement quality.

In fact, in this example, the economic argument for privatization could be stronger. It has been noted that the $1.3 million potential cost of privatization quantified in the foregoing analysis was an upper limit, because it is taken from the worst case in the sensitivity analysis of Table 1 and it is based on the difference between the profit-maximizing and welfare-maximizing maintenance policies. There are several reasons why the actual quality cost of privatization might be less than this upper limit.

First, although it would appear reasonable to assume that a private highway owner would seek to maximize profits from the highway, it is nevertheless true that in general, to the extent that other objectives (such as gross revenue maximization) enter the private owner's decisionmaking, his quality maintenance policy would be likely to approach more closely the welfare-maximizing policy. One case where this point would be important is the case in which the private owner of the highway also owns major real estate parcels served by the highway. Then the external benefit of improved highway quality would be to some extent internalized within the highway owner because the value of the owner's real estate is improved by the quality of the access to it.

Second, it is perhaps less reasonable to assume that a government owner would adopt the maintenance policy that maximizes welfare. Numerous constraints and limitations, legal, political, and otherwise, enter into the information processing and decision-making capabilities of government agencies, causing the resulting policies to diverge from economic efficiency. Indeed, as noted in the example case the profit-maximizing pavement maintenance policy exceeds the current standards applied to Interstate highways by government owners (even when not constrained by insufficient funding).

Finally, it should be noted that it may be possible for the government to regulate, subsidize, or otherwise control the privatized highway so that it does produce the welfare-maximizing highway quality without destroying its incentives for production efficiency *(2)*. It is significant that in Table 1 the difference in profit between the welfare-maximizing and the profit-maximizing policies is not great. Nevertheless, a regulatory process would likely be difficult and tricky, and not without cost in terms of the deadweight burden of regulatory administration.

SUMMARY

Given the likely difficulty of obtaining efficient highway quality over the long run from privately owned highways, it is important in considering and evaluating highway privatization proposals to attempt, as was done in this paper, to put quantitative limits on the potential economic costs of suboptimal highway quality that could result from privatization. The analysis here indicates that this cost may not be too great in some circumstances. But different conclusions might be reached in other examples and with other assumptions.

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Economic Factors of Developing Fine Schedules for Overweight Vehicles in Texas

MARK A. EURITT

A rapid deterioration of the state's highway network can have serious economic consequences for Texas. Many communities depend entirely on the trucking industry for the transport of goods to principal markets. In order to protect the structural integrity of the highway system, which represents a significant economic investment, statutes limit the gross weight and axle weights of vehicles. However, despite the illegality of an overloaded vehicle, a large number of trucks operating on Texas highways exceed their maximum allowable weights. These illegal operations deprive the state of nearly $48 million per year. The current schedule of fines and penalties is wholly inadequate. By its very structure it encourages rather than discourages overweight violations. Truck operators have merely accepted these penalties as a cost of doing business. An operator of a 120,000-lb, 18-wheel vehicle, for example, has a $2,621 incentive to operate above the 80,000-lb legal gross weight limit. The low probability of being caught and the small fine fail to discourage a decision to overload a vehicle.

Road transport has become the predominant mode for domestic freight, outstripping the rail industry in this respect. In the state of Texas, nearly two-thirds of the communities depend entirely on trucks for the transporting of goods to principal markets *(1)*. The construction and maintenance of highways is thus central to the economic well being of the trucking industry and to the state's communities. A rapid deterioration of the state's highway network could have serious economic ramifications.

The construction and maintenance of highway facilities requires a significant economic investment. Since 1980, the Texas State Department of Highways and Public Transportation (SDHPT) has spent an average of $1.5 billion per year on construction and maintenance of state highways *(2)*. The SDHPT's 1982 strategic plan indicated a need of $57.6 billion (in 1982 dollars) for highway facilities over the next 20 years *(3)*. In order to protect the structural integrity of the highway system, statutes limit the size and weight of motor vehicles. These limitations have significant (and opposite) effects on the trucking industry and the state highway system. Reduction of operating costs is an important objective in trucking operations; increases in the per vehicle payload through increases in the size and allowable weight of trucks can yield considerable productivity benefits and reductions in unit shipping costs. These savings, however, are achieved at the expense of damage to the state's pavements and bridges, the amount depending on the number and weight of resulting axle passages, because increases in vehicle operating weights result in a more rapid deterioration of highway facilities.

In recent years, state transportation agencies have become concerned with their ability to generate sufficient resources to maintain adequate service levels for highways. Because of the impact of vehicle weights on highways and structures, load limitation statutes regulate vehicle operating weights. In Texas, the legislature has set the maximum gross vehicle weight at 80,000 lb, the maximum single-axle load at 20,000 lb, and the maximum tandem-axle load at 34,000 lb. Exceptions to these limits are allowed for vehicles operating with a special permit or those operating under special legislation (e.g., ready-mixed concrete trucks and vehicles transporting seed cotton modules, fertilizer, milk, poles, piling, unrefined timber, electric power transmission poles, cotton, and unladen lift equipment). In this paper, overweight vehicles operating illegally are emphasized. Figure 1 shows the number of reported weight violations in the years 1981–1984 (unpublished data, Texas Department of Public Safety).

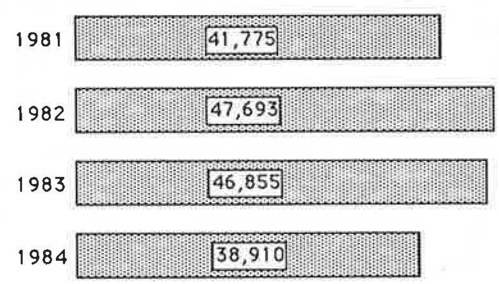

FIGURE 1 Number of overweight violations (unpublished data, Texas Department of Public Safety).

The economic implications of overweight vehicle operations are important to the state of Texas. Analysis of the Texas Truck Weight Survey reveals that the number of overweight operations ranged from 21 to 25 percent for all truck operators in 1984 *(4)*. If the state is to maintain a viable highway network, the effects of overweight vehicle operations must be documented. In this paper, economic damages to the Texas highway system and economic benefits to the trucking industry are noted. In addition, the economic implications of fines resulting from the vehicle weight laws are reviewed and an alternative fine schedule is presented. From this discussion, policy makers and analysts may gain a greater appreciation for the magnitude of the effects of overweight vehicle operations.

ECONOMIC IMPLICATIONS OF OVERWEIGHT VEHICLES

There are two major factors associated with overweight vehicle operations: (a) the economic cost resulting from damage to

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highway facilities, and (b) truck operating profits. A vehicle operating above its allowable weight in effect is stealing life from the roadway. Increased wear and tear on a roadway requires earlier repairs or replacement to the structure and can adversely affect a state transportation budget. On the other hand, adding weight to a vehicle has little effect on the operator's costs, but increases the payload. The resulting extra profit can be passed on in the form of lower shipping rates that give the illegal operator an unfair rate advantage over competitors who obey the law. Combined, these two major factors present important problems for a state transportation system.

Economic Damages to Highway Facilities

Texas highway facilities are typically designed to last for about 20 years. In the highway planning stage, engineers design highways to withstand a specified number of passages by an axle of prescribed weight. A properly built facility given routine maintenance and traffic loads not in excess of designed capacity should last for 20 years. When a vehicle imposes a load on a highway greater than that for which the facility was designed, the life of the highway is reduced. Herein lies the nature of the damage caused by overweight vehicles; in essence, overweight vehicles steel life from the roadway.

The relationship of load to pavement damage was documented by the American Association of State Highway Officials (AASHO) [since renamed American Association of State Highway and Transportation Officials (AASHTO)] Road Test in 1962. The AASHO Road Test, conducted from 1958 to 1961 at a cost of $30 million, was the most definitive work ever performed to determine the effects of truck size on pavements. The methodology used in the AASHO Road Test establishes the capability of converting any single-axle load to a standard load (generally, an 18,000-lb single-axle load) in terms of damage to the pavement *(5)*. This process allows engineers to convert axle loads of various truck classifications into equivalent axle loads (EALs). Roadways are now designed to bear a specified number of EALs during their life.

The dependence of pavement damage on axle weight closely approximates an exponential relationship. Consequently, when axle weights are increased above a roadway's designed capacity, damage to the facility increases significantly. For example, an axle weight of 26,000 lb is only 30 percent greater than an axle weight of 20,000 lb, but the damage effect on the roadway is 200 percent greater. Similarly, a 3S-2 loaded to 80,000 lb weighs about the same as 20 automobiles, but impacts the roadway at an equivalence of 9,600 automobiles *(6)*. (See Figure 2 for an illustration of the 3S-2 and other vehicles.)

Combining typical axle weight distributions with the AASHO EALs allows calculation of relative damage equivalencies and thus relative damage of overweight vehicles. Table 1 converts the AASHO EALs to an 80,000-lb standard 3S-2 combination vehicle. These data demonstrate, for example, that a single 110,000-lb 3S-2 vehicle, 30,000 lb or 37.5 percent over the legal gross weight, causes the same damage as three and one-third legal 80,000-lb 3S-2 vehicles. In all instances, increases in vehicle weight cause disproportionate increases in relative damage.

The data in Table 1 also illustrate a second relationship between weight and vehicle class. The relative equivalencies demonstrate that in addition to total weight relative damage is also associated with the number of axles on a vehicle. One 80,000-lb 2S-2 combination (four axles) causes the same damage as two 80,000-lb 3S-2 vehicles (five axles each). On the other hand, an 80,000-lb 3S-1-2 combination (six axles) causes the same damage as only 0.6 of an 80,000-lb 3S-2 combination. These two examples demonstrate quite clearly the relationship of damage to the number of axles on a vehicle. Increasing the number of axles on the vehicle reduces the overall stress associated with a given load.

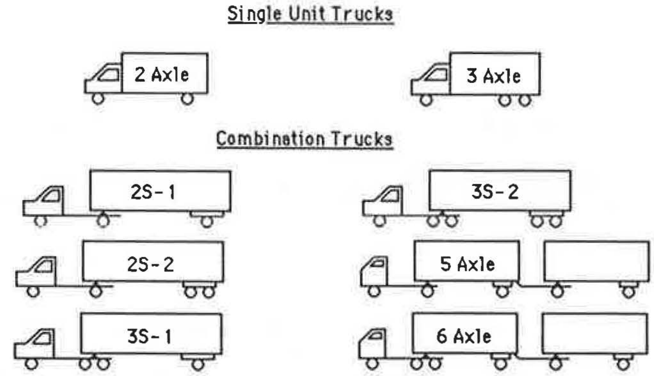

FIGURE 2 Vehicle classifications.

A final damage factor, not given in Table 1 but derived from the AASHO Road Test, is the relationship between axle spacing and pavement stress. An equation known as the "bridge formula" that determines the maximum allowable gross weight of a vehicle based on the number and spacings between axles takes the following form:

$$W = 500 \times [LN/(N - 1) + 12N + 36]$$

where

W = maximum weight in pounds that can be carried on a group of two or more axles to the nearest 500 lb,
L = spacing in feet between the outer axles of any two or more consecutive axles, and
N = number of axles being considered *(8)*.

The logic of this equation is similar to that of a person's attempting to walk across ice that is too thin to support the person's weight; the person is likely to fall through. If the same person stretches out prone on the ice and squirms across, it is unlikely that the person would fall through *(8)*. Application of the bridge formula is especially important in the design of bridges. A comparison of the stress effects of two 3S-2 vehicles of equal weight but different lengths is shown in Figure 3 *(8)*. The bridge formula is a widely accepted principle that has been adopted by most states for determining gross vehicle weight limits.

Although the relative damage concept is widely accepted, the actual damages associated with overweight vehicles are not known, due primarily to the difficulty in determining the number and extent of illegal weight operations. Two approaches for estimating the costs of overweight vehicles in Texas are presented. The first is a scenario approach that was completed in a

TABLE 1 RELATIVE EQUIVALENCIES BY TRUCK TYPE *(7)*

Gross Vehicle Weight (lb)	Two-Axle	Three-Axle	2S-1	2S-2[a]	3S-2	Five-Axle[b]	Six-Axle[c]
30,000	0.42	0.07	0.07	0.04			
40,000	1.22	0.26	0.32	0.11	0.05	0.05	0.03
50,000	2.83	0.79	0.81	0.32	0.13	0.11	0.08
60,000		1.66	1.69	0.74	0.30	0.28	0.17
70,000			3.11	1.23	0.60	0.51	0.33
80,000				2.01	1.00	0.94	0.59
90,000				3.23	1.69	1.60	0.95
100,000					2.50	2.37	1.49
110,000					3.39	3.39	2.16
120,000						4.67	3.05
130,000							4.08
140,000							5.10

NOTE: Relative equivalencies (1.00 for 80,000-lb 3S-2 combination) are for rigid pavement that distributes loads to the subgrade, having as one course a portland cement concrete slab of relatively high bending resistance.

[a]The 3S-1 combination has equivalencies nearly identical to the 2S-2 combination.
[b]The 2S-1-2 combination is the vehicle used for the five-axle category.
[c]The 3S-1-2 combination is used for the six-axle category.

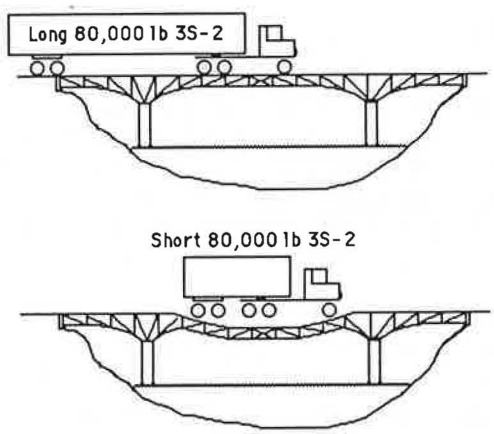

FIGURE 3 Truck length and bridge stress *(8)*.

1983 study by The University of Texas at Austin Center for Transportation Research (CTR). The second approach is a new approach called the "revenue method."

CTR Scenario Approach

Utilizing 1980 Texas Truck Weight Survey data, two scenarios were simulated. The first scenario depicted the existing condition with respect to sizes and weights of vehicles operating on Texas highways. The second scenario represented a 100 percent compliance situation, that is, no overweight vehicles, accomplished by removing all overweight vehicles from the truck fleet and reassigning their payloads to an additional group of vehicles that could legally carry the payloads at maximum allowable weights. Equivalent axle loads (EALs) were then calculated and compared over a 20-year planning period.

The total EALs and their ratio calculated for the two scenarios are summarized in the following table *(1)*:

	EALs (millions)		*Ratio of EALs in Scenario 2 to Scenario 1*
	Scenario 1	*Scenario 2*	
All highways	28.133	26.240	0.93

The results show that pavement damage for the 100 percent compliance situation is less than that for the existing condition, and that therefore pavement life is reduced by overweight vehicles. The financial costs associated with these changes were derived from a SDHPT computer program (REHAB) that forecasts pavement rehabilitation costs. Comparing the REHAB results from the two scenarios, $9 million in pavement rehabilitation costs can be attributed to overweight vehicles in 1980, and $125 million can be attributed over the 20-year design period *(1)*.

The $125 million represents a conservative amount. It does not include financial damages associated with bridge deterioration, which was beyond the scope of the CTR study because bridges are typically designed for a life of more than 20 years. The amount is also based on the Texas Truck Weight Survey, which underestimates the actual number of overweight violators. Finally, it excludes costs associated with enforcement and administration. Inclusion of these items would result in an additional $135 million over the 20-year period *(1)*.

Revenue Method

The cost to the state of overweight truck operations can be looked at in another way. Highway transportation financing is based on a user fee concept, that is, the users of the highway facilities pay for the construction, maintenance, and operation of the system. Accordingly, the more an operator uses the facilities, the more the operator pays for that privilege. The problem with overweight vehicles is that they do not contribute additional funds for the extra burden they place on the highway system. As noted earlier, overweight vehicles steal life from the roadways.

In 1980, highway users contributed nearly $1.3 billion to the highway system through a variety of taxes and fees. Of this amount, heavy trucks (as shown in Figure 2) contributed $402 million, or 31 percent. Applying 1980 vehicle registration numbers (375,830 heavy trucks), each heavy truck contributed an average of $1,070 *(9)*. This amount represents the amount that truck operators contribute based on legal weight limits. If a vehicle has operated at a capacity exceeding legal limits, it has deprived the state of additional revenues needed to maintain the system. An estimate of this amount can be calculated using the EAL relative damage concept. According to the CTR study, 24 percent of the weighed vehicles exceeded legal limits by an average of 8,000 lb *(1)*. This amounts to 90,199 trucks (24 percent × 375,830 registered trucks). Because the 3S-2 combination is the most common violator, more than 90 percent of the 1980 violations, it is used as the standard vehicle. Applying the equivalencies presented in Table 1, a 3S-2 combination overloaded by 8,000 lb has an equivalency factor of approximately 1.5. Therefore, because the overweight truck actually represents 1.5 trucks, each overweight truck should have paid an average of $1,605, or $535 more than what was actually paid. Based on the user fee approach, overweight vehicles deprived the state of Texas of $48 million in 1980.

Regardless of how actual damages are calculated, overweight vehicles contribute to a faster deterioration of the highways. This faster deterioration is documented in the examination of State Highway Fund (SHF) disbursements. In 1980, construction of highway facilities represented 76 percent of total SHF expenditures, while in 1983 construction fell to 60 percent. In real dollars, there was a 26 percent decrease in highway construction. At the same time, maintenance costs of existing facilities increased 26 percent from 1980 to 1983 *(2)*. Even more dramatic is the changing nature of the construction dollar. Review of the Texas SDHPT Operational Planning Document revealed that of the $37.1 billion needed for construction over the 20-year planning period (1983–2002), 82 percent would be used for reconstruction of existing facilities *(10)*. Combining this result with the effect of increasing weight loads found in the 1962 AASHO Road Test suggests that overweight vehicles cost the state of Texas many millions of dollars each year.

Economic Benefits for Overweight Operations

The benefit that a vehicle operator receives from overloading a vehicle is increased financial returns. Generally, truck operators are paid on an amount hauled basis. The more cargo that is transported, the more the hauler is paid. The profitability of overloading occurs because of the relationship between operating costs and vehicle weight. Using the 1980 Association of American Railroads Truck Cost Model and the 1979–1980 National Motor Transport Data Base, Gilckert and Paxson found that as cargo weight increases the operating cost per unit of weight decreases *(11)*. The data in the following table display this relationship for the typical intercity trucker:

Cargo Weight (tons)	*Line-Haul Cost Per Mile (¢)*	*Line-Haul Cost Per Ton-Mile (¢)*
10	89.1	8.91
15	89.5	5.97
20	90.3	4.52
25	90.5	3.62

The table shows that although cargo weight increased by 150 percent, from 10 to 25 tons, the line-haul cost per ton-mile increased only 1.4 cents, or 1.6 percent. As a result, the line-haul cost per ton-mile declined 5.29 cents, or 59 percent *(11)*.

The declining cost per ton-mile has a significant effect on trucker's profits. The more a truck is loaded, the greater the financial benefit. Table 2 gives the incremental economic incentives faced by a typical 3S-2 vehicle operator with a hauling rate of 5.6 cents/lb. Without consideration of any possible penalties, clearly, the operator has an incentive to load as much as possible on a vehicle.

The trucking industry as a whole can net considerable savings from illegal overweight operations. The 1983 CTR study estimated that overweight vehicles in Texas saved $46.5 million in operating costs in 1980 *(1)*. These savings are based on a comparison of the operating costs of the two scenarios discussed previously. The $46.5 million in savings represents the hypothetical cost of reassigning illegal payloads to additional vehicles.

TABLE 2 INCREMENTAL INCENTIVE TO OVERLOAD IN TEXAS *(12)*

Cargo Weight (lb)	Income[a] ($)	Operating Cost per Mile[b] (¢/mi)	Operating Cost per Trip[c] ($)	Net Income ($)	Incremental Incentive ($)
25,000	1,400	78.9	395	1,005	0
40,000	2,240	86.2	431	1,809	804
55,000	3,080	94.5	473	2,607	1,602
70,000	3,920	104.0	520	3,400	2,395
85,000	4,760	114.6	573	4,187	3,182
115,000	6,440	139.0	695	5,745	4,740

[a]Income = 5.6¢ × Cargo Weight.
[b]The operating cost per mile is based on research by Larkin.
[c]Operating costs are based on a 500-mi trip.

ECONOMIC EFFECTS OF OVERWEIGHT FINE SCHEDULES

Statutory vehicle weight limits specify maximum loads for vehicles operating on roads and highways. As noted earlier, these limits are designed to protect the structural integrity of the highway system. Although most trucking operations comply with the weight laws, violators are a significant threat to a well maintained highway network. In addition, violators impose hardships on the trucking industry in the form of unfair competition. Illegally weighted trucks generate cost savings that allow the operator to offer rates lower than the legal competitor. The resulting abuse to the highway system, and disruption to the trucking industry indicate a need to evaluate weight enforcement programs.

An effective program for discouraging weight violations is contingent on two factors, the probability of being caught and the penalty. If operators see the penalties are less than the economic benefits of overloading, there is little incentive to comply with weight statutes. Moreover, any penalty is meaningless if operators perceive only a small likelihood of being weighed.

Existing Fines for Weight Violations

Current Texas law prohibits operation of vehicles in excess of 80,000 lb gross vehicle weight (GVW). In addition, limits are set for single axles (20,000 lb), tandem axles (34,000 lb), and other axle groupings according to a table based on the bridge formula. Vehicles that operate in excess of the prescribed limits without a special permit are cited to justice of the peace courts for persecution of a Class C misdemeanor. Actual fines and possible jail sentences vary according to the number of offenses. The following table lists the current range of fines and penalties for Texas *(13)*:

Offense	*Minimum Fine ($)*	*Maximum Fine ($)*	*Jail Sentence (max) (days)*
First	100	150	0
Second	150	250	60
Third	200	500	182

The penalties for the second and third offenses are imposed only if they occur within 1 year of the prior offense. These penalties became effective in September of 1983, with penalties before this period ranging from $25 to $200. Table 3 gives the total and average fines collected over the last 4 years. The significant increase in the average fine in 1984 is reflective of the higher minimum fine ($100) and not an increase in overweight violations. Actual violations decreased by 17 percent, perhaps a reflection of the higher penalties for violators.

TABLE 3 TEXAS OVERWEIGHT FINE COLLECTIONS FOR 1981–1984

Year	Overweight Fines ($) Total	Average
1981	1,743,237	41.37
1982	2,072,193	43.45
1983	2,505,175	53.47
1984	3,989,190	102.52

SOURCE: Texas Department of Public Safety, unpublished data.

Unlike Texas, most states attempt to discourage overweight trucking by imposing fines based on the amount of weight in excess of legal weights. Generally, as the weight increases so does the fine. In all, 40 states had fine structures reflecting the amount of excess weight *(14)*. The four states surrounding Texas are a good sample of the types of fine schedules used by various states.

New Mexico and Oklahoma impose a specific fine depending on how much the vehicle is overweight. Table 4 presents the fine schedules for these two states. New Mexico's fines range from $25 to $500 whereas Oklahoma's fines range from $80 to $500. Both of the states allow some tolerance for overweight vehicles, 700 lb for Oklahoma and 1,000 lb for New Mexico.

TABLE 4 OKLAHOMA AND NEW MEXICO FINE SCHEDULES *(15)*

Amount Overweight (lb)	Fines ($) by State: Oklahoma	New Mexico
700–2,000	80	25[a]
2,001–3,000	130	25[a]
3,001–4,000	180	40
4,001–5,000	230	75
5,001–6,000	280	125
6,001–7,000	330	200
7,001–8,000	380	275
8,001–9,000	430	350
9,001–10,000	480	425
10,001 +	500	500

[a]The first overweight category for New Mexico is 1,000 to 3,000 lb.

Louisiana also operates its fine structure on a graduated scale, that is, the fine increases as the amount of excess weight increases. However, instead of assessing a specific fine for each weight grouping, a cents-per-pound fine is charged. The Louisiana schedule, as shown in the following table, ensures that violators not only receive a higher fine per pound overweight but also are charged at a higher rate *(16)*.

Amount Overweight (lb)	*Fine (¢/lb) Over Gross Weight*	*Over Axle Weight*
0–3,000	2	1
3,001–5,000	3	1.5
5,001–10,000	4	2
10,001 +	5	5

A flat fine of $100 is added for overweights in excess of 10,001 lb. If vehicle exceeds gross weight but not axle weight, the "over gross weight" schedule is used. If vehicle exceeds axle weight but not gross weight, the "over axle weight" schedule is used. When two or more axles are overweight, these fines are figured separately and added together. If vehicle exceeds both gross and axle weight, fines are figured for both schedules and the larger of the two penalties is imposed. This approach attempts to offset the economic incentives for increasing vehicle loads. In addition, a cents-per-pound approach does not limit the maximum penalty as do the Oklahoma and New Mexico schedules. This is an important factor when considering excessive legal weight violations. [In Texas, nearly 10 percent of all violators exceed weight limits by 20,000 lb or more *(4)*.]

Arkansas combines a fine structure similar to Louisiana with a penalty based on the operator's number of offenses. In addition to the fines imposed according to the following table, overweight violators are charged by the Arkansas motor vehicle laws a maximum of $100 for the first offense, $200 for the second offense within 1 year of the first, and $500 for third and successive offenses within 1 year of a previous offense.

Amount Overweight (lb)	*Fine (max) (¢/lb)*
0–1,000	2
1,001–2,000	3
2,001–3,000	4
3,001 +	5

For overweights of 0–1,000 lb a minimum fine of $10 is imposed. If an operator is found to have willfully avoided being weighed at a weigh station, the penalty is doubled. This type of arrangement punishes the recurrent violator as well as the excessive offender.

Economic Effects of Penalties

Truck operators have an incentive to overload their vehicles. A vehicle's payload increases much more rapidly than do the corresponding operating costs. In order to offset this incentive, states have imposed fines to serve as an economic disincentive. On the surface, the various types of fine schedules appear to incorporate an increasing economic disincentive that offsets the incremental benefits to overloading. However, as shown by the data in Table 5, this result is not necessarily the case.

The different weight scenarios in Table 6 are for a first-time GVW offense charged at a maximum allowable rate. Because of its flat fee approach, Texas represents the worst-case scenario. A trucker in Texas who decides to overload can minimize the cost associated with the fine by maximizing the load. To a less extent, a similar problem persists in Oklahoma and New Mexico. The overall fines increase with weight, but the costs associated with each pound of weight decline at certain points in the schedule. Thus, overweight operators in all three states can minimize the effects of the fine by increasing their loads. The Arkansas schedule, which appears as the most excessive of the listed fine schedules, also has a problem with a declining fine per pound overweight. Clearly, if a vehicle operator makes a conscious decision to overload, the fine schedules provide an incentive, not a disincentive, to maximize the overload.

The economic incentive problem for the various schedules occurs when a flat rate fine is introduced. The decline in the cents-per-pound charge in the arkansas case is a result of the $100 fine charged all first offenders. In Louisiana, the decline occurs when the $100 is added to all weight in excess of 10,000 lb. For New Mexico, it is a result of the $500 flat rate for all weights above 10,000 lb. The Oklahoma schedule suffers from the same problem, as well as from a poor selection of fines for the various weight groupings.

Applying these various fine schedules with the incremental incentives to overload (Table 2) demonstrates the potential effects of fines. Table 7 gives the overall incremental incentive to overload for a typical 3S-2 vehicle on a 500-mi trip. The Arkansas schedule provides a disincentive for violators as long as their gross weight is below 120,000 lb; for more than 120,000 lb, the venture becomes profitable again. The Louisiana schedule allows for an incentive up to 90,000 GVW and for more than 120,000 lb GVW. Between these two amounts there is a declining economic disincentive. The schedules of the remaining three states do not offset the economic benefits of overloading.

TABLE 5 OVERWEIGHT FINES FOR FIRST OFFENSES

Amount over Gross Weight (lb)	Arkansas ($)	Louisiana ($)	New Mexico ($)	Oklahoma ($)	Texas ($)
2,000	160	40	25	80	150
6,500	425	260	200	330	150
10,000	600	400	425	480	150
15,000	850	850	500	500	150
30,000	1,600	1,600	500	500	150

TABLE 6 OVERWEIGHT FINES PER POUND FOR FIRST OFFENSES

Amount over Gross Weight (lb)	Arkansas (¢)	Louisiana (¢)	New Mexico (¢)	Oklahoma (¢)	Texas (¢)
2,000	8.0	2.0	1.3	4.0	7.5
6,500	6.5	4.0	3.1	5.1	2.3
10,000	6.0	4.0	4.3	4.8	1.5
15,000	5.7	5.7	3.3	3.3	1.0
30,000	5.3	5.3	1.7	1.7	0.5

TABLE 7 INCREMENTAL INCENTIVES TO OVERLOAD, VARIOUS STATES

Vehicle Weight (lb)	Incremental Incentive ($)	Potential Fine ($)	Overall Incremental Incentive ($)
Arkansas			
80,000	0	0	0
85,000	265	350	−85
90,000	529	600	−71
95,000	793	850	−57
100,000	1,056	1,100	−44
110,000	1,580	1,600	−20
130,000	2,621	2,600	+21
Louisiana			
80,000	0	0	0
85,000	265	150	+115
90,000	529	400	+129
95,000	793	850	−57
100,000	1,056	1,100	−44
110,000	1,580	1,600	−20
130,000	2,621	2,600	+21
New Mexico			
80,000	0	0	0
85,000	265	75	+190
90,000	529	425	+104
95,000	793	500	+293
100,000	1,056	500	+556
110,000	1,580	500	+1,080
130,000	2,621	500	+2,121
Oklahoma			
80,000	0	0	0
85,000	265	230	+35
90,000	529	480	+49
95,000	793	500	+293
100,000	1,056	500	+556
110,000	1,580	500	+1,080
130,000	2,621	500	+2,121
Texas			
80,000	0	0	0
85,000	265	150	+115
90,000	529	150	+379
95,000	793	150	+643
100,000	1,056	150	+906
110,000	1,580	150	+1,430
130,000	2,621	150	+2,471

Probability of Apprehension

Until now, it has been assumed in the economic incentive calculations that violators will be apprehended. In practice, this does not happen and therefore expected fines are significantly less than potential fines. For example, if the probability of being weighed by a state weight enforcement agency is 10 percent and the probability of paying a $200 fine for being overweight is 50 percent, the expected fine is only $10. [$200 (fine) × 0.10 (probability of being caught) × 0.50 (probability of being required to pay the fine) = $10.] Knowing the probability of apprehension is, therefore, very important in developing a fine schedule. Estimating this figure is difficult, however, because the figure is dependent not only on the actual level of enforcement but the vehicle operator's perceptions. Glickert and Paxson interviewed officials from three states and asked them to give an estimate assuming the trucker was using avoidance measures. The officials' estimates ranged from a low of 5 percent in Tennessee to a high of 20 percent in Indiana, with 15 percent for Iowa *(17)*.

The probability of apprehension in Texas is lower than that in most other states because of the number of highway miles that must be patrolled. The following table gives the number of vehicles that are checked and weighed each year by Department of Public Safety (DPS) license and weight officers:

Year	*No. Vehicles Checked*	*No. Vehicles Weighed*	*Vehicles Checked That Are Weighed (%)*
1981	616,091	208,270	33.8
1982	675,356	228,922	33.9
1983	633,409	213,408	33.7
1984	644,662	219,766	34.1

According to the DPS, license and weight inspectors check vehicles about every 12,500 mi, based on an estimated 7.8 billion miles of truck travel and checking by the Texas DPS of at least 625,000 trucks a year. Using this figure, it is possible to estimate the probability of apprehension based on the length of a trip. These probabilities are given in Table 8. The overweight violator's chance of being apprehended is further reduced because every vehicle checked is not weighed. According to the DPS, during 1981–1984 about 34 percent of all vehicles checked were weighed.

TABLE 8 PROBABILITY OF APPREHENSION BASED ON TRIP LENGTH

Trip Length (mi)	Chance of Being Checked (%)	Chance of Being Weighed (%)
50	0.4	0.1
100	0.8	0.3
250	2.0	0.7
500	4.0	1.4
800	6.4	2.2
1,100	8.8	3.0
1,500	12.0	4.1

It is possible to present a more realistic picture of the incremental incentives to overload. Table 9 shows recalculated incentives for a 500-mi trip based on effective fines for Arkansas, the state with the highest penalties, and Texas, the state with the lowest. Because of their enforcement activity, a 20-percent probability is used for Arkansas. A 4-percent probability is used for Texas to compensate for the fact that the DPS vehicle checks include vehicles that are not heavy trucks. Therefore, the percentage chance of a heavy truck's being weighed would be higher than 34 percent. A 4-percent apprehension rate reflects a situation where all heavy trucks, as identified in Figure 2, are weighed. The results present a disturbing picture. Despite efforts of law enforcement officials and the designers of the various fine schedules, current weight statutes have little effect on the economic decisions of overweight violators.

TABLE 9 ADJUSTED INCREMENTAL INCENTIVES TO OVERLOAD

Vehicle Weight (lb)	Incremental Incentive ($)	Effective Fine[a] ($)	Adjusted Incremental Incentive ($)
Arkansas			
80,000	0	0	+0
85,000	265	70	+195
90,000	529	120	+409
95,000	793	170	+623
100,000	1,056	220	+836
110,000	1,580	320	+1,260
130,000	2,621	520	+2,101
Texas			
80,000	0	0	+0
85,000	265	6	+259
90,000	529	6	+523
95,000	793	6	+787
100,000	1,056	6	+1,050
110,000	1,580	6	+1,574
130,000	2,621	6	+2,615

[a]Effective Fine = Potential Fine × Probability of Apprehension.

A Fine Schedule for Texas

There are three important considerations in the design of an overweight fine schedule. First, the schedule should establish large enough disincentives to offset any incentives for overloading vehicles. Second, the fines should recover damages that have been inflicted on the highway system. And, third, the fines should recover an adequate portion of the administrative costs associated with enforcement. Because of the significance of the incremental benefits to overloading, the disincentive is the key variable in the fine schedule.

A review of the schedules of the states surrounding Texas provide useful information for developing an effective schedule. The schedule should have a graduated scale, that is, the amount of the fine should increase as the weight increases. The schedule should also use a cents-per-pound basis and not a flat fee amount to avoid fluctuations that occurred in the Louisiana schedule (see Table 5). Table 10 provides a fine schedule for Texas based on an effective rate that offsets the incremental incentives to overload.

TABLE 10 ALTERNATIVE FINE SCHEDULE FOR TEXAS

Amount Overweight (lb)	Fine (¢/lb)
0–2,000	5.0
2,001–5,000	5.5
5,001–8,000	6.0
8,001–12,000	6.5
12,001–18,000	7.0
18,001–25,000	7.5
25,001 +	9.0

The discussion of the relative damage concept by AASHO EALs revealed that damage is directly related to axle weights. Therefore, if a fine schedule is to recover highway damages, the fine schedule should focus on axle weight violations (single, tandem, and axle grouping according to the bridge formula). The schedule in Table 11 is an adaptation of that in Table 10 but with an emphasis on axle weight violations. The difference in the fines for vehicles over their legal GVW and legal axle weight reduces some of the disparity with regard to relative pavement damage. (As noted previously in Table 1, a two-axle vehicle with a GVW of 40,000 lb does more damage than a six-axle vehicle weighing 90,000 lb.) Because pavement damage is related to the magnitude and repetition of axle loads, this fine schedule penalizes vehicles more heavily for exceeding their axle weights than for exceeding their GVWs. It is important to note, however, that this fine schedule does not eliminate the disparity between axle weight and GVW calculations and is not a pure damage-based schedule. A pure damage-based schedule approach would require separate fine schedules for each type of vehicle. Because the key element of the fine schedule is economic disincentive, this type of approach is unnecessary.

TABLE 11 ALTERNATIVE FINE SCHEDULE FOR TEXAS ADJUSTED FOR GVW AND AXLE WEIGHT

	Fine (¢/lb)	
Amount Overweight (lb)	Over GVW	Over Axle Weight
0–2,000	2.0	3.0
2,001–5,000	3.0	4.0
5,001–8,000	4.5	6.0
8,001–12,000	6.0	8.0
12,001–18,000	7.5	10.0
18,001–25,000	9.0	12.0
25,001 +	11.0	15.0

Unlike the Louisiana schedule, fines for vehicles whose weight exceeds both the legal GVW and legal axle weights are cumulative in this schedule. For example, if a 3S-2 combination has a GVW of 90,000 lb with 6,000 lb over maximum on one tandem axle and 4,000 lb over maximum on the other tandem axle, the fine is calculated as follows:

Total fine	= GVW fine + axle weight fine		
GVW fine	= 10,000 × 6¢	=	$ 600
Axle weight fine	= (6,000 + 4,000) × 8¢	=	$ 800
Total fine	= $600 + $800	=	$1,400

The real test for the fine schedule in Table 11 is to determine if it offsets the incremental incentives to overload. Using the examples cited previously, the Texas incremental incentive to overload using the new fine schedule is presented in Table 12. The schedule has an increasing economic disincentive built into it. A potential violator pays a stiff penalty for increasing cargo weight beyond tolerable limits.

The current fine schedules for overweight violations in Texas and many other states are wholly inadequate. By their structure, they encourage rather than discourage overweight violations. If a schedule similar to the one presented in Table 12 were operational, the number of overweight violations would decrease. Truck operators are aware of the penalties associated with illegal operations. The DPS, for example, reported that

TABLE 12 INCREMENTAL INCENTIVE TO OVERLOAD IN TEXAS BASED ON THE NEW FINE SCHEDULE

Vehicle Weight (lb)	Incremental Incentive ($)	Fine ($)	Adjusted Incremental Incentive ($)
Arkansas			
80,000	0	0	0
85,000	265	350	−85
90,000	529	1,400	−871
95,000	793	2,625	−1,832
100,000	1,056	4,200	−3,144
110,000	1,580	7,800	−6,220
130,000	2,621	13,000	−10,379

because of the increased fines in 1983 (a $75 increase in the minimum fine) and new Texas legislation on aiding and abetting, there was a 12 percent reduction in overweight violations *(18)*. If Texas is to maintain the integrity of its highway system, a further increase in its fine schedule is required.

CONCLUSIONS

Overweight trucking has serious economic consequences for the Texas highway system, costing between $6 and $48 million a year. Although road deterioration dominates the overweight vehicle debate, other issues are also important in the design of weight laws. In addition to protecting the roadway, vehicle weight limits promote public safety and reduce undue traffic delays for motorists. Heavy truck accidents account for a large share of all traffic accident losses. One highway fatality in nine occurs in accidents involving heavy trucks, even though heavy trucks represent only about 3 percent of the vehicles on Texas highways *(19, 20)*. Although conclusive statistics are not available regarding the impact of vehicles on highway safety, public safety is an important consideration in the design and enforcement of weight statutes.

Overweight operations can also adversely affect a state's economy through unfair competition. Illegal trucking results in considerable cost savings for the vehicle operator that can be passed on in the form of lower freight rates that enable the illegal trucker to enjoy an unfair advantage over competing legal vehicles. Overweight vehicles may also affect other modes of transportation. A recent U.S. Department of Transportation study suggests that large-scale evasions of weight limits could result in some shifting of freight from rail to truck *(21)*.

The economics of overloading have had significant implications for the state highway system and the trucking industry. The dynamics of vehicle operating costs have provided truck operators with strong incentives to increase their payloads. Consequently, some operators have chosen to load their vehicle at a weight higher than what the highway facility was designed to bear. The result, expensive and rapid deterioration of the state roadways, has forced reevaluation of weight enforcement programs. The first step in these programs is the development of fine schedules that reduce the incentives to overload vehicles.

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Regional Economic Impacts of Local Transit Financing Alternatives: Input-Output Results for Portland

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Mass transit providers are facing mounting pressure to extend the scope of local financing in the wake of reductions in federal operating subsidies. In this study are discussed the economic impacts in the Portland, Oregon, metropolitan area associated with generating $1 million in local transit funding from the following seven alternative sources: personal income, property, retail sales, gasoline sales, downtown parking, payrolls, and a transit fare increase. An input-output model of the metropolitan area is used to estimate the change in sectoral output that would result from transferring resources from nontransit activities to transit operations. Aggregate economic activity declines for all seven financing alternatives, although net increases are calculated for a number of individual sectors. Overall, the reduction in economic activity was minimized with a gasoline tax and maximized with a fare increase. Although the value of external transit benefits was not considered in the analysis, a rationale for evaluating these benefits in light of the study results was outlined.

In the 1980s, transit providers in the United States face a worsening predicament: preserving service in the wake of planned phaseouts of federal operating subsidies. The loss of federal funding has underscored the need to secure additional revenues through either higher fares or increases in state and local subsidies. The growth of transit system deficits since 1979 suggests, however, that the effort to replace federal subsidies with locally based financing has been less than successful.

The pressure to increase farebox yields marks a turnaround from the 1970s, when "(t)he movement toward lower and more simplified fare structures . . . was encouraged by nearly all government agencies involved in transportation planning, as well as by many rider groups and other transit advocates" *(1)*. Alternatively, attempts to expand already sizeable local and state contributions are being met with hesitancy, skepticism, or outright opposition, apparently signaling the perception that social benefits associated with mass transit are in tune with the level of financial support already committed. In short, local transit agencies are generally finding themselves mired in budgetary crises, with their options being reduced to substantial reorganization and service cuts.

Interest in the subject of local transit assistance is motivated by uncertainty regarding its economic impacts. Even in the simple situation where the externalities associated with transit use are ignored, it is not clear who would gain and who would lose when local financial assistance is provided to mass transit. Moreover, it is not clear whether total economic activity in an area would increase or decrease if such a transfer were made. Finally, the extent to which aggregate and disaggregate economic impacts would vary with alternative local transit financing options is also unknown.

In this paper, these questions are addressed and the results of an input-output analysis of the economic impacts of seven local transit financing alternatives are reported. The alternatives include dedicated taxes on gasoline, property, personal income, downtown parking, retail sales, and employers' payrolls. The final alternative involves a transit fare increase. The basic question posed in the analysis is the following: What would be the net economic impact of a $1 million increase in transit operating assistance generated by each of the financing options, and how would this impact be distributed across the sectors of the local economy? The net impact is defined as the difference between the direct, indirect, and induced gains associated with the change in transit operating expenditures and the losses stemming from the reduction in expenditures that results from financing the subsidy.

The analysis pertains to the Portland tricounty metropolitan area and conditions as they existed in 1984. The U.S. Forest Service IMPLAN model is used to estimate the direct, indirect, and induced impacts of the financing alternatives. This model is derived from the 1977 national input-output model and utilizes a conventional nonsurvey coefficient adjustment procedure to permit analysis at the county and multicounty level. The model was aggregated to 25 sectors for this study, and includes an endogenous household sector.

The framework used in the analysis is partial in that it does not deal with a number of elements that would be contained in a comprehensive study of the costs and benefits of transit service. For example, the organization of the transit system is taken as given, and no effort is made to assess the structure of service delivery or the outlays made by a transit agency in providing service. Second, it is assumed that the input factor prices faced by transit providers are unaffected by subsidies, and thus factor payments are characterized by fixed coefficients. Third, equity-related issues associated with the distribution of costs and benefits with respect to income, space, and time are not considered. Fourth, costs and benefits to transit users (e.g., safety, convenience, cost, and travel time) and nonusers (e.g., congestion relief, air quality, and safety) are also ignored, although in the final section the threshold values that external transit benefits must achieve to generate a potential Pareto improvement are estimated.

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Studies addressing the preceding elements indicate that each would have a bearing on the outcome of a comprehensive analysis of transit service, and thus it is important to keep the limitations of the assumptions in mind. The evidence related to the organization of transit service *(2)*; the effects of subsidies on operating costs and factor prices *(1, 3–5)*; the equity impacts related to income *(6–8)*, space *(9)*, and time *(10)*; and, finally, externalities *(11)* suggest that the results presented in this paper represent only one of a number of criteria against which transit subsidies should be evaluated.

The remainder of the paper is organized as follows. In the next section the methodological framework for the analysis and the approach used to determine the net direct impacts of the alternative financing options are described. The net direct, indirect, and induced changes in sectoral output and household income associated with each of the alternatives are then presented. Finally, the rationale for providing transit operating subsidies in light of the results is explained.

METHODOLOGY

The framework for estimating the economic impacts of the transit financing alternatives can be traced to Metzler *(12)*, who first addressed the issue of taxes and subsides in input-output analysis. He posed the following question: Supposing one input-output sector is subsidized by the proceeds of a tax imposed on the other sectors in the system, what effect would this transfer have on aggregate economic activity and the cost of production of the taxed sectors? Metzler reasoned that if a taxed sector was an intensive user of the output of the subsidized sector, its direct losses (from paying the tax) could be offset by secondary gains in the form of lower cost inputs directly and indirectly obtained from the subsidized sector. However, he demonstrated that overall the secondary benefits derived from a subsidy could not outweigh the cost of the tax.

The approach described here differs from Metzler's in several respects. First, the taxes associated with the transit financing alternatives are, with the exception of the payroll tax and the business share of the property tax, imposed on the household sector. This sector resides in the final demand component of the model, and the direct effect of a tax would be to reduce disposable household income. In this case, the analysis must address whether the effects of the reduction of disposable income would be offset by gains from the transit provider's disposition of the subsidy. Second, Metzler's results hold for a closed input-output system, which does not characterize a typical urban economy. The present study uses an open model, and thus the results are subject to the influence of two factors not contained in Metzler's analysis: the ability of households and sectors to "export" a part of the tax burden through deductibility *(13)*, and the potential to retain a relatively large share of the direct, indirect, and induced economic activity generated by transit agency layouts versus the activity foregone by paying for the transit subsidy. The latter effect, of course, would work in the other direction if the "leakages" associated with transit outlays exceeded those associated with the foregone activity resulting from the tax.

The direct losses associated with the alternative taxes are defined in terms of the reduction in sectoral final demands that would follow the imposition of the tax. The composition of the changes in final demand varies according to the tax under consideration and corresponds to one of three general formats:

1. Reduction in Total Disposable Income. The direct effect of the property and income tax alternatives on households is to reduce their disposable income by the amount of the tax minus the value of federal and state taxes avoided as a result of deducting the transit tax from household taxable income. The value of this deduction is the portion of the tax that is exported, and is a function of the households' real marginal federal and state income tax rate. This rate is equal to the marginal nominal tax rate multiplied by the propensity to itemize *(14)*. The real reduction in household income from these taxes is then allocated across the final demand sectors on the basis of sectoral consumption propensities. These propensities are of the fixed coefficient type, and assume that the income elasticity of demand for the output of each sector is equal to 1.0.

2. General Increases in Prices. The direct effect of the payroll tax and the property tax paid by business is represented by an increase in the prices of goods and services produced in the urban economy. Price increases to final consumers are estimated using an approach suggested by Leontief and Ford *(15)*. This procedure estimates price effects through a system of standard value added equations.

$$p' = v' \cdot (I - A)^{-1}$$

where

p' = a vector index of the change in sectoral prices;
v' = a vector of the change in value added coefficients resulting from the transit tax, taking into account the deductibility of the tax from taxable corporate income at the federal and state levels; and
$(I - A)^{-1}$ = the Leontief inverse.

Given the vector of sectoral price increases, final demands can then be adjusted on the basis of sectoral price elasticities. These price elasticities were set at −1.0.

3. Selective Price Increases. The gasoline, parking, and retail sales taxes are limited to particular items consumed by households. Changes in sectoral final demands resulting from the gasoline and parking taxes were based on price elasticities reported by Dahl *(16)* and Pickrell and Shoup *(17)*. A price elasticity of −1.0 was applied to goods subject to the sales tax.

The direct losses associated with a fare increase are represented by the change in final demand resulting from the reduction in real household income of transit users faced with higher travel costs. For travelers whose demand for transit declines on the basis of the fare elasticity *(18)*, the change in travel cost (assuming that these riders switched to automobiles) was estimated and allocated to the final demand sectors.

The direct gains from the financing alternatives are represented by the transit agency's disposition of the subsidy in the form of operating outlays for goods and services. The sectoral distribution of these outlays was determined by allocating the itemized operating expenditures reported in the agency's fiscal 1984 budget *(19)*. Outlays for labor and material were distinguished, with labor expenditures treated as an increase in household income and expenditures for materials allocated to the appropriate final demand sectors. Corresponding with the partial export of the tax burden is a leakage of operating outlays associated with several fringe benefits (F.I.C.A. and unemployment insurance), in addition to taxes paid by transit employees.

The net value of the direct impacts is finally determined by taking the difference between the increases and decreases in sectoral final demands that follow from each of the financing alternatives. The major methodological steps involved in determining the final demand changes are discussed in the following paragraphs.

Gasoline Tax

Reported gasoline sales in 1984 in the three counties of the study area totaled 482,368,600 gallons at an average pump price of $1.22. Using a price elasticity of –0.2 *(16)*, a tax rate of 0.0017 would be required to generate $1 million in revenues. The direct impact of this tax would include losses to sectors producing and selling gasoline, sectors producing and selling related products, and households.

The reduction in demand for gasoline resulting from the tax was estimated to total 164,000 gallons, equivalent to approximately $200,000 in retail sales. Because the input-output model is specified in producer prices, this value must be partitioned to allocate the sales margin to wholesalers and retailers, and the remainder to the original producing sector. A retail-wholesale margin of 0.21, a composite average *(20)*, was adopted. Reductions of $42,000 and $158,000 for retailers and producers, respectively, were derived.

The reduction in gasoline consumption in turn triggers a reduction in the direct demand for other products consumed in the operation of automobiles: repairs and maintenance, tires, oil, accessories, and expenditures for parking and tolls. The outlays for these items were derived from FHWA data *(21)* covering the operating cost per mile of an intermediate-sized automobile. The reduction in gasoline consumption was converted to a reduction in total miles traveled using an estimate of average efficiency of 13.8 mpg. The corresponding reduction in outlays for the items noted previously totaled $142,000. The itemized outlays comprising this total were allocated to the appropriate final demand sectors.

The cost to households from the gasoline tax was defined to equal the real cost of the tax minus the savings from the reduction in travel cost. The real cost of the tax equals the nominal tax minus the proportion exported as a result of deductibility. This proportion was set at 0.166 *(14, 22)*, resulting in a real tax cost of $834,000. The savings to households from reduced travel comprises avoided outlays for gasoline and other operating expenses, with the value of tax deductibility netted from the price of gasoline. Travel cost savings totaled $338,000, leaving a net direct cost to households of $496,000. This cost was allocated to final demand using the household sectoral consumption coefficients contained in the input-output model. The sum total of the direct cost to all parties was $838,268.

Property Tax

Because assessment records from the three counties reveal that residential property accounts for 66 percent and commercial and industrial property 34 percent of the total nonagricultural assessed valuation, the tax liabilities required to generate $1 million were apportioned accordingly.

The impact of the property tax on households is again lessened by the effect of deductibility, resulting in a real tax cost of $550,000. The commercial and industrial tax burdens are also reduced by deductibility. Data on 1984 corporate filings provided by the State Legislative Revenue Office revealed that 0.502 of this total is exported from the metropolitan area, leaving a real direct tax cost of $169,000. This total was allocated to the commercial and industrial sectors of the input-output model on the basis of their relative capital intensities *(23)*. The changes in the sectoral value added coefficients resulting from the real tax costs were then determined. The corresponding effect on sectoral prices was then estimated according to Leontief and Ford's method *(15)*.

The value of total final demand—by households, government, capital formation, and exports—sums to approximately $13 billion in the input-output model. Using a price elasticity of –1.0, reductions in sectoral final demands corresponding to the sector-specific price increases were determined. The change in the value of total final demand resulting from the sectoral price increases totaled $283,000. The sum total effect of the property tax was estimated to be $833,781.

Personal Income Tax

The impact of the personal income tax on households was determined by netting out the fraction exported due to deductibility. This decrease left $834,000, which was allocated to the final demand sectors using the model's household consumption coefficients.

Parking Tax

The Portland central business district contains approximately 21,200 off-street parking spaces, and in 1984 they generated nearly $16.5 million in revenue. Assuming a price elasticity of –0.3 *(17)*, it was determined that a tax cost of the parking tax includes both a reduction in parking revenues and an increase in parking costs. The reduction in parking revenues totaled $300,000. The increase in parking costs is equal to the real tax cost minus the value of the reduction in the demand for parking, or $534,000. This cost was allocated to final demand on the basis of the household sectoral consumption coefficients, whereas the loss in parking revenues was absorbed by the service sector. The total cost of the tax was $834,000.

Retail Sales Tax

The sales tax was defined to apply to all retail expenditures with the exception of food purchased for home consumption, medicine, and drugs. The Consumer Expenditure Survey (CES) of 1972–1973 *(24)* offers the only source covering household consumption patterns that is sufficiently disaggregated to permit estimation of the direct effect of a sales tax with these exemptions. CES data for the Western Region were used to allocate the real tax burden to the appropriate expenditure categories, and reductions in expenditures were calculated using a price elasticity of −1.0. The changes in expenditures were then allocated to the appropriate final demand sectors. Considering again the effects of deductibility, the direct impact of the sales tax on household disposable income was $834,000.

Payroll Tax

The payroll tax was defined to apply to wage and salary payments made by firms to individuals employed in nonagricultural and nonpublic activities. Considering deductibility, the direct impact of this tax totaled $498,000. This cost was allocated on the basis of the sectoral distribution of wage and salary payments in the input-output model. Changes in sectoral value added coefficients were then determined, and the corresponding changes in sectoral prices were estimated. Changes in the value of final demand resulting from the increase in prices were recovered in the same manner as described for the business property tax. The change in the value of final demand was calculated to be $961,567.

Fare Increase

Data supplied by TRI-MET show that in 1984 the system served 36.8 million originating riders at an average fare of $0.49, generating farebox revenues of approximately $18 million. Assuming a fare elasticity of −0.29 *(18)*, a fare increase of slightly more than 8 percent would be required to increase fare revenues by $1 million. This increase would also lead to a reduction of 863,000 originating riders.

The direct impact of the fare increase would be threefold: (a) higher costs for users of the transit system; (b) higher costs for riders who leave the system; and (c) an increase in sales corresponding to an increase in automobile travel.

The increase in travel cost for transit users following the fare increase was estimated to be $1,424,700. It was assumed that riders who left the system would still undertake the same number of trips and would travel by automobile. The increase in travel cost for this group was defined to be the difference between automobile operating costs and the amount that had originally been paid for transit, or

$$(T \cdot 1/vo \cdot D \cdot C) - F$$

where

T = the number of trips diverted from transit as a result of the fare increase;
vo = the vehicle occupancy rate;
D = the average trip length;
C = automobile operating costs per mile; and
F = the average transit fare before fare increase.

Data for 1984 provided by the Metropolitan Service District, the agency responsible for transportation planning in the Portland metropolitan area, show an average vehicle occupancy of 1.4 persons and an average trip length of 6.5 mi. The FHWA data on vehicle operating costs per mile for an intermediate-sized automobile (excluding the cost of insurance) were used. Adjustments were made for the deductibility of gasoline taxes, giving an operating cost of $0.109/mi. The net increase in travel cost was found to equal $13,900, giving a total increase in travel cost for transit users and former users of $1,438,600. This value represents a reduction in household disposable income and was allocated to final demand using the model's household sectoral consumption coefficients.

The decline in total household outlays is partly offset by an increase in sales associated with greater automobile use. The vehicle operating expenditures noted previously, which equaled $437,000, were allocated to the sectors associated with automobile maintenance and repair, tires, accessories, fuel, oil, and parking. The combined effect of the reduction in household disposable income and the increase in sales serving vehicle operation gave a total of $1,001,601 as the direct impact of the fare increase on final demand.

TRI-MET Expenditures

With an operating budget augmented by a local subsidy of $1 million, transit agency outlays are assumed to expand in accordance with the pattern that existed in the fiscal 1984 budget. The expenditures for goods and services total less than $1 million, however, because payments made by the agency for social security and unemployment insurance, and taxes paid by transit employees, do not qualify as disposable expenditures in the input-output model. These items amount to 4.3, 1.1, and 15.8 percent, respectively, of total operating outlays. After accounting for these leakages, the $788,500 that remains represents the direct outlays made by the agency. Of this total, $461,200 represents an increase in transit employee disposable income, and this value was allocated to final demand using the household sectoral consumption coefficients. The remaining $327,300 in outlays for goods and services consumed for transit operations was itemized and allocated to the appropriate input-output sectors.

Table 1 presents a summary of the total final demand changes associated with the seven transit financing alternatives along with the increase in transit operating outlays. In all cases, the reduction in final demand associated with providing the operating subsidy exceeds the increase associated with transit operating outlays. The difference is noticeably larger for the payroll tax and fare increase than it is for the other alternatives. The total effects of these changes and their distributional consequences are reported in the next section.

TABLE 1 TOTAL FINAL DEMAND CHANGES

Financing Alternative	Amount ($)	Financing Alternative	Amount ($)
TRI-MET	+788,500	Parking tax	−834,000
Gasoline tax	−838,268	Sales tax	−834,000
Property tax	−833,781	Payroll tax	−961,567
Income tax	−834,000	Fare increase	−1,001,601

RESULTS

The net change in sectoral final demands associated with the alternative transit financing schemes is given in Table 2. The value of total final demand declines for each alternative, and the sectoral distribution of the reduction varies according to the type of tax under consideration. Despite the aggregate declines, net increases in final demand are observed in a number of sectors for each financing alternative.

The distributional impacts of the financing alternatives on sectoral final demands are consistent with what might be expected. A gasoline tax leads to reductions largely concentrated in the petroleum, transportation equipment, and trade sectors, with gains concentrated in finance, insurance, and real estate (FIRE); electrical equipment; transportation, communications, and utilities (TCU); and service sectors due to their relative emphasis in the transit operating budget. The reductions associated with the property tax are attributable to either the capital intensity of a given sector or a sector's relative importance to household consumption. As a result, reductions are concentrated in the trade, service, food products, and FIRE sectors. The largest gains from the property tax are observed for the petroleum products, electrical equipment, and pulp and paper sectors, reflecting their relative importance in the transit operating budget. For the income tax, the major changes in sectoral final demands reflect the relative importance of each sector to households as compared to transit. The largest losses are observed in the trade, services, and food products sectors, while the largest gains are realized in the petroleum, electrical equipment, and TCU sectors. Losses from the parking tax are highly concentrated in the service sector, which includes parking services, whereas the sectoral gains again are attributable to the relative emphasis of transit operating expenditures. The most noteworthy change associated with the sales tax is an increase in trade sector activity, where losses from the tax are more than offset by transit operating expenditures. The largest losses observed for the sales tax are in those sectors supplying goods and services subject to the tax: food and kindred products (as related to food consumed away from home, tobacco, and alcohol); textiles and apparel; transportation equipment; TCU; wood products (i.e., furniture and fixtures); and services. The largest increases are in FIRE (not taxed), petroleum, and electrical equipment. The direct impact of the payroll tax falls disproportionately on labor-intensive sectors, such as trade and construction, whereas gains are observed for sectors that are either not subject to the tax (e.g., agriculture, the public utilities, and local government enterprises) or are relatively capital intensive (e.g., electric services and petroleum). Losses from the fare increase primarily reflect the relative importance of the affected sectors to household consumption: services, FIRE, trade, and food products. The gains are attributable to sectors with an emphasis on servicing transit and automobile transport: petroleum, transportation equipment, electrical equipment, and rubber products.

In Table 2, the sectoral distribution of the direct impacts of the alternative transit financing options varies considerably, even among those alternatives for which the total net change is roughly the same. With this variance, noticeable differences in the magnitude of the indirect and induced effects, given the range in the value of the input-output model's sectoral multipliers, can be anticipated.

Table 3 presents the direct, indirect, and induced changes in net output resulting from the alternative financing options. The range of total impacts is considerable—from a net reduction of

TABLE 2 NET CHANGE IN FINAL DEMAND FOR ALTERNATIVE FINANCING SCENARIOS

Sector	Gasoline Tax ($)	Property Tax ($)	Income Tax ($)	Parking Tax ($)	Sales Tax ($)	Payroll Tax ($)	Fare Increase ($)
Agriculture/forestry/fisheries	−295	−822	−3,235	−625	−7,908	3,628	−8,495
Mining and quarrying	0	−5	0	0	0	−451	0
Contract construction	0	−8,500	0	0	0	−46,100	0
Food and kindred products	−2,678	−11,135	−28,194	5,544	−102,503	−17,453	−73,840
Textiles and apparel	824	6	−3,772	308	−158,646	5,273	−11,995
Wood products	253	−3,025	−3,058	−568	−17,903	−4,866	−8,076
Pulp and paper products	7,287	3,880	4,515	6,975	5,434	734	−442
Petroleum and chemical products	−105,564	53,605	49,966	54,286	61,976	61,022	191,704
Rubber and leather products	1,192	10,403	10,094	10,604	11,512	10,810	25,843
Stone, clay and glass products	−3	−114	−273	−33	394	158	−757
Primary and fabricated metal products	1,097	−5,504	285	1,005	−9,472	−28,473	−1,166
Machinery	−52	−2,621	−357	−87	−16,536	−17,066	−901
Electrical equipment and instruments	34,964	30,017	32,192	34,652	39,031	9,741	27,235
Transportation equipment	−84,332	−4,434	−7,005	−1,365	−106,418	−7,706	129,864
Miscellaneous manufactured products	−121	−399	−1,439	−269	1,814	1,068	−3,796
TCU	34,590	−4,620	15,394	32,434	−39,997	−165	−18,946
Electrical services	6,544	2,277	−654	5,736	17,110	15,484	−13,532
Wholesale-retail trade	−47,251	−75,891	−55,892	11,608	2,321	−206,842	−108,067
FIRE	78,566	−10,714	−3,931	69,299	198,480	−21,652	−151,509
Services	24,656	−17,232	−42,682	−264,022	−17,745	21,693	−163,534
Local government enterprises	1,393	533	−3,406	854	8,437	8,172	−11,991
Federal electric utilities	−52	−141	−357	−87	394	324	−901
State and local electric utilities	−119	−302	−1,166	−236	1,419	1,382	−3,041
Scrap	−77	−224	−990	−180	1,262	1,262	−2,622
Households	−83	−317	−1,535	−246	2,050	2,050	−4,136
Total	−49,768	−45,281	−45,500	−45,500	−45,500	−173,067	−213,101

TABLE 3 NET CHANGE IN SECTORAL OUTPUT FOR ALTERNATIVE FINANCING SCENARIOS

Sector	Gasoline Tax ($)	Property Tax ($)	Income Tax ($)	Parking Tax ($)	Sales Tax ($)	Payroll Tax ($)	Fare Increase ($)
Agriculture/forestry/fisheries	−731	−3,483	−8,035	−4,081	−23,148	2,453	22,528
Mining and quarrying	−135	8	35	72	37	−607	141
Contract construction	4,131	−10,051	−1,533	942	11,676	−49,060	−15,365
Food and kindred products	−3,152	−15,480	−35,797	−22,203	−119,623	13,642	−98,673
Textiles and apparel	787	−122	−5,220	−323	−210,412	6,315	−16,488
Wood products	−3,047	−5,282	−4,767	−957	−29,369	−13,074	−9,615
Pulp and paper products	6,615	2,838	2,688	5,580	−188	−4,618	−10,273
Petroleum and chemical products	118,733	60,019	55,848	60,085	64,475	65,152	212,368
Rubber and leather products	681	10,831	10,357	10,581	10,266	10,738	26,574
Stone, clay, and glass products	−1,246	−411	−553	−128	−1,517	−1,851	−938
Primary and fabricated metal products	−9,157	−6,914	−502	1,340	−29,349	−40,399	10,673
Machinery	−2,139	−2,774	−363	−615	−20,582	−19,497	1,900
Electrical equipment and instruments	36,844	32,247	34,641	35,365	39,935	8,223	29,573
Transportation equipment	−89,567	−5,688	−8,659	−6,166	−114,492	−10,061	133,379
Miscellaneous manufactured products	−199	−533	−1,618	−753	1,432	608	−4,472
TCU	−32,550	−9,058	13,043	29,120	35,792	−15,199	−36,930
Electrical services	5,337	792	−2,577	3,289	16,019	11,403	−20,701
Wholesale-retail trade	−54,039	−84,606	−64,944	−7,301	−26,839	−234,510	−136,675
FIRE	−85,513	−25,303	−17,353	49,135	210,099	−62,509	−221,995
Services	21,894	−31,707	−56,389	−295,104	−29,432	−22,870	−221,285
Local government enterprises	1,718	−557	−4,403	−937	8,791	5,117	−17,111
Federal electric utilities	−110	−193	−429	−178	345	176	−1,163
State and local electric utilities	−262	−485	−1,394	−563	1,255	867	−3,898
Scrap	−341	−401	−1,012	−267	275	4	−2,512
Total	−86,789	−96,314	−98,938	−144,785	−204,554	−349,555	−426,017
Household income	−14,660	−45,342	−42,297	−85,247	−68,761	−139,166	−160,480
Percent of total net change	16.9	47.1	42.8	58.9	33.6	39.8	37.7
Multiplier	1.744	2.127	2.174	3.182	4.496	2.020	1.999

$87,000 associated with the gasoline tax to a loss of $426,000 following a fare increase. More interestingly, for the five alternatives whose direct impacts were of similar magnitude—the gasoline, property, income, parking, and sales taxes—a sizeable range is now observed in the total effects. For two of these alternatives (parking and sales), the indirect and induced effects are noticeably greater than the others. This difference suggests that the relative sectoral distributions of the direct tax costs are of some importance apart from their relative total magnitudes.

The sectoral distribution of net gains and losses in total output roughly corresponds to the distribution of final demands, and so a full description of the relative sectoral changes in output would be repetitious. The relative distribution of sectoral final demand changes is important, however, in terms of the relationship between the sectoral concentrations of the direct changes and the corresponding values of the sectoral multipliers. To the extent that the direct changes are concentrated in sectors with large (small) multipliers, the total output impacts will be amplified (dampened). For example, the direct losses associated with the gasoline tax are heavily concentrated in the petroleum and FIRE sectors, whose multipliers are among the smallest in the model. The direct gains from the gasoline tax are concentrated in the electrical equipment, services, and pulp and paper sectors, whose multipliers are relatively large. Thus, the net indirect and induced losses stemming from the gasoline tax are the smallest of all the financing alternatives, absolutely and after accounting for differences in the total value of the direct effects. For the parking and sales taxes, with aggregate direct impacts comparable to the gasoline tax, the situation is reversed, with direct losses concentrated in sectors with large multipliers (services, food products, transportation equipment, textiles, and apparel), and direct gains concentrated in sectors with small multipliers (FIRE and petroleum products).

The direct, indirect, and induced multipliers presented across the bottom row of Table 3 reflect these distributional differences. The multiplier effects of the gasoline, property, and income taxes are substantially lower than those for the parking and sales taxes. The payroll tax and fare increase multipliers are also relatively small, but because the direct impacts of these alternatives are much larger than the others their total output effects remain the largest.

The changes in household income, which are a component of the change in total output, range in rough order of magnitude with total output. Some variation in their share of total output change is, however, evident. Generally, if the changes in total output are concentrated in capital-intensive (labor-intensive) sectors, the share of household income in the total change is lower (higher). For example, the reduction in output associated with the gasoline tax is concentrated in the petroleum, FIRE, transportation equipment, and TCU sectors, all relatively capital intensive. The reduction associated with the parking tax is concentrated in the service sector, which is relatively labor intensive.

CONCLUSIONS

The input-output analysis reveals a considerable variation in economic impacts across the seven financing alternatives. Although the net change in total sectoral output is negative for all the alternatives—from −$87,000 for the gasoline tax to −$426,000 for the fare increase—the range is substantial. This variation results from two general influences. The first, which is evident in Table 2, is primarily associated with variations in the deductibility of the transit tax from personal and corporate income tax liabilities. The second, which is evident in Table 3, is associated with differences in the sectoral multipliers. Variation in these multipliers, in turn, is partly due to the degree to which direct and indirect economic activity includes local production. In effect, part of the transit tax liability is indirectly exported to producers outside the region whose outputs are imported by local producers. This fact largely explains why the gasoline tax fared relatively well, because gasoline is retailed, but not produced, in the region.

One way of interpreting these findings is to return to the assumptions imposed in the introduction and provide a rationale for relaxing them, thereby extending the scope of conditions pertaining to the results.

Until now it has been assumed that the level of transit service has been fixed. This assumption is now relaxed, and a simple situation may be defined that presumes a direct relationship between operating outlays, service levels, and ridership. Thus, a marginal increase in operating outlays is presumed to generate a corresponding increase in transit use. With respect to the 1984 budget, a $1 million transit subsidy would represent a 1.5 percent increase in operating outlays, and if service and ridership were to increase correspondingly 554,000 new originating riders would result. Dividing the changes in total output for the different financing alternatives obtained from the input-output analysis by the number of new riders yields what can be termed the net deficit per originating rider. This value represents a benchmark against which external transit benefits, which have been ignored until now, can be evaluated. To the extent that benefits can be shown to exceed this value, a potential Pareto improvement, characterized as a situation where with costless transfers everyone is at least as well off as before, is achieved. The benchmark values for the transit benefits required to achieve this outcome for the situation outlined previously are presented in Table 4. These values range from approximately 16 cents per originating rider under the gasoline tax to 79 cents per rider under the fare increase.

TABLE 4 TRANSIT BENEFIT REQUIRED TO ACHIEVE A POTENTIAL PARETO IMPROVEMENT

Financing Alternative	Benefit Required Per Originating Rider ($)	Financing Alternative	Benefit Required Per Originating Rider ($)
Gasoline tax	0.157	Sales tax	0.369
Property tax	0.174	Payroll tax	0.631
Income tax	0.179	Fare increase	0.786
Parking tax	0.261		

Studies of the transmission of operating subsidies suggest less than a full correspondence between changes in subsidies and changes in user benefits, however. In the leakage model *(4)*, the injection of a subsidy in a transit system will generate factor price inflation, productivity declines, and service utilization declines, all of which detract from the benefits users ultimately witness in the form of lower fares or new transit trips. Lee reports leakage estimates of 77 percent resulting from federal operating subsidies *(4)*.

The implications of the leakage hypothesis for the benchmark values presented in Table 4 are evident. These values represent thresholds assuming no leakage, and to the extent that leakages are present, the appropriate values would be greater. If a 75 percent leakage rate is applied, for example, the corresponding threshold values associated with the financing alternatives would be four times greater than those presented in Table 4. The relative positions of the financing alternatives would not be influenced by leakages. But it is likely that with increases in the leakage rate fewer financing options would tend to satisfy the optimality conditions discussed previously.

A primary objective of this paper has been to examine the disaggregate impacts of local alternatives for financing transit. Input-output analysis provides a means for achieving this end. But the framework has also precluded addressing some important questions associated with tax incidence, administration, and implementation. In particular, the distribution of the impacts on total household income will vary with the level of income. Rock, for example, has examined the relative incidence of several of the alternatives studied here and found (in descending order) the fare increase, gasoline, and sales taxes to be regressive, and the parking tax to be progressive *(8)*. In terms of factors associated with the administration of the tax, a survey of transit systems conducted by Walther revealed that the stability of the revenue stream provided by a financing program was a principal concern in terms of facilitating long-term planning *(25)*. Finally, with respect to the design and implementation of transit financing programs Jones notes that political expediency has often taken precedence over normative criteria, and he concludes that "many would question whether the political process is capable of the disciplined craftsmanship necessary to devise a program of appropriate design" *(2)*.

That these issues have not been addressed in this paper is not an indication of an assessment of their unimportance. Rather, in a limited way, the results are intended to contribute to the economic, social, and political craftsmanship needed in forging new transit financing programs.

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Benefit Analysis for Sketch Planning of Highway Improvements

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A streamlined procedure for evaluating the user benefit from highway improvements was demonstrated. The focus of the procedure was on roadway improvements that included changes in intersection design for the reduction of travel delay. The procedure was synthesized from existing literature primarily for sketch planning analysis; however, its application at more detailed levels of analysis is also appropriate. The procedure simplifies and improves previous methods of estimating the benefit from intersection improvements through the application of delay estimation techniques. A variety of policy and design alternatives can be easily evaluated. Estimation of the benefit derived from upgrading a two-lane roadway to a four-lane cross section with appropriate improvements in the intersection design was used as a case study. Given assumptions regarding the intersection design for the base and the improved condition, and an assumed average daily traffic increasing from 15,000 vehicles in Year 1 to 26,300 vehicles in Year 20, the benefit-cost ratio of the upgrade was estimated to be between 3.6 and 4.5. Ninety-six percent of the benefit originated in the reduction in travel time resulting from adding a lane to each intersection approach.

The objectives of this study were to synthesize a quick-response procedure for evaluating the potential benefit attributable to roadway improvements at the sketch planning level, and to demonstrate the use of the procedure with a generic example. Decision makers and the public generally demand the exhibition of benefit-cost ratios in excess of 1.0 before the acceptance of roadway improvement plans. Local transportation officials are often required to demonstrate the general benefit associated with a class of projects before gaining acceptance for the inclusion of these projects in the regional transportation plan. It is also valuable to know the conditions under which improvement becomes economically viable so that implementation can be made with the proper timing.

This evaluation technique was intended as a guide for planning and decision making. The approach was designed to present a conservative estimate of benefit. The result can be considered the potential minimum attributable to the general class of roadway improvements described.

The procedure and its application were developed in response to a request from the Pima County Department of Transportation in Tucson, Arizona, in support of long-range planning activities.

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ESTIMATION OF ROADWAY IMPROVEMENT BENEFITS

Procedures for the calculation of road user benefits are well documented in the *AASHTO Manual on User Benefit Analysis of Highway and Bus Transit Improvements (1)* and its parent document NCHRP Report 133 *(2)*. The basic methods described in these reports are sound. However, these procedures base the calculation of benefits on highway user cost curves that were developed in the late 1960s, and on estimates of delay based on volume-capacity (v/c) ratios derived from the 1965 version of the *Highway Capacity Manual* (HCM) *(3)*. The vehicle running cost and speed curves presented in the AASHTO Manual and NCHRP Report 133 are also based on v/c ratios derived using procedures from the 1965 HCM.

Using the 1965 HCM, the estimate of intersection delay can be seriously in error. This error is primarily a result of an approach v/c ratio calculation that fails to consider the differential demand for lane utilization (specifically with regard to exclusive turn lanes), which normally exists at an intersection. Where lane demand is not distributed in a manner similar to lane capacity, for example, where turning movements are relatively low, the approach v/c ratio and delay do not equal the corresponding lane v/c ratio and delay. Hence, it is inappropriate to evaluate intersection delay using the v/c ratio for the entire approach. A cursory evaluation of the case study described in this paper using the 1965 HCM procedures revealed virtually no benefit from improvement because the approach v/c ratios were too low for the base condition. This lack occurred even though the predominant lane demand far exceeded lane capacity. The benefit calculation procedures presented in the AASHTO Manual are also needlessly detailed for sketch planning application.

A flow chart describing the basic elements of the procedure is given in Figure 1. The procedure follows the methods described in the AASHTO Manual and NCHRP Report 133, except that the changes in vehicle travel time and vehicle operating cost were based on the 1985 HCM *(4)* and other reports *(5, 6)*. The procedure is relatively streamlined, produces rational results, can be applied manually in a reasonable amount of time, and can easily be adapted for computer applications. The following section details the elements of Figure 1 through a case study.

Existing and Improved Roadway and Traffic Conditions

The initial phase of the evaluation procedure is the definition of

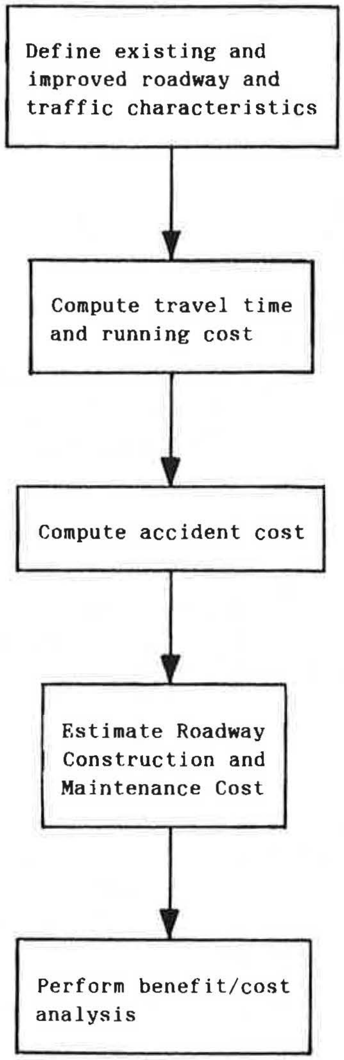

FIGURE 1 Procedural steps for benefit-cost analysis.

characteristics of the existing and improved roadway. The general improvement type considered in this analysis is the upgrade of a (one-way) two-lane cross section to a four-lane roadway with commensurate intersection improvements.

The primary characteristics of the two- and four-lane roadways assumed for the case study were as follows:

- 12-ft lanes with adequate improved shoulders;
- Straight, level tangent section (no horizontal or vertical curves);
- 1 mi in length;
- Major intersections separated by at least 1 mi;
- Signalized major intersections; and
- Uninterrupted flow between major intersections.

The intersection approaches of the two-lane roadway were assumed to consist of one through lane and one exclusive left- or right-turn lane. The intersection approaches of the four-lane improved roadway were assumed to consist of two through lanes and exclusive left- and right-turn lanes. The assumption that the roadway was straight and level was conservative in that this would yield less benefit than an analysis that included alignment improvements.

Intersection signalization for both the two- and four-lane roadway was assumed to have the following characteristics:

- 60-sec cycle length;
- Green-to-cycle time ratio of 0.5; and
- Two-phase signalization (i.e., no exclusive turn phases).

The signalization assumptions represented simplifications designed to reduce the number of computations that were required in the delay calculation. These assumptions also were conservative in that a longer cycle length would have increased the average intersection delay on the two-lane roadway more than on the four-lane. The two-phase signal assumption facilitated intersection capacity calculations, and was a conservative assumption in that protected turn phases generally increase average delay if the through movement dominates.

For this study, both the existing and improved roadway were assumed to have an initial average daily traffic (ADT) of 15,000 vehicles per day. This volume represented a situation where the intersection approaches of the roadway would be nearing capacity.

Review of available data indicated that in general the Pima County roadways have been experiencing between 4 and 5 percent annual traffic growth rate over the past 5 years. It was doubtful that this rate of growth would continue for the next 20 years, and, therefore, 4 to 5 percent was viewed as the upper limit of actual annual growth for this study. The hypothesized growth rate was taken as a uniform 3 percent per year for the 20-year analysis period, resulting in a final ADT value of 26,300 vehicles per day.

Review of available data also indicated that approximately 9 percent of the ADT occurred during the peak hours of the day on Pima County roads and that a 60/40 directional split of traffic in the peak hours was a reasonable approximation. For Year 1, this condition resulted in a peak-hour demand of 810 vehicles per hour (vph) and 540 vph in the peak and off-peak directions, respectively. Corresponding values were 1,420 and 947 vph for Year 20.

The temporal distribution of traffic volume could be modeled effectively assuming that the ADT occurred over an 18-hr day consisting of 2 peak hours and 16 off-peak hours. This assumption was made to facilitate computational procedures, and in recognition of the extremely low traffic volumes that occur during the remaining 6 hr of the 24-hr day. Off-peak traffic volumes were assumed uniform throughout the day with a 50/50 directional split. This assumption resulted in directional demands of 390 and 684 vph for off-peak hours in Years 1 and 20, respectively. The model consisted of 618 peak hours and 5,952 off-peak hours per year, when adjusted for weekend days and holidays, which were assumed to contain 1 peak hour of traffic and 17 nonpeak hours each.

Traffic flow was assumed to consist only of passenger cars. This assumption was made to facilitate capacity and delay computations, and it ultimately generated a conservative estimate of user benefits, because the presence of trucks in the traffic stream reduces intersection capacity and increases delay per vehicle. These changes would result in a more detrimental scenario for the base condition and in more benefit being attributed to the improved roadway. Also, because a higher value for travel time is generally associated with truck travel, a unit reduction in delay would be worth more.

Turning movements were assumed to be 10 percent of the approach volume for both right and left turns. This assumption was deemed adequate for sketch planning analysis.

The assumptions regarding ADT, the directional distribution of traffic, and the percentage of traffic during the peak hours were such that the traffic during the peak hour on the two-lane roadway reached the intersection capacity in the ninth year of the analysis period. The assumption regarding the temporal distribution of demand beyond the ninth year was critical to the analysis. An assumption that the directional distribution would change once the intersection reached capacity would have been unrealistic, and would have biased the result in favor of the base condition. Assuming that traffic was diverted away from the intersection would have implied that adjacent facilities were available, and argued for a systems analysis of the problem. The point of this analysis was to determine the benefit of an isolated improvement under the assumption that the demand would increase as hypothesized. Therefore, it was assumed that traffic volumes would continue to grow under the initial hypothesis, resulting in significant queuing and increase in delay in both the peak and off-peak hours for the base condition.

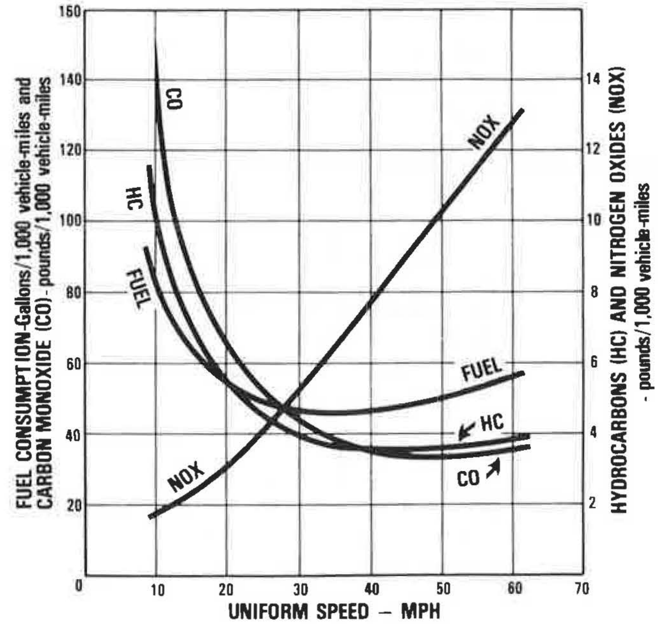

FIGURE 2 Fuel consumption and emissions of carbon monoxide, hydrocarbons, and nitrogen oxides from driving 1,000 mi at various uniform speeds (for light-duty vehicles) *(5)*.

Travel Time and Running Costs

Vehicle travel time and running costs were determined following the steps outlined in Table 1. The analysis was performed for the peak and off-peak hours, with the peak hour analysis being directional. The average approach speed was determined based on the demand volumes using the 1985 HCM procedures for two-lane and multilane roadways. The base and improved condition design speeds were 50 and 60 mph, respectively. This assumption was required to estimate travel speeds on the roadway.

The running cost factor at constant speed was determined using the fuel consumption curve shown in Figure 2, taken from a report by Dale *(5)*. The fuel consumption rate taken from Figure 2 multiplied by the cost per gallon of fuel ($1.00 for purposes of this study) represented the cost of fuel per 1,000 veh-mi of travel. This was factored to represent the total running cost of vehicle operation at a constant speed based on the proportion of the total that was the cost of fuel. The AASHTO Manual indicates the following equation can be used to update the running cost curves presented in that document:

$$M = 0.28(CF) + 0.01(CO) + 0.05(CT) + 0.27(CM) + 0.39(CA) \quad (1)$$

where

M = updating multiplier;
CF = ratio of the 1985 to 1970 consumer price index for private transportation, gasoline, regular and premium;

TABLE 1 TRAVEL PARAMETERS FOR TWO-LANE ROADWAY, YEAR 1

	Peak Period		
	Peak Direction	Off-Peak Direction	Off-Peak Period
Average tangent speed (mph)	45	45	45
Running time at tangent speed (hr/1,000 mi)	22.2	22.2	22.2
Fuel consumption rate (gal/1,000 veh-mi)	48	48	48
Running cost factor ($/1,000 veh-mi)	123.07	123.07	123.07
Stopped time delay (hr/1,000 veh)	3.78	2.28	1.97
Total intersection delay (hr/1,000 veh)	4.91	2.96	2.56
Added cost due to delay ($/1,000 veh)	11.49	8.46	7.03
Total time (hr/1,000 veh)	27.11	25.16	24.76
Total cost ($/1,000 veh)	134.56	131.53	130.10
Annual travel (veh-mi, millions)	0.500	0.334	2.321
Annual travel time (hr, thousands)	13.57	8.40	57.47
Annual running cost ($, thousands)	67.35	43.89	302.00

CO = ratio of the 1985 to 1970 consumer price index for private transportation, motor oil, premium;
CT = ratio of the 1985 to 1970 consumer price index for private transportation, tires, new, tubeless;
CM = ratio of the 1985 to 1970 consumer price index for private transportation, automobile repairs and maintenance; and
CA = ratio of the 1985 to 1970 consumer price index for private transportation, automobiles, new.

The coefficients in Equation 1 represent the proportion of total running cost that was contributed by each element of the relationship. In 1970, the cost of fuel represented 28 percent of the total running cost of a passenger car. The consumer price indices shown in the adjoining table indicate that as a result of the differential rate of inflation for the elements of Equation 1, the cost of fuel was approximately 39 percent of the running cost in 1985.

	CPI	
Category	*1970*	*1985*
Fuel	120.0	375.8
Oil	147.1	268.3
Tires	122.4	174.0
Maintenance	147.5	359.4
Automobiles	131.2	217.5

In this table, the column elements are normalized to a value of 100.0 for the year 1967. The factor 0.39 was then applied to the fuel consumption rate from Figure 2 to determine the 1985 running cost factor for automobiles.

$$RCF = (FCR)(FC)/0.39 \qquad (2)$$

where

RCF = running cost factor (dollars per 1,000 veh-mi),
FCR = fuel consumption rate (gallons per 1,000 veh-mi) (Figure 2), and
FC = cost of fuel (dollars/gal).

The calculation of stopped time delay was based on the operational procedures described in Chapter 9 of the 1985 HCM. For this analysis, random arrival was assumed as the arrival type. The total delay per vehicle, which includes the delay due to slowing down and accelerating to the average running speed, was calculated as

$$TDPV = 1.3(SDPV) \qquad (3)$$

where $TDPV$ is total intersection delay per vehicle and $SDPV$ is stopped delay per vehicle.

The average delay per vehicle for the base and improved condition is presented in the adjoining table for the Years 1 and 20 of the analysis period.

	Peak Hours		*Off-Peak Hours*	
	Two Lanes (sec)	*Four Lanes (sec)*	*Two Lanes (sec)*	*Four Lanes (sec)*
Year 1	11.4	6.8	7.1	6.2
Year 20	461.0	13.8	50.8	6.8

As indicated, the base condition intersection breaks down, causing extensive delays during the final years of the analysis period. The peak hour condition is simulated to be so poor that the estimated average stopped delay during the off-peak hours increased from 10 to 50 sec per vehicle.

The increase in the delay in the off-peak hour resulting from queuing during the peak hour was estimated using the procedures detailed in NCHRP Report 133. The time to dissipate the queue built up during the peak period was calculated as the fraction

$$QDT = D(PHV - C)/(C - OPHV) \qquad (4)$$

where

QDT = time required to dissipate the queue (hr),
D = duration of the peak period (hr),
PHV = peak hour demand volume (vph),
C = peak hour intersection capacity (vph), and
$OPHV$ = off-peak hour demand volume (vph).

The increase in the average delay in the off-peak period was calculated using the expression

$$IOPD = (QDT/OD)(PHD - OPHD) \qquad (5)$$

where

$IOPD$ = increase in off-peak period stopped delay (sec/veh),
PHD = average peak period stopped delay (sec/veh),
$OPHD$ = average off-peak period stopped delay (sec/veh), and
OD = duration of the off-peak period (hr).

The total delay per vehicle was calculated as the additional time required to traverse the roadway section exceeding the time required at a constant running speed. The total travel time was the sum of the time at the running speed and the total intersection delay.

The added running cost due to intersection delay was assumed to be only the additional fuel cost resulting from vehicle stops, speed changes, and idling. The additional fuel consumed from stops, speed changes, and idling was determined using information presented by Dale *(5)* and Ismart *(6)*. Figure 2 represents the curves for fuel consumption and emission rates at a constant travel speed. Similar graphs were presented for the incremental emission rates due to vehicle speed changes.

Ismart *(6)* also presented a series of equations to calculate the incremental fuel consumption and emissions based on the average stopped time delay at an intersection. The following are relationships for the incremental fuel consumption due to stopping, speed changes, and idling.

1. Stopping:

$$AFC1 = [0.5497 \log (1.3SDPV) - 0.1404](TTEI)(FCR/1{,}000) \quad (6)$$

2. Speed changes:

$$AFC2 = [(TTEI)(FCR)(0.04SDPV + 0.03)]/[(3{,}600)(HPSC)] \quad (7)$$

3. Idling:

$$AFC3 = (TTEI/3{,}600)(SDPV)(0.65) \quad (8)$$

where

*AFC*1,*AFC*2,*AFC*3 = additional fuel consumption due to stops, speed changes, and idling, respectively (gal),
TTEI = total traffic entering the intersection (veh),
FCR = fuel consumption rate for speed changes *(5, 6)*, and
HPSC = time in hours for 1,000 speed changes [see Ismart *(6)*].

The total additional fuel consumption resulting from intersection delay is the sum of *AFC*1, *AFC*2, and *AFC*3. The total additional cost due to intersection delay was calculated as the additional fuel consumption factored by the price per gallon of gasoline. Equation 7 was ignored for the case in which all of the vehicles entering the intersection stopped. For speed changes, it was assumed that the average speed reduction was one-half of the average running speed. Similar equations for the incremental vehicle emissions resulting from intersection delay were also presented by Ismart *(6)*.

Costs of Accidents

The primary source of the required accident data was the Pima County Traffic Accident Statistics *(7)*. Accident statistics from July 1982 through June 1985 were reviewed for 259 two-lane and 29 four-lane Pima County roadway segments that had not been altered by construction during the time period represented by the data. The accident rates for the roadway segments were 1.48 and 1.46 accidents per million vehicle miles (MVM) for the two- and four-lane roadways, respectively.

The accident rate for intersections was determined separately. Intersections with geometrics similar to those assumed for the base and improved conditions were identified, and the accident rates were calculated and expressed as the number of accidents per million vehicles entering (MVE) the intersection. The accident rates for six intersections on two-lane roadways and four intersections on four-lane roadways were 1.46 and 1.22 accidents per MVE, respectively. These rates were assumed to remain constant throughout the duration of the analysis period. The accident rates for the roadway segment and the intersection were summed to represent a total accident rate.

The computed accident rates represent the unadjusted values for reported accidents. The property damage (PD) accident rate was increased by a factor of 2.5 to account for the incidence of unreported accidents. This increase, which assumes that only 40 percent of PD accidents were reported, is consistent with guidelines for default values given in the literature *(1, 2)*.

The accident rates were stratified by accident severity to adjust the aggregate rate for the underreporting of PD accidents. This stratification was accomplished using the data available in the Arizona Traffic Accident Summary for 1982 through 1984 *(8–10)*. The percentages of reported accidents on Pima County roads that were fatalities (F), personal injuries (PI), and property damages (PD) were determined from the data. The PD accident rate was adjusted for underreporting. These accident rates appear in Table 2.

The monetary values for accidents were based on 1984 National Safety Council estimates *(10)*. These values were adjusted upwards by 3.75 percent to represent 1985 values due to the increase in the general consumer price index from 1984 to 1985. The cost of PD accidents was adjusted further to include the cost of unreported accidents that were estimated to have a cost equal to 60 percent of the reported PD accidents based on data in the AASHTO Manual. Therefore, the costs reported in Table 2 represent the total cost per accident by severity type.

Roadway Construction and Maintenance Costs

Based on Pima County records, the recent cost of upgrading a two-lane roadway to four lanes has been between $2 and $2.5 million/mi. This cost includes earthwork, grading, structures, paving, design, the purchase of right-of-way, and construction inspection.

The annual maintenance cost of two-lane roadways has been approximately $4,100/mi. This cost includes a chip seal every 5 years, shoulder maintenance, and the upkeep of traffic control devices and pavement markings.

As a modest simplification, the average maintenance cost per year for the four-lane roadway was assumed to be $5,800/mi. Maintenance cost for a new four-lane roadway was estimated at approximately $2,200/mi per year for the first 10 years. This represents the cost of the upkeep of the roadside, traffic control devices, and pavement markings. After the first 10 years, it was assumed that the roadway would require chip sealing at 5-year intervals, increasing the annual maintenance cost to $9,400/mi for the remaining 10 years of the analysis period.

Benefit-Cost Analysis

The case study considered those road user benefits attributable to the reduction in vehicle operating cost, travel time, and accidents. The change in roadway maintenance was also considered on the benefit side of the ledger, although this is not a direct user benefit. Maintenance benefits were included in the case study to evaluate the potential impact of this on total benefit.

TABLE 2 ACCIDENT RATES AND COST OF ACCIDENTS BY ACCIDENT TYPE

	Accident Type[a]			
	F	PI	PD	Total
Unadjusted accident rate (%)	0.9	39.4	59.7	100.0
Unadjusted accident rate (MVM or MVE):				
Two-lane	0.028	1.158	1.754	2.940
Four-lane	0.026	1.056	1.600	2.680
Adjusted accident rate (%)	0.5	20.8	78.7	100.0
Adjusted accident rate (MVM or MVE):				
Two-lane	0.028	1.158	4.384	5.570
Four-lane	0.026	1.056	3.998	5.080
Adjusted cost per accident ($)	228,500	9,600	960	—

[a]F = Fatal, PI = Personal Injury, PD = Property Damage.

Benefits were computed using the consumer's surplus approach:

$$\text{Benefits} = (P0 - P1)[(V0 + V1)/2] \quad (9)$$

where

$P0$ = cost per vehicle under the existing condition,
$P1$ = cost per vehicle under the improved condition,
$V0$ = traffic volume under the existing condition, and
$V1$ = traffic volume under the improved condition.

The total value of travel time was based on an assumed value $5.00/hr. The annual running and accident costs were used to determine the average cost per vehicle. Resulting benefits for two- and four-lane roadways are presented in Table 3. A comparison of the alternatives is presented in Table 4. Average annual change in running and accident costs, highway maintenance, and value of travel time were used to compute the present worth of benefits. The present worth factors were selected based on an interest rate of 7 percent (the interest rate of the March 1986 Pima County sewer revenue bonds). The residual value of the improved condition was ignored.

The summary of the economic indices from the analysis is summarized in the following list.

Item	*Amount*
Cost and time value reductions ($, thousands)	
Year 1	
Running and accident cost	−19.33
Vehicle travel time value	59.70
Year 20	
Running and accident cost	210.59
Vehicle travel time value	2,142.00
Annual increase in benefits	
Running and accident cost	7.09
Vehicle travel time value	103.43
Present (1986) total worth of benefits	
Running and accident cost	344.76
Highway maintenance cost	−18.00
Vehicle travel time value	8,795.00
Total	9,121.76
Highway investment cost ($, thousands)	2,000.00–2,500.00
Benefit-cost ratio	4.5–3.6
Value of travel time ($/hr)	0.95–1.20

The benefit-cost ratio was between 4.5 and 3.6 for an improvement costing between $2 and $2.5 million, respectively. For the assumed demand volumes, these figures are the minimum benefit-cost ratios expected from improvements of this type, because alignment improvements and the effect of trucks on the

TABLE 3 SUMMARY OF USER COST AND TIME REDUCTIONS

	Year 1		Year 20	
	Two-Lane	Four-Lane	Two-Lane	Four-Lane
Vehicle time (hr, thousands)	136.91	121.97	648.15	219.72
Running cost ($, thousands)	715.24	745.09	1,501.20	1,318.03
Accident cost ($, thousands)	119.62	109.10	209.79	191.32
Annual traffic volume (veh, millions)	5.48	5.48	9.60	9.60
Average costs and travel time				
Vehicle time (hr/1,000 veh)	25.00	22.28	67.52	22.89
Running cost ($/1,000 veh)	130.64	136.09	156.38	137.30
Accident cost ($/1,000 veh)	21.85	19.93	21.85	19.93

TABLE 4 BENEFITS RESULTING FROM WIDENING TO FOUR-LANE ROADWAY

	Year 1	Year 20
Reduction in Unit Costs and Time		
Vehicle time (hr/1,000 veh)	2.72	44.63
Running cost ($/1,000 veh)	–5.45	19.08
Accident cost ($/1,000 veh)	1.92	1.92
Total Time and Cost Reductions		
Vehicle time (hr, thousands)	14.90	428.40
Running cost ($, thousands)	–29.84	183.16
Accident cost ($, thousands)	10.51	18.43
Value of passenger car time ($, thousands)	73.50	2,142.00

delay and on running cost calculations are ignored. The value of travel time that would result in a benefit-cost ratio of 1.0 is between $0.95/hr and $1.20/hr. This range represents the value of travel time where benefits equal costs.

Ninety-six percent of the benefits generated by the improvement are a result of the reduction in travel time. The benefits resulting from the reduction in running costs and accident costs are minor. The running cost on the improved roadway increases relative to the base condition because of the increased running speed, and traffic volumes are too low to generate appreciable benefits in running cost at the intersection. The accident rates between the base and improved condition are not significantly different, and, therefore, these benefits are not a significant portion of the total cost savings. The difference in the accident rates was consistent with that found in the literature *(1)* for the type of roadways considered.

The estimates of annual fuel consumption and vehicle emissions are presented in Table 5. The improved roadway results in a 5 percent increase in fuel consumption in Year 1 due to increased operating speed, and a 26 percent reduction in Year 20. Carbon monoxide, hydrocarbon, and nitrogen oxide emissions are estimated to increase slightly in Year 1, and to decrease by 57, 51, and 7 percent, respectively, in Year 20.

SUMMARY AND CONCLUSIONS

The recent developments in procedures for evaluating intersection capacity and delay at the operational level have significantly improved planning analysis of improvement benefits as well. The computational procedures presented in the AASHTO Manual and NCHRP Report 133 can be effectively streamlined, particularly for the evaluation of improvements that involve major intersection changes. These computational procedures can be improved significantly by use of the delay calculation procedures presented in the 1985 HCM *(4)* and the updated data by Dale *(5)*. Also, the computational procedures presented by Ismart *(6)* significantly improve the ease of calculating the changes in fuel consumption and vehicle emissions from an intersection improvement.

The delay and benefit calculations can be further simplified by ignoring the influence of trucks and by alignment improvements at the sketch planning level. However, if trucks and alignment improvements are considered to represent a significant contribution to benefits, these factors can effectively be considered using the procedures described in the 1985 HCM.

Assumptions regarding traffic signalization need not be design specific and are only required to be realistic in terms of the intersection type being evaluated. However, the benefits of improved signal timing and signal synchronization can be evaluated as well.

Other policy and design alternatives can be easily evaluated using this procedure. For example, the benefits of staggered work hours could be tested by varying the temporal distribution of the ADT. The benefits of carpooling could be evaluated by reducing the demand volume during the peak hour. As a design alternative, the benefits of replacing at-grade intersections with grade separations could also be estimated.

The evaluation procedure also provided other valuable information than the alternatives being considered. From the case study, it became clear that the use of exclusive turn lanes on the intersection approach of a two-lane highway effectively extends the capacity of the roadway to accommodate an ADT of between 15,000 and 16,000 vehicles, depending on the percent of turning movements and the temporal distribution of the demand. Exclusive turn lanes appear as an excellent intermediate improvement. At more than approximately 18,000 vehicles per day, intersection delay during the peak hour becomes extreme and extends into the off-peak period on the two-lane roadway even with the use of exclusive turn lanes.

The benefit generated by the improved roadway condition is dominated by the reduction in travel time, unless the improvement is specifically designed to reduce accidents. Running cost did not become significant for the traffic volumes assumed in this analysis. Therefore, for traffic volume and improvement conditions similar to those of the case study, benefits due to the reduction in accidents and vehicle running cost can be ignored. The change in maintenance cost was also minor, and for sketch planning evaluation this change can be ignored as well.

TABLE 5 ANNUAL FUEL CONSUMPTION AND VEHICLE EMISSIONS

	Year 1			Year 20		
	Two-Lane	Four-Lane	Difference	Two-Lane	Four-Lane	Difference
Fuel (gal, thousands)	307.3	322.5	+15.2	782.4	576.5	–205.9
Emissions						
CO (lb, thousands)	314.8	317.1	+2.3	1,386.6	590.7	–795.9
HC (lb, thousands)	28.0	28.0	0	104.7	51.4	–53.3
NO (lb, thousands)	57.5	65.7	+8.2	125.1	117.0	–8.1

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Dynamic Highway Impacts on Economic Development

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Economic development is increasingly used by state departments of transportation as a criterion in highway funding. However, past studies of the interactions between highways and development provide little or no evidence justifying the use of such a criterion. Existing techniques usually rely on cross-sectional analysis, which only determines correlations between highways and development. In this paper, a time series methodology is developed to differentiate the effects of highways on development from the effects of development on highways. This methodology, which includes both structural plot analysis and causality tests, is based on pooled time series and cross-sectional data on highway construction expenditures and county employment. The results indicate that increases in highway expenditures do not in general lead to increases in employment other than temporary increases in the year of construction. However, in the counties that are economic centers of the state, highway expenditures do have a positive long-term effect, that is, employment increases more than it would for the normal trend of the economy.

Possible economic effects of highways influence highway funding decisions either directly through stated objectives or indirectly through the political arena. For example, departments of transportation in 36 states explicitly consider regional economic development in their highway program selection *(1)*. In this paper, the question of whether highway projects have a definite and foreseeable effect on economic development, increasing the number of jobs more than would the normal trend of the economy, is studied. If highway projects lack such an effect, then in certain states some funds are being inefficiently allocated. On the other hand, if highway projects significantly affect economic development and if the aim is to stimulate the economy, more use of highway funds for economic development purposes may be justified.

Although transportation historically has had undeniable effects on economic development by opening up the frontier, some studies indicate that now that the highway system is mature additional highway improvements in transportation have little, if any, effect on economic development. Unfortunately, the existing empirical evidence when investigated with cross-sectional or input-output analysis is mixed and inconclusive. The purpose of this work is to address the causality issue more directly by using statistical time series techniques instead of wholly cross-sectional techniques.

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The analysis uses annual data on highway expenditures and employment for all 87 Minnesota counties from 1964 to 1982. Although cross-sectional data are pooled with time series data, the time series aspects of the data are analyzed. By first paneling the data, the cross-sectional element for each county is removed. Causality tests of Granger-Sims type *(2, 3)* are used to test whether highway expenditures affect employment levels and whether employment levels affect highway expenditures. Structural time series analysis supplements these causality tests by quantifying the dynamics associated with these relationships.

The evidence indicates that causality from highway expenditures to employment is weak. However, when counties that are economic centers of the state (regional center counties) are separately analyzed, the evidence indicates that higher highway expenditures in these counties lead to a statistically significant increase in employment levels, larger than the normal trend of the economy.

LITERATURE REVIEW

Historically, transportation in the United States has had undeniable effects on economic development. The location of communities has often been determined by the location of transportation, be it a river or railroad. However, today's mature highway network provides a high degree of accessibility relative to what existed 100 years ago. Thus, today's highway projects may lack the stimulative economic effects experienced as the country was developed.

Possible ways that highways may be able to affect economic development include

1. Residential location. In response to changes in the transportation infrastructure, people may change their residences to take advantage of the new transportation facilities. In urban areas this effect has been well studied and its existence verified *(4)*.
2. Work place location. A transportation facility may enable people to work far from where they reside *(5)*.
3. Enterprise location resulting from change in labor supply. Stephanedes and Eagle *(6)* argue that if new transportation facilities allow people to participate in the labor market of an area to which they previously lacked accessibility, then that area's labor supply may increase. The increased labor supply may attract new industry to the area.
4. Enterprise location resulting from decreased transportation costs. An improvement in transportation often will de-

crease the transportation costs of companies in the area served by the transportation facility. These decreased costs may attract new firms to the area *(7)*.

In this paper, the validity of Points 3 and 4 is tested, that is, whether changes in the transportation network affect enterprise location or expansion. Moreover, enterprise location or expansion with employment levels is determined in the counties where highway changes take place.

Several investigators have studied the effects of Interstate highways on population and employment growth *(8–10)*. These investigators have found that counties with Interstate highways have an advantage over other counties with regard to population and employment growth but only in counties within 25 mi of a metropolitan area. The effects on employment are primarily related to industries servicing those using the highways (e.g., service stations, restaurants, and motels) and are not related to manufacturing or wholesale operations. Research in the Atlantic region of Canada (which includes New Brunswick, Newfoundland, Nova Scotia, and Prince Edward Island) has shown that increased investment in transportation infrastructure and freight subsidies would attract few industries because "a reasonably mature transportation system [is] properly in place and maintained" *(11)*. Similarly, in a study of the region around the Ozark Plateau in Arkansas, little correlation was found between highways and economic development *(12)*.

Other sources have found that a significant relationship exists between highways and economic growth. Expressway investments in north England have been found to lead to greater regional employment growth *(13)*, although this greater growth was minimal. In Connecticut, manufacturing employment and population increased more in towns close to the new turnpike than in towns farther away *(14, 15)*.

Regional economic forecasting and policy analysis using large-scale regional models *(16)* often based on the input-output method *(17–22)* have indicated that some economic effects do result from changes in transportation. The implications of these models, however, often depend critically on the users' assumptions. An important variable in input-output models is market share, the amount of the total final demand that is produced locally. In some models, such as SIMLAB *(21)*, the user determines market share. In other models, such as the Amherst Model *(22)*, market share is estimated using an equation relating variables of the model.

When models estimate market share, the parameters of the estimation are often based on statistical cross-sectional studies and, therefore, merely represent correlation. However, by their very existence within the large-scale models, these parameters are used as if they did represent a causal relationship. The direction and nature of that relationship often follow from an ad hoc model structure. For example, Modeler A may specify market share as a function of the number of highways in the region relative to the rest of the country. On the other hand, Modeler B may specify the number of highways in the region as a function of the market share. Both modelers use the same data and cross-sectional analysis. The correlation they obtain is therefore the same, but the two modelers will interpret that correlation as two different causal relationships.

Most of the studies discussed use cross-sectional techniques. However, time series techniques address the issue of causality more directly than do cross-sectional techniques. Because time series techniques can test whether changes in one series (such as highway expenditures) statistically precede changes in another series (such as employment levels), this time series investigation into the causal links between highway investment and economic development was undertaken.

DATA

In this section, the data, the groupings of counties, and the normalization of the data to filter out the effects of inflation, regional or national trends, and other factors common to each particular grouping are described. The data consist of annual observations of state highway system construction expenditures and employment for all 87 Minnesota counties. The expenditure data, provided by the Minnesota Department of Transportation, are broken down by county for the fiscal years 1957–1982. The employment data from the *County Business Patterns (23)* for the years 1964–1982 represent the employment in the middle of March each year. (These data do not include self-employed workers, railroad workers, or governmental employees.) Because the majority of each fiscal year's highway budget (a fiscal year is from July 1 of one year to June 30 of the next) is spent before March, the yearly expenditure data are viewed as preceding the employment data.

The length of each county's employment time series is 19 years; the length of each county's highway expenditures time series is 26 years. Traditional time series analysis could accomplish little with such short series. However, by pooling the cross-sectional data with the time series data, the data elements increase from 19 to 1,653 for employment and from 26 to 2,262 for highway expenditures.

Before the analysis, changes reflecting regional or national trends, inflation, and other effects that are common to the grouping of counties are filtered out. To accomplish this filtering, variables for the statistical analysis are defined as follows.

Let $\bar{\bar{x}}_{i,t}$ be the basic variable (such as expenditures or employment) for county i in year t. Then,

$$\hat{x}_{i,t} = \frac{\bar{\bar{x}}_{i,t}}{\sum_{j \text{ in } G} \bar{\bar{x}}_{j,t}}; \text{ for each } i \text{ in } G,$$

where G is the grouping of counties considered. The $\hat{x}_{i,t}$ variables relate each county in a grouping to the total of the counties in the grouping.

The groupings of counties considered are defined in Figure 1. These groupings are

1. Statewide. All 87 Minnesota counties.
2. Urban. Counties in the Twin Cities seven-county metropolitan area and counties containing a city with a population of 28,000 or larger. (This definition is followed strictly. Thus, even St. Louis County, which includes the city of Duluth and a very large rural area, is classified as an urban county.)
3. Next-to-urban. Counties bordering the urban counties.
4. Regional center. In the Twin Cities metropolitan area, these counties include Hennepin and Ramsey counties, which

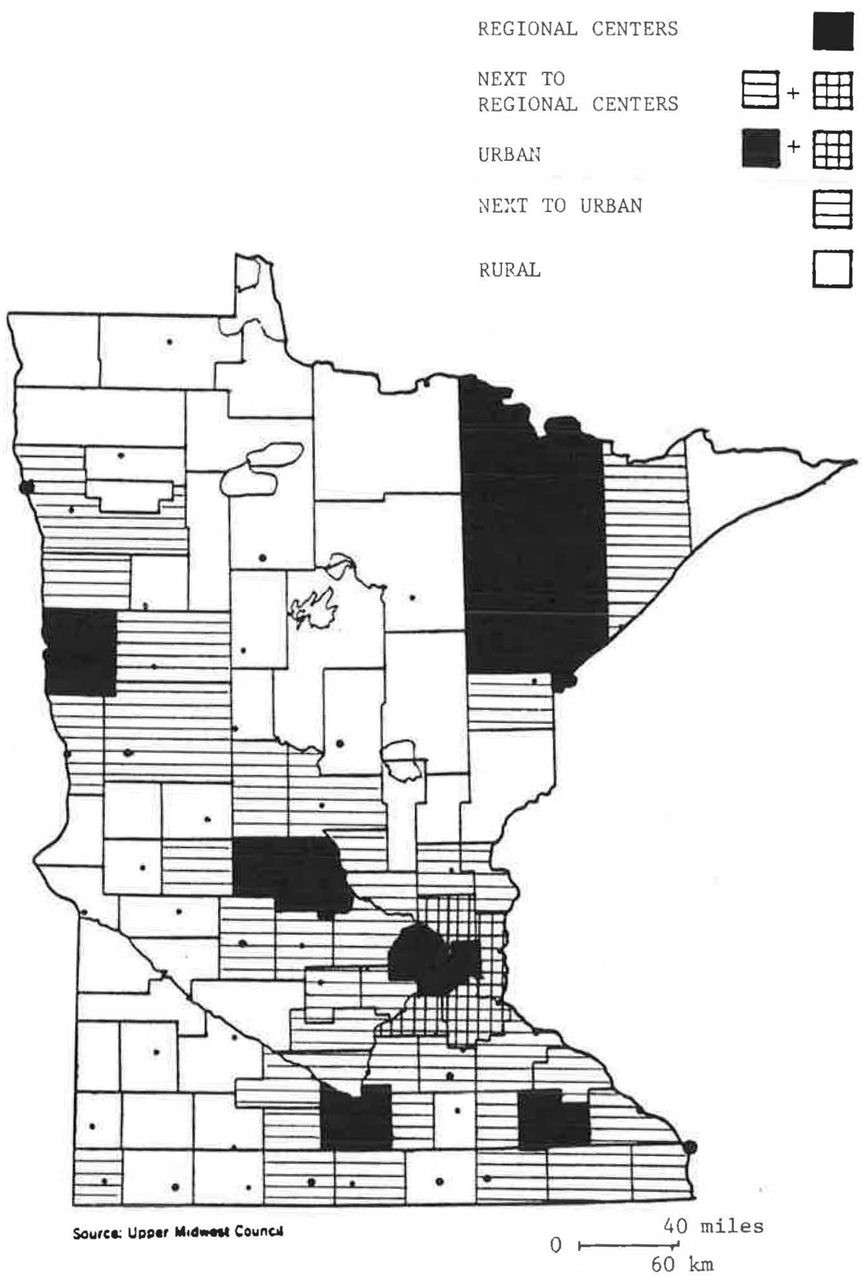

FIGURE 1 County groupings.

include the cities of Minneapolis and St. Paul. Outside this metropolitan area, counties are included if they contain a city the size of Mankato (located in south Minnesota and having a population of 28,000) or larger. These counties are the economic centers of the state as they employ two-thirds of the state workers and contain approximately one-half of the population.

5. Next-to-regional center. Next-to-urban counties plus the Twin Cities metropolitan counties other than Hennepin and Ramsey.

6. Rural. Counties not included in Categories 2 or 3.

Naturally, other types of groupings are possible, for example, counties whose economy is agriculturally based, light manufacturing based, or border counties. However, such groupings have not yet been analyzed.

EQUATIONS

The variables $y_{i,t}$ and $x_{i,t}$ (e.g., employment and highway expenditures) are assumed to be stationary stochastic processes having the following form for some q and constants α_i for each county i in the grouping:

$$\hat{y}_{i,t} = \alpha_i + a_1\hat{y}_{i,t-1} + a_2\hat{y}_{i,t-2} + \ldots + a_q\hat{y}_{i,t-q} + b_1\hat{x}_{i,t-1} + b_2\hat{x}_{i,t-2} + \ldots + b_q\hat{x}_{i,t-q} + \mu_{i,t} \quad (1)$$

where $\mu_{i,t}$ is the error term assumed to be serially uncorrelated.

That the as and bs are the same across counties is a crucial assumption of this formulation, implying that the processes behave similarly across counties. However, the αs do reflect differences among the counties. Although a joint estimation of all the coefficients in Equation 1 would be most efficient, a two-step procedure enables the estimation of the *a*s, *b*s, and αs in a manner that reduces the statistical efficiency slightly but greatly saves computer time.

In the first step of the procedure, the sample mean of each variable over time is subtracted out. This subtraction panels the data, forming the following new variables:

$$\bar{x}_{i,t} \equiv \hat{x}_{i,t} - \frac{\sum_{s=k}^{m} \hat{x}_{i,t}}{m - k + 1}$$

where k and m are the first and last years, respectively, of the data. Because the sample mean is the estimate of the true mean of each variable, the αs are then eliminated from the equation. Therefore, Equation 1 can be rewritten as

$$\bar{y}_{i,t} = a_1\bar{y}_{i,t-1} + a_2\bar{y}_{i,t-2} + \ldots + a_q\bar{y}_{i,t-q} + b_1\bar{x}_{i,t-1} + b_2\bar{x}_{i,t-2} + \ldots + b_q\bar{x}_{i,t-q} + \mu_{i,t} \quad (2)$$

The absolute variation of employment and highway expenditures is expected to be greater in large counties than in small counties. If the statistical methods do not adjust for this difference in variation, the largest two counties containing the Twin Cities would dominate, giving biased results. To eliminate this bias, a county's $\mu_{i,t}$ is considered to be the sum of n independent and identical random variables; then the variance of $\mu_{i,t}$ equals n times the variance of one of the individual random variables. Next, it is assumed that the number of the random variables in a county is proportional to its total employment E_i; then $\varepsilon_{i,t} \equiv \mu_{i,t}/\sqrt{E_i}$ is serially uncorrelated and has variance σ^2, which is independent of the county. This specification is reasonably consistent with the data.

The final transformation of dividing both sides of Equation 2 by $\sqrt{E_i}$ filters out the effects of county size on data fluctuations:

$$y_{i,t} = a_1y_{i,t-1} + a_2y_{i,t-2} + \ldots + a_qy_{i,t-q} + b_1x_{i,t-1} + b_2x_{i,t-2} + \ldots + b_qx_{i,t-q} + \varepsilon_{i,t} \quad (3)$$

where $y_{i,t} \equiv \bar{y}_{i,t}/\sqrt{E_i}$ and $x_{i,t} \equiv \bar{x}_{i,t}/\sqrt{E_i}$. Because this two-step procedure is not perfectly efficient, a constant term independent of the county is added to Equation 3, yielding a standard regression form:

$$y_{i,t} = \gamma + a_1y_{i,t-1} + a_2y_{i,t-2} + \ldots + a_qy_{i,t-q} + b_1x_{i,t-1} + b_2x_{i,t-2} + \ldots + b_qx_{i,t-q} + \varepsilon_{i,t} \quad (4)$$

Equation 4 is the process to be estimated.

METHODOLOGY

Two methods are used to investigate the link between transportation and economic development: (a) Granger-causality tests, and (b) structural time series plots.

Granger-Causality Tests

The direct Sims test of whether a variable x Granger-causes a variable y first formulates the null hypothesis that x does not Granger-cause y. Then, x is regressed on past, present, and future values of y.

$$x_{i,t} = \gamma + a_1x_{i,t-1} + a_2x_{i,t-2} + \ldots + a_qx_{i,t-q} + b_0y_{i,t} + b_1y_{i,t-1} + \ldots + b_qy_{i,t-q} + c_1y_{i,t+1} + c_2y_{i,t+2} + \ldots + c_ky_{i,t+k} + \varepsilon_{i,t} \quad (5)$$

for some integers q and k.

Under the null hypothesis of no causality, all future coefficients of y should be zero, that is, $c_h = 0$ for $h = 1, 2, \ldots, k$. An F-test is used to test whether these coefficients are zero. If the F-test indicates the observed data are unlikely to have occurred if all the future coefficients of y were zero, then the null hypothesis is rejected and it is concluded that x does Granger-cause y.

Structural Plots

To estimate a structural specification of employment, it is hypothesized that, for some q and k,

$$E_{i,t} = \gamma_1 + a_{20}H_{i,t} + a_{21}H_{i,t-1} + \ldots + a_{2q}H_{i,t-q} + b_{21}E_{i,t-1} + b_{22}E_{i,t-2} + \ldots + b_{2k}E_{i,t-k} + \varepsilon_{i,t} \quad (6)$$

All variables on the right-hand side of Equation 6 are hypothesized to be predetermined, and thus the structural Equation 6 is identified. The only variable that can be viewed as not being predetermined is $H_{i,t}$. However, the highway expenditure data are available by fiscal year, that is, from July 1 to June 30, whereas each year's employment data represent employment in the second week of March. Because the vast majority of the highway expenditures have already been expended (and certainly appropriated) by the second week in March, the vast majority of $H_{i,t}$ values are predetermined when $E_{i,t}$ occur.

To interpret the structures of Equation 6, an exogenous change in highway expenditures is simulated. In the resulting structural plot (see Figure 2 for examples), which explains employment, highway expenditures are exogenously increased 10 percent for one period and then the expenditures are returned to their original level. The reason the change in highway expenditures for Equation 6 is taken as temporary is that the effects of highways after construction, not the effects from the construction of the highway, are of interest.

Although Equation 6 can be viewed as the structural equation representing employment, clearly highway expenditure is not the only variable that affects employment. Thus, a degree of misspecification in Equation 6 is expected. Also, part of the justification of no simultaneity bias in Equation 6 stems from properties of the data rather than from true structural properties. To address these issues, vector autoregressions that complement the structural equations are being developed.

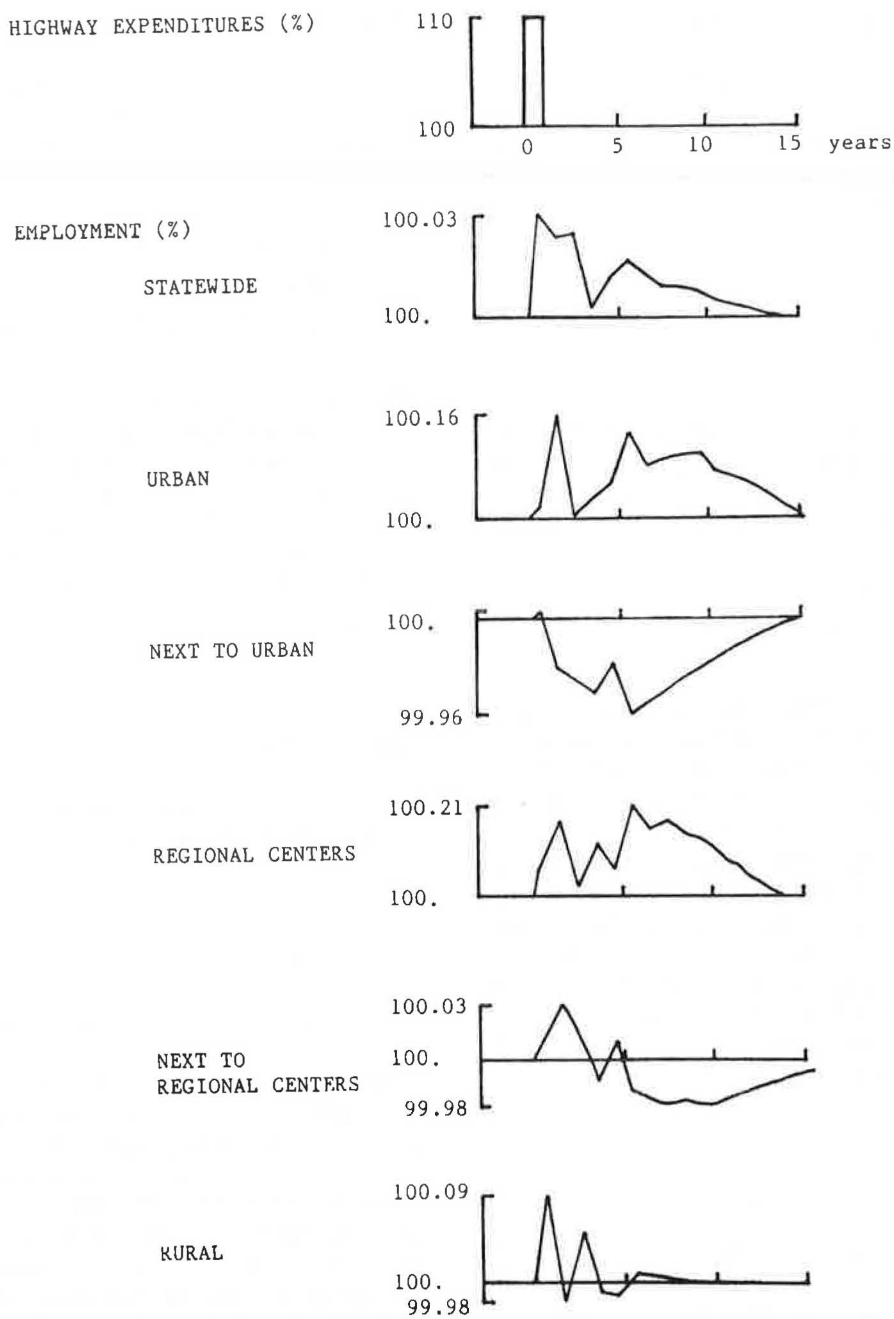

FIGURE 2 Effect of a change in highway expenditures on employment.

RESULTS

The causality tests and structural plots were used to analyze the possible impacts of highway expenditures on employment for statewide, urban, next-to-urban, regional centers, next-to-regional centers, and rural groupings of counties.

Because a lag structure of three to five lags usually captures most of the dynamics of a system, an autoregressive structure of five lags is used for the structural plots, that is, $q = 5$ and $k = 5$ in Equation 6. However, because of leads in Equation 5, the causality tests require more data for a given autoregressive structure than do the structural plots. Therefore, because the length of the time series is only 19 years and each additional lag decreases the degrees of freedom by the number of counties, three lags are used in the causality tests, that is, $q = 3$ in Equation 5.

Corresponding to the three-lag autoregressive structure, three leads are initially used in the causality tests, that is, $k = 3$ in Equation 5. However, the major effects of highways on economic development may occur beyond 3 years into the future. Thus, the causality tests were also performed for six leads. Table 1 presents both the three-lead and six-lead causality tests. A low significance level in the three-lead tests indicates the existence of a short-term effect, whereas a low significance level in the six-lead tests indicates the existence of a long-term effect.

The results of the causality tests and structural plots are given in Table 1, and the structural plots are shown in Figure 2.

TABLE 1 EFFECT OF HIGHWAYS ON EMPLOYMENT

	F-Statistic[a]					
	Three Leads	Significance Level (%)	Six Leads	Significance Level (%)	Increase in No. of Jobs[b]	Elasticity
Statewide	0.43	>20	0.37	>20	7.5	0.001
Urban	1.26	>20	1.66	12.86	52.0	0.008
Next-to-urban	0.49	>20	0.47	>20	−14.0	−0.002
Regional centers	2.51	4.82[c]	3.31	0.60[d]	107.6	0.013
Next to regional centers	0.24	>20	0.77	>20	−3.1	−0.001
Rural	2.10	7.83[e]	0.83	>20	5.3	0.001

[a]The hypothesis H_0 is that construction of highways does not cause additional employment.
[b]Due to $1 million in highway expenditures. The number of jobs represents the average annual increase of jobs over the base year's employment for a typical county in each grouping. The structural plots simulate the direct effects on employment of a 1-year impulse in highway expenditures. Thereafter, highway expenditures are exogenously set at base level. However, after the first period, the VAR treats highway expenditures as endogenous; thus, the VAR reflects feedback effects in addition to the direct effects.
[c]Significant at the 5 percent level.
[d]Significant at the 1 percent level.
[e]Significant at the 10 percent level.

Effect of Highway Expenditures on Employment

Based on the results from the causality tests and structural plots, Table 1 summarizes for each grouping how highway expenditures lead to employment. For the causality tests, the lower the significance level the greater the indication of causality. In particular, a significance level around 1 percent or less is considered as strong indication of causality. A 5 percent significance level may indicate causality, but such a significance level would have about a 50 percent chance of occurring for at least one of the groupings if no causality existed. A 10 percent significance level provides a small indication of causality, but results with such a significance level would have more than a 70 percent chance of occurring in the absence of causality. Significance levels greater than 10 percent provide little indication of causality.

For the structural plots, highway expenditures are temporarily increased by 10 percent as indicated in the top graph of Figure 2; the increase occurs completely within 1 year. The resulting effect on employment is illustrated in the remaining graphs of Figure 2.

The statewide structural plot indicates that for the typical Minnesota county a 1-year increase of highway expenditures of $274,000 (10 percent) leads to an annual average increase of two jobs (0.01 percent) over the 10 years following the first change in highway expenditures. This calculation is based on measuring the area under the curve. As summarized in Table 1, this result implies that 7.5 new jobs statewide follow a $1 million increase in highway construction expenditures (an elasticity of 0.001).

As indicated by the causality tests in Table 1, the effects of highway expenditures on employment depicted in the structural plots are statistically insignificant; neither the three-lead nor the six-lead tests indicate any evidence of highways Granger-causing employment. This insignificance is due to the small magnitude of these effects.

In the evaluation of the statewide data set, the model assumes that all counties behave the same. If, in fact, they behave differently, then the above results may only be true on average, but not for every type of county. To isolate differences in behavior, different groupings of counties were analyzed according to their urbanization.

The causality tests indicate strong causality only for the regional centers, although a small degree of causality is indicated for rural counties. For the regional centers, the six-lead significance level of 0.60 percent strongly indicates a long-term employment effect of highways on employment.

The structural plot for regional centers indicates that two effects occur. The first is the construction effect, which lasts 2 to 3 years. The effect of the construction effect on the economy is due to the road construction. For example, construction jobs are created, the workers spend some of their earnings in the county, and the construction companies make local purchases, causing multiplier effects throughout the county's economy. The second effect is the longer-term employment effect that results because the highway improvement exists. The latter effect is the more sustaining effect of highways and the one primarily of interest here.

Some causality is also indicated for the rural counties. The structural plot for the rural counties indicates that the effects of highway expenditures on rural economies are short term and primarily due to the construction effect. That the construction effect and not a longer-term effect of highways takes place in rural economies is also indicated by the causality tests. In particular, the causality for three leads (short-term) has a significance level of 7.83 percent, but the significance level for the six-lead test is greater than 20 percent, that is, there is no evidence of long-term causality.

Although causality is not indicated for the other groupings, the structural plots do indicate that the effects of highways on employment are not always positive. For the next-to-urban counties, for instance, analysis of Figure 2 indicates that a $274,000 (10 percent) increase in highway expenditures over 1 year is followed by an average decline of 3.5 jobs (0.02 percent) over the next decade. As summarized in Table 1, this effect amounts to −14 jobs per $1 million of new highway expenditures (an elasticity of −0.002). One explanation of this negative employment effect is that improved highways into a regional center allow business activity to move from the next-to-urban counties to the regional centers. This explanation also may be the reason that employment in regional centers significantly increases following an increase in highway expenditures.

In summary, the statewide data set did not indicate any significant effect of highway expenditures on employment levels. Nevertheless, in regional centers, higher levels of expenditures did lead to significantly greater levels of employment. In counties next to urban areas, employment actually dropped following increases in expenditures, although this effect lacks statistical significance. A possible explanation of these results is that improved highways in or around urban areas cause business activity to be drawn into the regional centers from counties near the urban area.

CONCLUSIONS

The time series analysis indicates that increases in highway expenditures do not in general lead to increases in employment levels. Some previous observers have mistaken high correlation between highway expenditures and employment as an indication that highway expenditures do have a substantial effect on economic development. However, analysis indicates that this correlation stems from two other factors: (a) higher employment levels attract higher levels of expenditures, and (b) during the year of construction, employment levels do increase. However, this effect is only temporary and disappears when the period of construction ends.

Thus, it is concluded that highway expenditures do not Granger-cause total employment to increase. However, in counties that are economic centers of the state (defined as regional center counties—these counties employ two-thirds of the state workers and approximately one-half of the population), highway expenditures do have an effect on total employment, exceeding the normal trend of the economy. In these counties, a 1-year, $1-million increase in highway expenditures leads to approximately 108 new jobs.

Although the analysis implied that in general highway expenditures do not Granger-cause total employment to increase, highway expenditures may Granger-cause employment to increase within a specific economic sector. Results from ongoing work in this area indicate that for some sectors the Granger-causality of highway expenditures is significant even for groupings other than the regional centers.

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Measuring the Regional Transportation Benefits and Economic Impacts of Airports

STEWART E. BUTLER AND LAURENCE J. KIERNAN

In this paper, methods of measuring the importance of an airport to the economy of the surrounding area are described. Various measures of economic significance, the circumstances in which they are applicable, and guidelines for their estimation are presented. The two main measures that may be quantified and cited as evidence of an airport's importance are its transportation benefits and its economic impacts. Transportation benefits are the services that a local airport makes available to the community. The two services emphasized in this paper are time saved and cost avoided by travelers, but benefits also include other advantages, such as improved safety and comfort. Economic impacts are the regional economic activities, employment, and payrolls that can be attributed directly and indirectly to the operation of a local airport.

The United States has the world's most extensive airport system. The system is essential to national transportation, and there is a large federal investment in it. However, most public airports are owned and operated by units of local government.

Public airports must compete for funds with other governmental activities. They are scrutinized during budget preparation and may be the subject of public debate, particularly if major improvements or new construction is anticipated. They may even be the target of proposed restrictions aimed at limiting aircraft noise levels. In such instances, the future of an airport is determined primarily through the local political process.

If the public is to continue supporting airports, the public and its representatives must appreciate the economic significance of airports. This paper is designed to assist analyses of the economic importance of airports. It is not intended for use in financial feasibility studies or cost-benefit analyses. Rather, it provides basic guidance on how some simple rules of thumb can be used to obtain first-cut approximations of the value of an airport to the area that it serves. Suggestions for conducting a more comprehensive assessment are contained in Section 3.3 of the FAA's recent report, *Measuring the Regional Economic Significance of Airports (1)*.

This paper is directed to a wide audience with varying levels of sophistication in the field of economics. One objective is to encourage a standard approach to the measurement of the economic significance of airports. The paper includes a uniform set of definitions, illustrations of the most useful analytical techniques, and descriptions of the conditions under which they are most appropriately applied. The procedures described in the paper can be used to evaluate the economic significance of an existing or proposed airport or to study the consequences of increased activity at an airport.

The two main indicators that may be measured and cited as evidence of an airport's importance are its transportation benefits and its economic impacts. Transportation benefits are the services that a local airport makes available to the surrounding area. The two services emphasized in this paper are time saved and cost avoided by travelers, but benefits also include other advantages, such as improved transportation safety and comfort. Benefits are a measure of the improved transportation that the airport provides, and thus reflect the primary motive of a community in operating a public airport. Economic impacts are the regional economic activities, employment, and payrolls that can be attributed, directly and indirectly, to the operation of a local airport. They describe the importance of aviation as an industry.

Information about the economic significance of airports has a wide variety of uses. It is an important element in airport master plans and system plans, because it helps to describe the basis for and consequences of the development of airports and the public involvement in them. The public is more likely to support airports when aware of the substantial positive effects on the surrounding area. Economic impact and benefit data can be useful in evaluating the effects of airport use restrictions or curfews. Benefit data can be combined with income projections to help determine the viability of airport development proposals.

TRANSPORTATION BENEFITS

Airports provide a variety of public benefits to the surrounding service areas. The most substantial of these are the time saved and cost avoided by using air transportation. These transportation benefits can be expressed in dollars, using the technique described in this section. Other benefits include the high levels of safety, comfort, and convenience of aviation; the access that an airport provides to the national airport system; and enhancements to community well being. These benefits cannot be expressed in dollars, but they can be explained and demonstrated by examples. In the case of reliever airports in metropolitan areas, a reduction in delays at airline airports can be cited and quantified.

The primary benefits of an airport are usually the time saved and cost avoided by travelers who use it instead of the next best alternative. The following procedure measures the value of time saved and cost avoided by travelers as a result of a primary airport located at Point A (see Figure 1). The nearest

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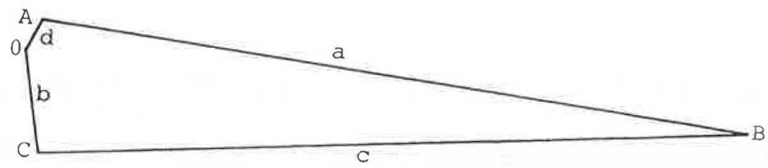

FIGURE 1 Transportation benefit of an airport.

alternative airport is located at Point C, which is located farther from Point O, where the trip originates. The time saved by using Airport A would be the difference between the time for the O–C–B trip and the time for the more direct O–A–B trip. The benefit is the time saved per trip times the number of passenger trips, all multiplied by the value of the passengers' time. There is also a benefit as a result of reduced ground travel costs, because Airport A is closer to the origin of trips than Airport C. There could be additional benefits if x, the flight distance between Airports A and B were shorter than y, the alternative flight distance between Airports C and B. In the following analysis, it is assumed for the sake of simplicity that the flight distances x and y are equal.

The variables that must be considered in the analysis are listed in Table 1. Most of them do not have to be determined for each analysis; typical values can be used instead. The critical variables that must be determined for each individual analysis are the number of based aircraft, the number of passengers in commercial air service, and the access distances to Airports A and C. The total benefit is the sum of the time saving and travel cost reduction. The equations are shown separately and combined. The cost of aircraft flight time may be considered if the distance x is substantially different from the distance y *(2)*.

Time saved

$$\begin{aligned} \text{Annual passengers} &= FGN + Y \\ \text{O–C–B time} &= b/P + y/S \\ \text{O–A–B time} &= d/P + x/S \\ \text{Annual benefit} &= E(FGN + Y)(b/P + y/S - x/S - d/P) \end{aligned}$$

Reduced ground travel cost

$$\begin{aligned} \text{Annual ground trips} &= GN + Y \\ \text{O–C–B trip costs} &= Qb \\ \text{O–A–B trip costs} &= Qd \\ \text{Annual benefit} &= (GN + Y)(Qb - Qd) \end{aligned}$$

GN, the number of annual itinerant general aviation (GA) operations, is equal to the number of GA-related ground trips on the assumption that passengers making a GA trip together are acquainted and share one automobile in traveling between the trip origin and the airport. FGN is the number of annual GA passengers. Y, the number of annual commercial passengers, equals the number of ground trips related to commercial service on the assumption that each commercial passenger is traveling alone and requires a separate motor vehicle. P is the ground transit speed in miles per hour; S is the GA regional aircraft speed in miles per hour. E is the passenger time value in dollars per hour; and Q is automobile cost, including amortization, in dollars per mile.

Total annual benefit

If $x = y$, the total annual benefit = $E(FGN + Y)(b/P - d/P) + (GN + Y)(Qb - Qd)$. The transportation benefits from sample airports with various activity levels are illustrated in Table 2.

The transportation benefits depend on several variables, particularly the additional ground travel involved in reaching an alternative airport. When ground travel $(b - d)$ is 20 mi, and the other variables are as given in Table 1, the annual benefit from

TABLE 1 ENVIRONMENTAL PARAMETERS

Symbol	Variable	Typical Value[a]
G	Itinerant operations per based aircraft per year[b]	300
N	Number of based aircraft at Airport A	Varies
d	Ground access distance to Airport A (mi)	Varies
E	Passenger time value ($/hr)[c]	25
F	Number of passengers per trip for GA aircraft[d]	2.5
P	Car speed (mph)	45
Q	Car cost, including amortization ($/mi)[e]	0.24
b	Ground access distance to alternative Airport C (mi)	Varies
Y	Annual number of passengers in commercial service	Varies
x	Direct flight distance from origin Airport A to destination Airport B[f]	Varies
y	Alternative Airport C to destination Airport B flight distance[f]	Varies
S	GA or regional airline aircraft speed (mph)[f]	Varies

[a]Actual data used where available.
[b]An operation is either a landing or a takeoff. Aircraft based at airports with air traffic control towers averaged 302 itinerant operations each in 1985.
[c]There is no source of precise data on passenger time. The FAA uses $25/hr for estimating the value of aircraft owners' and pilots' time for internal reporting purposes. The Aircraft Owners and Pilots Association (AOPA) reports that the average annual income of its 260,000 members is $53,200, which is equivalent to $25.58/hr. The FAA used $22.30/hr as an estimate of the value of airline passenger time in 1984 for computing the cost of air traffic delays.
[d]The average number of passengers per trip varies with aircraft type and is 1.5 for single-engine piston aircraft with three seats or less, 2.3 for single-engine piston aircraft with four seats or more, and 3.1 for multiengine piston aircraft *(4)*.
[e]The American Automobile Association (AAA) reports that a medium-sized automobile driven 15,000 mi/year cost $0.243/mi to operate in 1985.
[f]Variable needed to compute total annual benefit when use of the alternative airport substantially changes flight distance, that is $x \neq y$.

TABLE 2 APPROXIMATE BENEFITS FOR VARIOUS ACTIVITY LEVELS

Based Aircraft	Annual Commercial Passengers[a]	Reduction in Distance to Airport $(b - d)$[b]	Value of Time Saved ($)	Reduction in Travel Cost ($)	Total Annual Transportation Benefit ($)
10	0	20	83,333	14,400	97,733
20	0	20	166,666	28,800	195,466
50	0	20	416,665	72,000	488,665
100	0	20	833,330	144,000	977,330
50	50,000	20	972,165	312,000	1,284,165
100	100,000	20	1,944,330	624,000	2,568,330
100	1,000,000	20	11,943,330	4,944,000	16,887,330

[a]Includes only origin and destination traffic; does not include through or transfer passengers.
[b]Highway mileage measured from the point where trips begin or end, typically the traveler's residence or place of business.

the airport is $9,773 per based aircraft plus $15.91 per passenger enplaned or deplaned in commercial service.

A proportionate adjustment should be made to the benefits if the additional ground travel $(b - d)$ is not equal to 20 mi. For instance, if $b - d$ is equal to 10 mi, the benefits would be $4,886 per based aircraft and $7.95 per commercial passenger. If $b - d$ is equal to 40 mi, the benefits would be $19,546 per based aircraft and $31.82 per passenger in commercial service. These figures can be used as a rule of thumb to estimate the transportation benefits of an airport.

For example, an airport being studied has 25 based aircraft, and a regional airline served 6,000 passengers at the airport in the preceding year. The nearest alternative airport is 20 highway miles farther from the area served by the airport under study. The total annual transportation benefit from the airport is (25 aircraft × $9,773 per aircraft) + (6,000 passengers × $15.91 per passenger), or $339,785.

An analysis can be used to determine the additional benefits that result from increased activity at an airport. The increased activity may be the result of gradual growth in the demand for air transportation (passenger enplanements in the United States are forecast to increase at a rate of 4.5 percent/year), or it may occur rapidly as the result of an improvement to the airport or the introduction of new service. When the expected number of additional based aircraft and commercial passengers is known, the analytical technique or rule of thumb described in the preceding sections can be used to estimate the increased benefit. This information may be used to evaluate proposals to improve an airport or to restrict airport growth.

A GA airport in a metropolitan area may be designated a reliever airport by the FAA. In addition to providing access to the surrounding area, the reliever airport relieves congestion at a busy air carrier airport by providing GA aircraft with an attractive alternative landing area. For instance, Teterboro Airport in New Jersey is a reliever for Newark Airport, serving more than 400 aircraft daily that might otherwise land at Newark and add to congestion there.

The value of delay reduction resulting from a reliever airport can be computed by estimating the amount of traffic that would be added to the air carrier airport if the reliever were not available and then using an airport capacity model to compute annual delays before and after this traffic is added. The average cost of an airline delay in 1984 was $1,647.00/hr for airline operating expenses plus $22.30 per passenger-hour. Aircraft delays increase exponentially as traffic is added to a congested airport, so the benefits of an effective reliever airport are usually quite large, and may be measured in millions of dollars.

Some beneficial aspects of airports are significant but difficult to quantify. For example, airports contribute to the prompt diagnosis and treatment of disease. Blood and tissue samples are sent by air to medical facilities for analysis; isotopes, serum, and antitoxin that cannot be stored locally are shipped by air whenever and wherever they are needed; organs for transplant operations are shipped by air; and patients often travel by air for dialysis and other treatment not available in their community.

A number of high schools, colleges, and universities have aviation programs, and many offer degrees in these subjects. The programs are designed to train young people for careers in aviation. General aviation is a major subject area for the airline pilots of tomorrow. Aviation vocations may be conceived and nurtured at the local public airport.

Airports are vital civil defense facilities. They are extremely durable, and aviation is a key source of relief from natural disasters such as floods and earthquakes. Airports also support police, Civil Air Patrol, and National Guard activities and may be used by aircraft involved in pipeline patrol, detection of fuel and chemical spills, and forest fire detection and suppression.

Although it is usually not possible to predict such uses of aviation facilities or to express them in dollars, they can be illustrated by references to specific instances in which the local airport, or one in the area, was used in an emergency. Anecdotal evidence and summaries of case studies can add a new dimension to discussions of airport benefits.

Aviation is an essential form of business transportation, and it has helped to shape the size and structure of many major corporations. The presence of an airport and the type of services it provides are important considerations in the siting of business and industrial facilities. Large airports are magnets for warehousing, distribution centers, office parks, hotels, and other development. Smaller airports help to attract industry to small- and medium-sized communities, though they must work in concert with other factors such as the availability of a market, raw materials, labor, utilities, favorable treatment by local government, low taxes, community amenities, and sites that are economical to develop. As an important part of a rural area's transportation network, an airport is a factor in fostering business.

State and local agencies, working with the federal government, have provided the United States with the world's most extensive and best equipped airport system. These airports accommodate about 40 percent of the commercial traffic in the world, and 60 percent of the GA traffic. It is through the local airport that an area gains access to this important national resource.

About 50 percent of travel on commercial airlines and about 30 percent of GA trips are for recreation or vacation. The recreational uses of GA include sailplaning, sky-diving, flying homebuilt aircraft, and local sightseeing. These flights are an important source of recreation and entertainment and also provide revenues that help to defray the cost of developing and operating airports.

There are many commercial activities involving aviation in addition to the carriage of passengers. Air cargo accounts for several distinct businesses, including air freight and express delivery of small parcels. Many high-value goods are shipped by air, and even relatively low-value, heavy goods, such as automobile parts, are often shipped by air to minimize inventory and warehousing costs. GA aircraft are used for such commercial activities as agricultural applications (e.g., crop dusting), pipeline and utility line patrols, transportation of checks and records of commercial transactions, and on-demand air taxi and charter services.

ECONOMIC IMPACTS

Economic impacts measure the importance of aviation as an industry, in terms of the employment it provides and the goods and services it consumes. Although the benefits described in the previous section are the primary motive for airport development, direct economic benefits help to generate and sustain public support for airports. The following definitions include virtually every type of economic impact applicable to airports.

Direct impacts are consequences of economic activities carried out at the airport by airlines, airport management, fixed base operators, and other tenants with a direct involvement in aviation. Employing labor, purchasing locally produced goods and services, and contracting for airport construction and capital improvements are examples of airport activities that generate direct impacts.

Some direct impacts, such as airport employment, occur on site; others, such as local production of goods and services for use at the airport, may occur off site. The distinguishing feature of a direct impact is that it is an immediate consequence of airport economic activity.

Strictly speaking, direct impacts should represent economic activities that would not have occurred in the absence of the airport. If it were determined that, without the airport, some on-site employees would be doing comparable work elsewhere in the region without displacing other workers, their employment should not be part of the airport's contribution to local economic activity. This would be significant in a region with full or nearly full employment, where airport employment might draw workers away from other employers in the region, who then have to operate their businesses with fewer workers than they would otherwise employ. A similar problem is posed by the possibility that, in the absence of the airport, the region might have developed alternative modes of common carrier transportation more extensively and thus created employment opportunities for workers now employed at the airport.

As a practical matter, however, it is rarely cost effective to develop a base-case scenario that depicts the economy of the region without the airport. The time and resources required for this exercise seldom warrant the resulting improvement in the estimates of employment, payroll, and expenditure impacts.

Expenditures by airlines, fixed base operators (FBOs), and tenants generate direct impacts, but only those that induce local business activity are relevant for a regional economic assessment. For this reason, it is important to distinguish between (a) the local value-added component of expenditures, and (b) the regional import component. Thus, airline expenditures on fuel generate local fuel storage and distribution services and the importation of fuel into the region. In most parts of the country, only the former component is relevant for the analysis.

Similar considerations apply to the expenditures of gift shops, restaurants, and other airport businesses that purchase regional imports for resale. They may apply as well to airport construction and capital improvements.

Indirect impacts derive primarily from off-site economic activities that are attributable to the airport. These activities include services provided by travel agencies, hotels, restaurants, and retail establishments. These enterprises, like airport businesses, employ labor, purchase locally produced goods and services, and invest in capital expansion and improvements. Indirect impacts differ from direct impacts in that they originate entirely off site. The same caveats regarding regional imports apply.

Like direct impacts, indirect impacts should theoretically represent economic activities that would not have occurred in the absence of the airport. For this reason, it would be desirable to distinguish between tourists (and other visitors) who would not have traveled to the region if there were no airport and those who would have come anyway by some other form of transportation. Only the former are really relevant for the estimation of indirect impacts. Unfortunately, it is seldom feasible to make this distinction. As a result, the impacts of expenditures of tourists and other visitors arriving at the airport may be overstated, particularly for regions that are easily accessible by rail, bus, and automobile.

Induced impacts are the multiplier effects of the direct and indirect impacts. These are the increases in employment and incomes exceeding the combined direct and indirect impacts created by successive rounds of spending. For example, most of the take-home income earned by airport employees is spent locally. Some of this spending becomes income to local individuals who provide services to the airport employees. Some of the spending by airport employees goes to local businesses and becomes income to the business owners and their employees. Then part of these second-round incomes is also spent locally and thus becomes income to another set of individuals. As successive rounds of spending occur, additional income is created.

Although some of the induced impacts occur locally, some are felt outside the region because of regional import components of the goods and services purchased. It is important, therefore, that the specific multiplier factor selected for the analysis take regional imports into account. More economically self-sufficient regions have higher multipliers than do regions that are more dependent on regional imports, because more of the spending and respending is done in the area. Similarly, two or more counties considered together as one economic region have higher multipliers than each individual county.

Total impacts are the sum of the direct, indirect, and induced impacts. Widespread adoption of the preceding definitions would contribute to the comparability of different airport impact assessments.

Rules of thumb for estimating economic impacts provide only rough approximations. They tend to yield low estimates because they do not capture the indirect impacts such as sales by travel agencies, restaurants, and hotels, or the direct impact of purchases by the airport and its tenants. More precise estimates may be obtained by using the methodology presented in the FAA report *(1)*.

Rules of thumb have been developed for the following broad categories of airports:

1. Air carrier airports with more than 4 million commercial passengers a year,
2. Air carrier airports with fewer than 4 million commercial passengers a year, and
3. GA airports.

Economic Impacts of Air Carrier Airports with More than 4 Million Commercial Passengers per Year

Step 1: Determine employment at the airport. If total airport employment is known, the analyst may proceed to Step 2. If airport employment is not known, it can be estimated by the following rule.

For every 10,000 annual commercial passengers, including through passengers, the airport has approximately 8.8 employees. The uncertainty associated with this statistically derived coefficient *(1)* is ±20 percent, yielding lower and upper limits of 7.0 and 10.6 employees, respectively. For example, an airport with 10 million commercial passengers per year would have approximately 8,800 (range 7,000–10,600) employees.

Note that this estimate does not include any large aircraft manufacturing or maintenance activity that may account for substantial additional employment at certain airports. These activities are addressed in Step 3.

Step 2: Convert airport employment into airport payroll. A review of airport impact studies indicates that annual airport payroll per employee at high-activity air carrier airports is approximately $27,000 (in 1984 dollars). From Step 1, the airport's estimated payroll would then be 8,800 × $27,000, or $237.6 (range $189–$286.2) million.

Step 3: Determine employment and payroll at aviation-related businesses. In some cases, an aviation manufacturing plant, aviation maintenance facility, or other type of aviation-related business is located on or near the airport site. If such facilities would not have located in the region in the absence of the airport, their employment and payroll impacts should be included in the analysis. These impacts are not taken into account in Step 1, and the employment and payroll data have to be obtained directly from the facility operators.

Step 4: Calculate induced impacts of airport and aviation-related employment and payrolls. As defined, induced impacts are the multiplier effects of employment, payroll, and other direct and indirect consequences of airport activity. Unfortunately, there is no single multiplier factor that applies to every region. The induced impacts of direct and indirect impacts are larger for regions that are relatively self-sufficient economically and smaller for areas that are highly dependent on regional imports. Estimates of the multiplier for the total United States economy are typically about 1.0 for induced impacts. Thus, 1.0 should be the upper limit for rule-of-thumb estimation and should generally be applied to large metropolitan areas with relatively self-sufficient economies. For rural areas or areas with little manufacturing capability, and where purchases of goods and services have a high regional import component, a multiplier factor as low as 0.5 may be appropriate.

Applying a multiplier of 0.75 to the direct employment and payrolls in the preceding example yields induced employment and payroll of 6,600 (range 5,250–7,950) employees and $178.2 (range $141.75–$214.65) million, respectively. Induced impacts would be larger if direct impacts included the employment and payrolls of aviation-related activities.

Step 5: Calculate total economic impacts. The total economic impacts would then be estimated as the sum of the direct and induced employment and payroll impacts. In the example, 15,400 (range 12,250–18,550) jobs and $415.8 (range $330.75–$500.85) million in incomes would be attributed to the airport.

These figures are rough estimates that may substantially understate an airport's economic impacts for the following reasons:

1. Airport employment and payroll and those of aviation-related facilities are the only direct impacts considered. Other expenditures by airlines, FBOs, and tenants are not included in the analysis.
2. No indirect impacts derived from off-site economic activities are considered, for example, services provided by travel agencies, hotels, restaurants, and retail establishments for the benefit of airport users.

These factors should be added to the estimated total economic impacts whenever suitable data are available.

Air Carrier Airports with Fewer than 4 Million Commercial Passengers per Year

The following steps are similar to those just developed, varying somewhat in their implementation.

Step 1: Determine employment at the airport. Employment at a smaller, less active air carrier airport is likely to be easier to determine by a direct head count than at a high-activity airport with a large number of tenants. But if airport employment must be estimated, the following rule can be used.

The statistics indicate that for every 10,000 annual commercial passengers, including through passengers, the smaller airport has 8.4 (range 6.7–10.1) employees *(1)*. If, for example, an airport has 1 million commercial passengers, estimated airport employment would be 840 (range 670–1,010).

Step 2: Convert airport employment into airport payroll. A review of reports on the economic impacts of airports indicates that the typical airport payroll per employee at low-activity airports is approximately $22,000 (in 1984 dollars). Thus the airport employment estimated at 840 in Step 1 would represent a payroll of $18.48 (range $14.74–$22.22) million.

Step 3: Determine employment and payrolls at aviation-related businesses. This step is implemented as described previously for high-activity airports.

Step 4: Calculate induced impacts of airport and aviation-related employment and payrolls. This step is implemented as described previously for more active airports. The appropriate multiplier factor depends on the degree of economic self-sufficiency of the region, not on the level of airport activity. If the region is unusually dependent on regional imports, a multiplier factor of 0.5 might be selected. This would yield induced employment of 420 (range 335–505) jobs; the induced incomes would be $9.24 (range $7.37–$11.11) million.

Step 5: Calculate total economic impacts. The total impacts can then be estimated by summing the direct and induced employment and payroll impacts. In the example, 1,260 (range 1,005–1,515) jobs would be attributed to the airport. In addition, the airport would be credited with adding incomes totaling $27.72 (range $22.11–$33.33) million to the region.

The discussion of the interpretation of rule-of-thumb estimates for high-activity airports also applies to low-activity airports. The caveats regarding the noninclusion of airport expenditures and indirect impacts apply in both cases.

GA Airports

At an airport where the principal use is GA, the five steps outlined previously may again be followed. In Step 1, employment and payroll data may be available from the airport manager. The scant data on GA airports suggest a rough ratio of one employee for every 7.2 based aircraft, but this ratio may be lower at small airports and higher at large ones. [From data on FBOs by employment-size class reported in the *1980 Survey of Airport Services (3)*, median FBO employment, including the FBO manager, is 4.5 for the nation as a whole. The average number of FBOs per airport is 1.1. Average FBO employment at an airport is thus 1.1 times 4.5, or approximately 5.0. The average number of permanently based aircraft per airport is 36.2, which divided by the average airport FBO employment of 5.0, yields 7.2 based aircraft per FBO employee.] Local expenditures may also be determined and added to the direct payroll impacts. Steps 2 through 5 could then be carried out as described.

The data in Table 3 illustrate the application of rule-of-thumb procedures to airports of various activity levels corresponding to Table 2. Implementation of the rules of thumb proposed in this section requires little time and a minimum of resources. However, it yields only a rough approximation.

Estimates of employment and payroll developed by the statistical rules of thumb can be projected by simply applying the same rules to forecasts of based aircraft and commercial passengers. For example, if the number of annual commercial passengers is expected to increase by 10,000 between the present and the year 2000 at an airport with fewer than 4 million commercial passengers a year, airport employment would be projected to increase by 8.4 employees. If airport payroll per employee is approximately $22,000 (in 1984 dollars), the increase in payroll would be projected to be about $176,000. This would lead to an induced impact of $132,000, assuming a multiplier of 0.75, and thus a total increase in regional incomes of $308,000 per year.

SUMMARY

Analytical techniques are available to quantify the transportation benefits and the economic impacts of airports. Rules of thumb, consistent with those analytical techniques, can provide preliminary (though imprecise) estimates by relating airport

TABLE 3 APPROXIMATE IMPACTS FOR VARIOUS ACTIVITY LEVELS

Airport Activity			Direct Impact[a]		Induced Impact[b]		Direct Plus Induced Impacts[c]	
Based Aircraft	Total Annual Commercial Passengers[d]	Estimated Employment[e]	Payroll per Employee ($)	Total Payroll ($)	Employment	Income ($)	Employment	Income ($)
10	0	1	22,000	22,000	1	16,500	2	38,500
20	0	3	22,000	66,000	2	49,500	5	115,500
50	0	7	22,000	154,000	5	115,500	12	269,500
100	0	14	22,000	308,000	11	231,000	25	539,000
50	50,000	42	22,000	924,000	32	693,000	74	1,617,000
100	100,000	84	22,000	1,848,000	63	1,386,000	147	3,234,000
100	1,000,000	840	22,000	18,480,000	630	13,860,000	1,470	32,340,000

[a]Direct impacts in table include only employment and payrolls. Expenditures should be added if available.
[b]In the examples presented in this table, it is assumed that 0.75 is the appropriate multiplier factor to be applied to the direct impact to obtain the induced impact.
[c]Indirect impacts are not shown because no rule of thumb has been developed for estimating them.
[d]Including through passengers.
[e]Employment for the first four examples is estimated by the employment rule of thumb for GA airports: one employee for every 7.2 based aircraft. Employment for the last three examples is estimated by the employment rule of thumb for air carrier airports with fewer than 4 million commercial passengers a year: 8.4 employees for every 10,000 passengers. Employment estimates are rounded to the nearest integer.

TABLE 4 APPROXIMATE BENEFITS AND IMPACTS FOR VARIOUS ACTIVITY LEVELS

		Benefits			Direct Plus Induced Impact	
Based Aircraft	Annual Commercial Passengers	Value of Time Saved ($)	Reduction in Travel Cost ($)	Total Annual Benefit ($)	Annual Payroll ($)	Number of Jobs
10	0	83,333	14,400	97,733	38,500	2
20	0	166,666	28,800	195,466	115,500	5
50	0	416,665	72,000	488,665	269,500	12
100	0	833,330	144,000	977,330	539,000	25
50	50,000	972,165	312,000	1,284,165	1,617,000	74
100	100,000	1,944,330	624,000	2,568,330	3,234,000	147
100	1,000,000	11,943,330	4,944,000	16,887,330	32,340,000	1,470

activity to benefits and to economic impact in terms of jobs and payroll that result from the airport. The data in Table 4 illustrate typical figures for airports with various activity levels.

These analytical techniques can also be used to predict the positive economic effects that are likely to result from increased aeronautical activity. For instance, if an airport with fewer than 4 million commercial passengers per year is forecast to have 50 additional based aircraft and 50,000 additional annual commercial passengers 10 years in the future, then it can be expected that there will be an accompanying increase in benefits of about $1,284,165 per year, and 74 jobs will be added to the local economy with a payroll impact of $1,617,000 per year.

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The Oak Lawn Area Transportation Management Plan: A Public-Private Partnership

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The case of the Oak Lawn area in Dallas is an example of a private initiative and of successful cooperation between residents, property owners, developers, and city officials in developing an area transportation management plan. The plan, instead of advocating the traditional approach of more and wider thoroughfares, suggests a system of traffic management activities to handle the projected increase in traffic while preserving the neighborhood character. The city council has implemented the plan in a special district ordinance for the Oak Lawn area.

The urban transportation planning process is undergoing critical transformations. Of particular interest is the emergence of private sector involvement in the planning, management, financing, and construction of transportation systems.

The concept of private sector participation in the planning process is not new. It stems from the community participation principles developed in the late 1960s and was anticipated in sections 3(e) of the UMTA Act of 1964 as amended in 1983. The underlying rationale for private sector participation is that the degree of involvement in the planning phases is related to the participant's attitude and behavior in subsequent phases. If the private sector assumes greater involvement in the formulation of plans, it can be expected that it will have an acceptance of the program and a strong interest in its implementation.

Private sector efforts are often undertaken to address needs that are not perceived to be adequately filled by the public sector and that are of particular concern. Regional and subarea mobility planning and management private initiatives have been successfully implemented in several major cities including Dallas, Hartford, Houston, and Los Angeles *(1–3)*.

Reviewed in this paper is the successful cooperation between residents, property owners, developers, and city officials in tackling mobility problems in the Oak Lawn area in Dallas. This case study is part of a larger research project on private sector involvement in urban transportation conducted by the Joint Center for Urban Mobility Research at Rice Center *(1, 4)*.

Overall, there is considerable private sector involvement in transportation planning and implementation in the Dallas area. Most of the involvement to date has been on an ad hoc basis with the public and private sectors coming together to address specific problems as needed. Public and private sponsors in the rapidly growing north Dallas area have agreed on a transportation management program that includes reduction of parking requirements, mandatory ridesharing and transit support, and an independent, ongoing funding mechanism *(5)*. Private sector involvement is allowing the Dallas Area Rapid Transit (DART) to expand transit services quickly and cost effectively throughout its service area. For example, a group of local businessmen on McKinney Avenue has formed the McKinney Avenue Transportation Authority (MATA) and is bringing back antique trolleys in an effort to link the downtown with the commercial development in the Oak Lawn area. So far, MATA, which plans to operate the trolley system privately, has been able to raise more than $2 million to fund capital construction and operations.

The Oak Lawn area of Dallas is north of and immediately adjacent to the downtown (Figure 1). It is a transition area between the commercial downtown and the exclusive residential communities of Highland Park and University Park. The area encompasses a broad spectrum of income groups in residential neighborhoods as well as a diversity of businesses and developments. Some portions of Oak Lawn have a historic character and some represent the latest in high-density commercial development. Some parts of the area maintain an appeal as older residential neighborhoods. Oak Lawn also is beginning to experience intensive commercial development, which has spread from downtown along the major thoroughfares passing through the area.

The area's office employment was expected to grow from 16,800 workers in 1985 to 48,800 workers in 1988. The additional 8.1 million net square feet of office space under construction or planned by 1988 will bring the total office space to 12.2 million net square feet *(6)*. Even though the rate of growth has slowed during 1986, the Oak Lawn area still maintains one of the higher office occupancy rates in the city of Dallas. The mixed residential and commercial land uses have led to conflicts between residents, developers, and the city, which has attempted to respond to both groups.

In 1982, area residents, businessmen, and developers formed the Oak Lawn Forum and in cooperation with the city prepared a plan to identify problems and achieve a consensus on the orderly evolution of the area.

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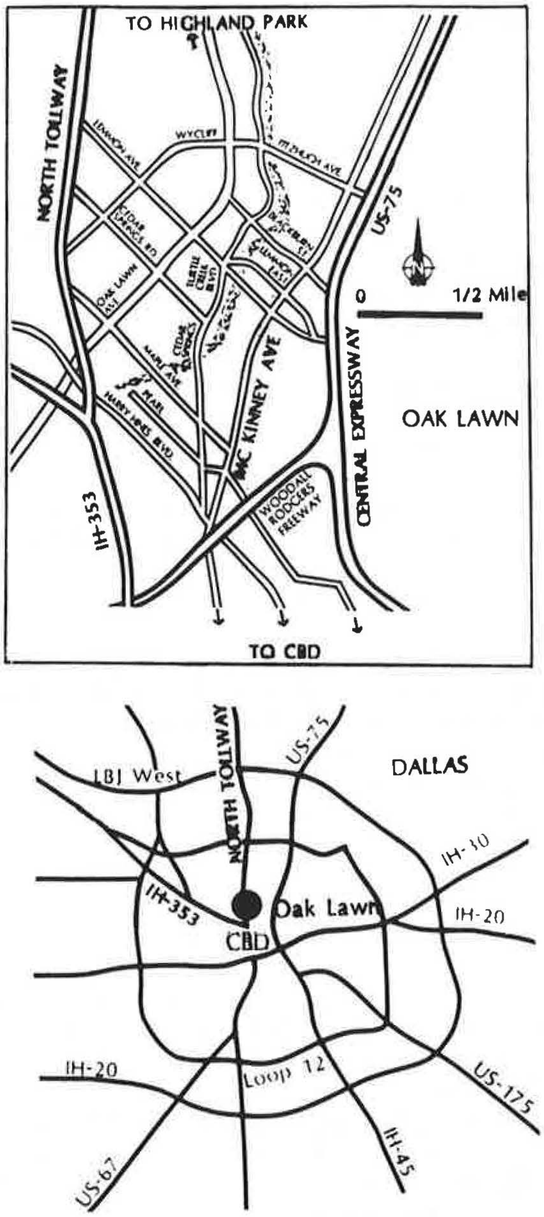

FIGURE 1 Map of Oak Lawn area north of and adjacent to downtown Dallas.

THE TRANSPORTATION MANAGEMENT PLAN

The Oak Lawn Forum's first activity was to study a broad range of study problems and potential solutions. An extensive amount of time was spent identifying the objectives of the Oak Lawn Forum members. The resultant plan addressed issues of zoning, neighborhood stability, protection of the unique retail environment, landscaping, parking, esthetics, urban design, and transportation *(7)*. Transportation was one of the largest and most difficult issues to resolve.

Overall, the program was unique for Dallas at the time in that the city and private interest groups in the area worked together to devise a comprehensive set of guidelines and plans for bringing a high quality of life to the area over a short period of time. The transportation planning for the Oak Lawn area was especially unique. The leaders of the Oak Lawn Forum demanded an approach completely different from typical transportation planning. Instead of advocating more and wider streets and freeways to accommodate ever increasing traffic, they advocated fewer, narrower roads along with other traffic management activities to more effectively handle traffic, while preserving the appearance and residential character of the neighborhoods.

The basic premise of the Oak Lawn Forum leaders was that the streets currently were inadequate to serve increased development activity. Widening the streets as shown on the city's major thoroughfare plan would have been permanently disruptive to the neighborhood and would have still not provided enough capacity to easily accommodate all of the traffic generated in the area as well as traffic that would pass through the area to access the downtown. As an alternative, the Oak Lawn Forum proposed minimal street improvements but an extensive array of techniques to more effectively manage traffic rather than to let traffic run rampant over the Oak Lawn area.

More specifically, the plan recommended a number of actions *(7)*, including

- Reduction of retail, residential, and office parking ratios to encourage transit use and to encourage developers to provide incentives for higher automobile occupancy and transit use among their tenants. Recommended reductions would achieve the double objective of smaller, less obtrusive parking facilities in the neighborhood and fewer cars on the streets.
- Development of a transportation systems management plan.
- Continuation of high zoning density to accommodate substantial growth in the Oak Lawn area.
- Increased use and availability of public transit through more frequent DART service and an internal shuttle bus system.
- Use of miscellaneous alternatives to automobiles and public transit such as jitneys, private trolleys, taxis, and ridesharing.

In June 1984, the first phase of a more detailed internal transit planning study was completed *(8)*. The plan again recommended closer working relationships with the Dallas Transit System (DTS) and DART, development of a local shuttle service (with a private operator recommended as the most cost-effective approach), and the establishment of an area-wide ridesharing coordinating service. That program was scheduled to be in place by the end of 1986.

The initial effort was concluded with adoption in February 1985 by the city council of a special district ordinance for the Oak Lawn area *(9)*. This ordinance was realized after many months of discussions between the Oak Lawn Forum and city officials. In the ordinance, parking ratios required for most land use categories were reduced by 10 percent as an incentive for developers to make a payment into the Oak Lawn transit fund, prepare an improved traffic management agreement, or qualify as a mixed-use development with shared parking. The traffic management plan required each developer to state a specific, detailed plan for traffic mitigation measures such as carpooling, vanpooling, bus pass subsidy, subscription transit, or bicycling programs. Specific vehicle trip reduction goals had to be achieved within 2 years. One of the plan recommendations included the development of a bus shuttle system for the area.

A DART study found that the proposed transit shuttle was feasible and DART has tentatively become committed to operate the system. As of April 1987, the Oak Lawn Forum was developing criteria for the use of the transit fund. One possible use was for the operation of the bus shuttle. The Oak Lawn Forum anticipated raising additional funds through a destination marketing program to cover part of the system's operating deficit.

Implementation Problems

Adoption of this ordinance was not easy to achieve. Deviation from the thoroughfare plan and extensive reliance on transit has been very unusual in a city such as Dallas with only a 2 to 3 percent peak-hour transit mode split. The city department of transportation (DOT) was concerned about the practicality of some aspects of the program.

Traffic forecasts indicated increasing need for thoroughfare improvements, not downgrading of the existing plan. There was no detailed program for providing transit, and transit in Dallas has not been used extensively, so the city DOT was skeptical that the alternatives offered could be successful unless there was a deep and continuing commitment to trip reduction by the city DOT, Oak Lawn Forum leaders, and all other concerned groups in the Oak Lawn area. Because setbacks for street easements were reduced or eliminated in the plan, there was no fallback position in case of failure of the Forum approach.

Initially, the city DOT staff was concerned about the proposed McKinney trolley's impact on existing traffic, expecting increases in actual congestion because of the trolley's stop and go operations. The city staff in transportation, planning, and other departments has worked closely with the Oak Lawn plan as it has developed in order to arrive at a mutually agreeable program.

DISCUSSION AND CONCLUSIONS

The Oak Lawn Forum experience provides important lessons with potentially far-reaching ramifications. As in most cases of private sector involvement, the initiative came from the private sector *(1)*. Interaction between the developers, property owners, and the city has brought about fresh ways of addressing traffic congestion. Developer incentive programs and intensive area transit treatment have been substituted for costly construction projects. It is still uncertain how the reduction in the local economic growth will affect implementation of the plan. Close monitoring of the results is needed so that adjustments to the plans can be made if necessary. So far, there has been a delay in the plan implementation that may be attributed to changes in local conditions.

In the following sections is a discussion of economic, political, and administrative issues bearing on the plan. An attempt is made to draw lessons for the benefit of other community areas that are considering such public-private partnerships for the solution of mobility problems.

Financial and Economic Benefits and Costs

The Oak Lawn plan has not been approached or evaluated from an economic perspective. If the plan is ultimately successful in maintaining the Oak Lawn area as a desirable close-in residential environment, then residential land values could be maintained or increased, thereby financially benefiting the residents and the tax base. The plan places a somewhat greater burden on developers because of recommendations for

- More costly below-ground parking,
- Traffic impact assessment studies,
- Subsequent on-site and off-site improvements,
- Contributions to a transit and traffic management plan, and
- Contributions to the transit fund.

These costs are partly offset by reduced parking ratios and increased development allowed where setbacks have been eased. It remains to be seen whether the development modifications will be viewed as amenities to the extent that commercial development projects in the area will be attractive to tenants. The city is certainly being relieved of the cost of many thoroughfare improvements.

Political and Administrative Issues

The administration of this program will present some additional burden to the city of Dallas. However, that burden may be a small price to pay for the harmonious coexistence of residents and developers in the Oak Lawn area. Moreover, the lack of thoroughfare improvements will put a great deal of pressure on the traffic management plan and those who administer it. The plan includes transit and traffic elements and mandatory fees to support them.

There is also an equity issue that needs to be addressed. There is no provision to make any requirements or participation in this plan retroactive. In other words, developments begun before the ordinance was passed, although contributing to the problems in the area, have no responsibility to contribute to solutions.

Lessons

Many participants can learn from the Oak Lawn planning process. Residents can learn to work with developers and governmental agencies rather than merely resisting various pressures to change. Developers can learn that by joining with nearby residents, mutually beneficial plans can be devised to satisfy the needs of both sides. City and other governmental agencies can learn to be more open to innovative approaches that may reduce strife between competing interests within the community. These agencies can also learn that the private sector can be interested in the community good and peaceful coexistence rather than retain purely selfish motives for their isolated developments.

City government may inadvertently frustrate the private sector through its "red tape." Frustration stems partly from the private sector's lack of familiarity with agency procedures and the occasional delays of any bureaucracy. All agencies should keep these same factors in mind to streamline their interaction with private sector organizations. There is a continuing need for all involved parties to be reminded of the tremendous continuing efforts that will be required for the success of this cooperation. Despite concerns, the planning and transportation staffs, the board of directors of the Oak Lawn Forum, and the majority of city council members believe that with diligent effort the alternative approaches can be made to work.

Until the final mix of services is operating for a significant period of time, it will be difficult to determine which approach is better: the traditional or the experimental. The traditional approach has the drawback of addressing capacity needs on an interim basis. The Oak Lawn approach, which attempts to manage transportation demand and services, is not widely tested and may require changes in habits and extensive efforts on the part of all parties concerned to ensure any degree of success. Whether the plan ultimately succeeds or fails, the primary benefit is a lesson in the building of cooperative spirit bringing all the parties together in the program, which is unique and experimental in nature but has the potential for extensive mutual benefits.

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The Economics of Reducing the Size of the Local Rural Road System

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The large number of miles of local rural roads in the United States originated in the Ordinance of 1785, which was passed by Congress to open new lands to settlement. Most of today's local rural roads were built in the late 1800s and early 1900s, when overland transportation was limited to horse and wagon and newly built railroad lines. From that time until World War II, each of these roads served dozens of farms. Since 1950, the number of farms has declined sharply and is expected to continue to decline in the future. The type of traffic on rural roads has changed from small vehicles serving many households and farms to large vehicles serving fewer households and farms. Many of the vehicles now traveling on these roads are heavy or wide farm tractors, trucks, and harvesting combines that impose major weight or width stress on the roads and bridges. However, the financial ability to maintain and rebuild the system is not keeping up with its rate of deterioration. Local officials have insufficient money to properly maintain the existing system for the types of vehicles that are traveling on it. Reducing the size of the local rural road and bridge system through the abandonment of road segments that contain no property accesses results in cost savings from discontinued maintaining, reconstructing, and resurfacing the roads and bridges that exceed the additional costs imposed on the traveling public when they are rerouted around the abandoned roads.

The local rural road system contains 71 percent of the 3.2 million mi of rural roads in the United States *(1)*. Local rural roads are defined as those roads that are under the jurisdiction of county and township governments. The large number of miles and the rectangular regularity of the local rural road system originated in the Ordinance of 1785, which established townships and 1-mile survey grids. The objective of Congress was to open the land for settlement.

Many of today's local rural roads and bridges were built in the late 1800s and early 1900s when overland transportation for both passengers and freight was limited to horse and wagon or recently built railroad lines. Farmers living on small farms needed road access to homes, schools, churches, and markets.

During the 1920s and 1930s, local rural roads were surfaced, mainly with gravel, and bridges were replaced to carry 6- to 7-ton loads. Since then, the number of farms has declined, farm size has increased, and the number of heavy vehicles traveling on these roads has increased.

In most instances, a farmer obtains more land by buying or leasing land from other farmers, frequently on nonadjoining farms. The increasing scatter of tracts of land operated by one farmer increases travel distances and size of farm equipment on the roads. Large tandem-axle and semitrailer trucks, farm tractor-wagon combinations, and harvesting combines now travel from homesteads to fields and back. Farm supply and marketing firms use large tandem-axle and semitrailer trucks for pickups and deliveries. The declining rural population causes school districts to use larger school buses to transport fewer children longer distances to consolidated schools. These school buses, which weigh up to 15 tons when fully loaded, cannot cross bridges that are posted at less than their gross loaded weights.

Precise data on the condition of the local rural road system are not available. However, there is ample evidence that the system is deteriorating rapidly. In a recent Illinois survey, farmers and agribusiness representatives rated about one-half of the Illinois local rural roads as needing more than regular maintenance, and over 20 percent were rated as needing major repair *(2)*. Common complaints about the local rural roads in many states include the following:

1. Overweight vehicles are breaking up road surfaces.
2. Lack of hard surfaces results in dust and rideability problems.
3. Road widths and other design characteristics are inadequate for today's large farm equipment and heavy trucks.
4. Narrow lanes create safety problems.

The condition of local bridges is also of great concern. On January 1, 1985, 184,977 (61 percent) of all the off-federal-aid bridges that had been inventoried were deficient *(3)*. In addition, 118,390 (39 percent) of the 306,388 off-federal-aid system bridges were posted, or should have been posted, at less than legal weight limits. However, even this deficiency understates the magnitude of the problem. Thousands of bridges under 20 ft long not included in the inventory needed replacement or repair.

Data for the distribution of deficient bridges among states indicate that the local bridge problem is national in scope *(3)*. States with the largest numbers of deficient bridges are Arkansas, Illinois, Indiana, Iowa, Kansas, Mississippi, Missouri, Nebraska, North Carolina, Oklahoma, Tennessee, and Texas. Other states in the northeast, midwest, southeast, and southwest regions are included in the group with a high percent or a large total number of deficient bridges.

The county road system faces many of the same problems that the railroad system encountered in the late 1960s and early

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1970s. The physical condition of the county road system is deteriorating. The heavy vehicles traveling on the system are causing damage; however, the financial ability to maintain and rebuild the system is not keeping up with the rate of deterioration. Although federal and state motor vehicle fuel taxes have increased sharply in recent years, there is increasing pressure to reallocate a larger share of these taxes to roads that are under city and state rather than rural jurisdiction. Moreover, a substantial share of the funds to maintain local rural roads originates in property taxes. The recent decline in rural property values is decreasing the amount of funds from this source. In short, money is lacking to properly maintain the existing system for the types of vehicles that are traveling on the roads.

Public debate about the county roads has focused mainly on the deteriorating condition of the system. The implicit assumption behind much of this debate is that the system should be maintained as it is. However, an increasing number of observers believe that the number of miles of local rural roads could be reduced, either by abandonment or by conversion to private drives. A 1976 editorial in the *Des Moines Register* states the following:

> County roads that served dozens of farms forty years ago may be serving only two or three farms today. Many roads that were once vital to a county's well-being have become, in effect, private roads, although the county is responsible for their upkeep. Such roads no longer belong in a county road system. *(1)*

Residents on the roads argue that abandoning these roads or converting them to private drives will force farmers and rural residents to travel longer distances and that the additional travel and maintenance costs on these longer roads will exceed the cost savings of removing the shorter roads from the public system.

Numerous analysts have discussed the deteriorating conditions of the local rural road and bridge system *(4)*. However, in only a small number of studies have alternative solutions been identified *(1, 2, 5, 6)*. In fewer studies yet have the impacts of the deteriorating roads and bridges on all travel costs or the impacts of alternative solutions on travel costs and local government costs been quantified. The Pennsylvania Department of Transportation identified those roads in two Pennsylvania counties that are most important to the rural agricultural areas for the transport of agricultural products to market and of supplies to the farm *(7)*. Tucker and Johnson examined the impact of alternative rural road development and maintenance policies on grain marketing costs in southeastern Michigan *(8)*. Their results indicate that grain marketing costs decrease as the road system is improved, but the savings in grain transport costs were far less than the costs of the road improvement. Nyamaah and Hitzhusen used a circuity model to estimate the rerouting costs to road users when 15 rural bridges in Ohio were posted or closed *(9)*. The model indicated substantially greater benefits from bridge repair or replacement than the county engineers estimated. Chicoine and Walzar surveyed farmers, township officials, and agricultural and rural business officials to identify their opinions and attitudes on a wide range of rural road and bridge questions and issues *(5)*.

No previous analyses quantitatively evaluated the impacts of alternative road and bridge investment strategies on all the traffic traveling on the rural road and bridge system. The purpose of this paper is to present estimates of the impacts on all traffic on the system from reducing the size of the public rural road system by abandoning selected roads.

METHOD OF ANALYSIS

Study Areas

The county roads in three 100-mi^2 areas in Iowa were included in the analysis. The three study areas were selected for their differences in terrain, quality of roads and bridges, and level and type of economic activity. Area 1, located in east central Iowa just north of Cedar Rapids, has a large nonfarm population, a productive cash grain agriculture, a high percentage of paved roads, and level terrain. Area 2, located in southwest Iowa, has a small population of farm and nonfarm residents; a large but declining livestock industry; a high percentage of gravel, oiled, and earth-surfaced county road system; and hilly terrain with many bridges. Area 3, located in north central Iowa, has a small farm and nonfarm population, high cash grain agriculture, a well-developed paved road system, and level terrain.

Benefit-Cost Analysis

A benefit-cost analysis is used to evaluate the economics of reducing the size of the county road system in the three study areas. The benefits derived from keeping up the roads that were evaluated for abandonment are defined as the additional travel costs incurred by the traveling public when the roads are removed from the system. The traveling public incurs additional travel costs when roads are abandoned because some traffic must travel longer distances to reach the intended destination or must travel on lower quality road surfaces. The cost portion of the benefit-cost analysis is the expense of keeping up the roads that were considered for abandonment. These costs include variable and fixed road maintenance, road resurfacing and reconstruction, and bridge maintenance and reconstruction costs on the abandoned roads, minus the variable maintenance, resurfacing, and reconstruction costs transferred to the roads inheriting the traffic from the abandoned roads. The costs also include the rental value foregone by having the land in roads rather than in production, minus the cost of converting the land from road to agricultural use.

The following benefit-cost ratio is used to evaluate whether a road segment, group of road segments, or bridge should remain in the county road system:

$$\frac{B}{C_{j_A}} = (TC_j - TC_{j-1})[(MC_{j-1} - MC_j) + (REC_{j-1} - REC_j) + (RES_{j-1} - RES_j) + (BREC_{j-1} - BREC_j) + (BMC_{j-1} - BMC_j) + (VL_j - ROW_j)]^{-1} \tag{1}$$

where

$\frac{B}{C_{j_A}}$ = the abandonment benefit-cost ratio of the jth set of road segments;

MC_{j-1} = the total annual road maintenance cost before the jth set of road segments is abandoned;

MC_j = the total annual road maintenance cost after the jth set of road segments is abandoned;

REC_{j-1} = the total annualized life cycle roadbed reconstruction cost before the jth set of road segments is abandoned;

REC_j = the total annualized life cycle roadbed reconstruction cost after the jth set of road segments is abandoned;

RES_{j-1} = the total annualized life cycle road resurfacing cost before the jth set of road segments is abandoned;

RES_j = the total annualized life cycle road resurfacing cost after the jth set of road segments is abandoned;

$BREC_{j-1}$ = the total annualized life cycle bridge reconstruction cost before the jth set of road segments is abandoned;

$BREC_j$ = the total annualized life cycle bridge reconstruction cost after the jth set of road segments is abandoned;

BMC_{j-1} = the total annual bridge maintenance cost before the jth set of road segments is abandoned;

BMC_j = the total annual bridge maintenance cost after the jth set of road segments is abandoned;

VL_j = the annual value of the land if the jth set of road segments is not maintained;

ROW_j = the annualized cost of converting the right-of-way of the jth set of road segments to agricultural production;

TC_j = the total annual vehicle transportation cost after the jth set of segments is abandoned; and

TC_{j-1} = the total annual vehicle transportation cost before the jth set of road segments is abandoned.

If the value of the ratio in Equation 1 is less than 1.0, the net benefits to the traveling public of keeping the road segment in the system are less than the cost of keeping the road segment in the system. If the ratio is greater than 1.0, the benefits to the traveling public of keeping the road are greater than the cost of keeping the road.

Benefit-Cost Estimation

Except for school bus and post office travel costs, the benefits accruing to the traveling public were estimated in two steps. First, a network model was used to estimate the minimum cost traffic flows for all 1982 traffic within each study area. The network model for each study area included all roads by type of surface; all bridges by load bearing capacity; all property and field tract access points; and all trips by origin, destination, and vehicle type. Travel costs were defined as the variable vehicle cost per mile by type of road surface times the number of miles traveled by each vehicle type on each type of road surface. Dijkstra's algorithm was chosen to estimate the minimum cost routing of traveling from each origin to each destination for each vehicle type because it preserves the origin-destination relationship and requires relatively few operations to find an optimal solution *(10)*. The actual estimation of the benefit to the traveling public of keeping a road or group of roads in the system was calculated as follows:

1. The computerized algorithm was run to route the trips through the study area road system to obtain the total miles traveled and cost of this travel.
2. The computerized road network was altered by removing a set of road segments.
3. The algorithm was run again to reroute trips through the altered road network to obtain the total miles traveled and cost of the travel on the "adjusted" network.
4. The change in travel costs between the two solutions is the estimated benefit from having the set of roads considered for abandonment in the system.

The basic assumptions behind the network model used in this analysis are the following:

1. Travel costs are a linear function of distance traveled for each vehicle type.
2. The number of trips from each origin to each destination in each time period by each vehicle type is independent of changes in the road system.
3. Vehicle purchase decisions are not affected by the relatively small changes in distance between an origin and a destination resulting from a change in the road system.
4. Travel routes are selected to minimize travel costs.
5. Vehicles with gross weight greater than the posted carrying capacity of a bridge cannot cross that bridge.

Detailed specifications of the network model are presented in Pautsch et al. *(10)*.

School bus and post office travel costs could not be estimated by the network model because much of the routing of these vehicles depends on the route structure outside the study areas. Existing school bus routes were used to estimate travel costs for Step 1. Then the school buses were rerouted manually after selected roads were removed from the system to obtain the change in school bus travel costs resulting from road abandonment. Postal service travel routes and costs before and after the selected roads were eliminated from the system were estimated by officials from the U.S. Post Office.

Maintenance Costs

Total maintenance costs for paved, gravel and dirt roads consist of fixed and variable maintenance costs. The fixed portion of maintenance cost is independent of the traffic level and composition and is associated with signing, slope erosion, ditching, and snow removal. The variable portion of maintenance cost for gravel and dirt roads is expressed as a function of the average daily traffic level of the road, whereas the variable portion of maintenance cost for paved roads is expressed as a function of kip loadings.

The basic assumption underlying the variable maintenance cost of paved roads is that a portion of the cost varies directly with the number of standardized (18-kip) axle loads passing on the road. Each type of pavement is designed to withstand a projected number of 18-kip loadings during the expected life of the road. An increase in the number of axle loadings in the form of more trips or heavier vehicles increases the maintenance cost of the road surface. Variable maintenance costs for paved roads were estimated as follows:

$$VMC = \frac{TK}{AK} \cdot AVMC \cdot D \qquad (2)$$

where

VMC = variable maintenance cost;
TK = total number of standardized (18-kip) loadings applied in 1982;
AK = average annual standardized (18-kip) axle loadings embodied in the pavement;
$AVMC$ = average annual variable maintenance cost per mile of paved road; and
D = length of the road segment in miles.

Equation 2 adjusts the average annual variable maintenance cost per mile of paved road for changes in the number of trips as well as for changes in vehicle size and weight.

The periodic reconstruction and resurfacing costs were annualized over a 45-year life cycle. The opportunity cost of keeping the land in roads rather than in alternative uses was assumed to be the annual rental value of nearby land in agricultural production minus the annualized cost of converting the right-of-way to agricultural production.

THE DATA

Travel Patterns

Data on 1982 personal and farm travel were obtained by a traffic survey of households and farms in the three study areas *(11)*. Data were obtained on the exact location of each respondent's home and land tracts within and outside the study areas as well as the location of home and field driveways. In addition, the number of trips was gathered by vehicle type for the following:

1. Origin of deliveries to each home and field tract;
2. Origin and destination of pickup truck and farm equipment trips;
3. Intra- and off-farm product hauling by type of product, origin, and destination;
4. Personal trips by origin, destination, and purpose; and
5. Origin of visits to each household.

Of the 753 farms that were interviewed, 727 completed questionnaires for a response rate of 96.5 percent. Of the 1,205 households that were interviewed, 1,146 completed questionnaires for a response rate of 95.1 percent. Neighbors were questioned about the characteristics of farms and households for the refused interviews. Questionnaires from respondents with similar traits were then substituted for the refusing respondents.

The questionnaire did not include data on school bus, post office, and overhead traffic that did not originate and terminate within the study area. School bus routes were obtained from the school districts operating buses in the study areas. The U.S. Post Office provided data on postal routes and costs. A "stop and go" traffic survey was conducted in Study Area 1 to obtain data on overhead traffic traveling through but not originating and terminating in the study area. Study Areas 2 and 3 were judged to have an insignificant amount of overhead traffic on county roads.

Vehicle Travel Costs

More than 100 different types of vehicles traveled over the county roads in the three study areas. The large number of vehicles made it necessary to group several different types of vehicles together and to then estimate costs for a typical vehicle in each group. The major vehicle groups for which travel costs were estimated were automobiles; pickup trucks; school buses; commercially owned vans and trucks; garbage trucks; farmer-owned single-axle, tandem-axle, and semitrailer trucks; and three farm combine sizes and four farm tractor sizes, each pulling seven sizes of grain wagons or farm tillage equipment.

Variable operating costs per mile were estimated for each of these vehicle groups operating on paved, gravel, and earth-surfaced roads where variable operating costs include fuel, oil, tires, maintenance, and travel time. Variable costs are assumed to be a linear function of the number of miles traveled on each surface type. Therefore, all estimated costs are estimated in cents per mile. The costs are based on 1982 prices and representative vehicles. In cases where 1982 prices were not available, the available prices were adjusted to 1982 price levels. The cost per mile estimates and the estimation procedure are described in Hansen et al. *(12)*.

A travel time penalty was added to the travel cost of the time-critical farming operations of planting and harvesting if changes in the road system required additional travel distances for these operations. The travel time penalty was estimated by calculating the cost of increasing machine capacity to permit the farmer to drive the additional distance and complete the time-critical farming operation in the same total time required before the change in the road system. A description of this procedure is presented in Baumel et al. *(11)*.

Maintenance and resurfacing costs for paved roads and reconstruction costs for all roads and bridges were obtained from the Iowa Department of Transportation *(13)*. Maintenance costs for bridges and gravel, earth, and oil-surfaced roads as well as the costs of converting abandoned road right-of-way were obtained from county engineers.

RESULTS

The base solution in each study area provided estimates of total miles and variable travel costs with the full 1982 road network

TABLE 1 NUMBER OF MILES OF ROAD ABANDONED AND CONVERTED TO PRIVATE DRIVES BY STUDY AREA SOLUTION

Study Area	Solution	Miles Abandoned
1	1	5.25
1	2	3.75
2	1	9.25
2	2	6.75
2	3	5.25
3	1	17.75

in the model. Then, low-traffic-volume road segments with no property access points were removed from the computerized road network, and the network model was rerun to obtain total miles and variable travel costs for the reduced network.

Table 1 gives the number of miles of roads abandoned by study area solution. Multiple solutions were run in Areas 1 and 2. In the multiple solutions, roads abandoned in the previous solutions remained abandoned in subsequent solutions.

Table 2 gives the base solution estimates of total miles of travel, cost of travel, and percentage distribution of the miles and cost by type of travel for the three study areas. The total number of miles of travel was more than four times larger in Area 1 than in Areas 2 or 3. The principal reason for this large number of miles of travel in Area 1 is that it contains a substantial number of housing developments. In addition, overhead traffic accounted for 25 percent of the total miles of travel in Area 1. No overhead traffic surveys were conducted in Areas 2 and 3.

Approximately two-thirds of all travel in all three areas was for household purposes, mostly by automobile. Travel for farming purposes accounted for less than 5 percent of total travel in Area 1 but about one-third of the travel in Areas 2 and 3. However, farm travel costs were 8 percent of travel costs in Area 1, 40 percent in Area 2, and almost 50 percent in Area 3. Thus, although farm travel miles is a relatively small portion of total travel miles in Area 1, it is a major share of total variable travel costs.

Table 3 gives the estimated change in travel costs resulting from road abandonment. The large computer cost to run these models limited the number of alternative solutions that could be run. Several major observations can be made from Table 3. First, none of the Area 1 overhead traffic traveled on the roads abandoned in the first solution, and only a small amount traveled on the roads abandoned in the second solution, so overhead traffic had little impact on this analysis. The fact that Area 1 has a large amount of overhead traffic and only a small amount of overhead traffic affected by road abandonment suggests that overhead traffic can be ignored in abandonment analyses if the study area size is approximately 100 mi^2. Second, additional travel costs per mile of abandoned road increase at an increasing rate as additional miles are taken out in multiple solutions in Area 2. Third, farm travel incurs the largest percentage of additional travel costs. If the travel time penalty cost is added to the change in farm travel costs, farm costs are about one-half or more of the total change in travel costs. Fourth, school bus and post office costs range from 2.8 to 26.7 percent of total additional travel costs depending on which roads are abandoned. Therefore, these costs should be included when evaluating road abandonment.

Table 4 gives the estimated annual savings from abandoning the roads in the three study areas. The average savings ranged from $4,205/mi to $10,887/mi of road abandoned. The major reason for the $10,887 savings in the first solution of Area 2 is the large number of bridges on the roads abandoned in this solution. Nearly 58 percent of the cost savings were from bridge maintenance and reconstruction cost savings. The other major sources of cost savings were fixed maintenance and reconstruction cost savings.

In several solutions, variable maintenance and paved resurfacing costs increased. These higher costs occur on roads that inherit the traffic from the abandoned roads. Thus, nearby roads incur increasing variable maintenance, reconstruction, and re-

TABLE 2 ESTIMATED TOTAL MILES OF TRAVEL AND COST OF TRAVEL IN THE BASE SOLUTION AND THE PERCENTAGE DISTRIBUTION OF TRAVEL MILES AND COST BY TYPE OF TRAVEL AND STUDY AREA, 1982

	Area 1		Area 2		Area 3	
Total and Percent of Miles and Cost by Type of Travel	Total Miles	Total Cost	Total Miles	Total Cost	Total Miles	Total Cost
Total travel (mi)	28,213,628		6,212,210		5,075,169	
Total cost ($)		6,864,943		1,857,246		1,515,083
Percent of miles and cost by:						
Household (%)	69.7	66.0	68.5	55.0	63.3	47.3
Overhead (%)	25.0	24.6	—[a]	—[a]	—[a]	—[a]
Farm (%)						
Automobile (%)	0.1	0.1	0.6	0.5	1.0	0.8
Pickup (%)	3.4	4.1	23.3	23.4	26.9	25.6
Trucks (%)	0.7	1.2	2.9	3.9	2.7	3.5
Tractor-wagon (%)	0.1	0.5	0.7	3.0	1.0	4.7
Tractor-equipment and combines (%)	0.4	2.1	2.2	9.8	3.1	13.6
School buses (%)	0.3	0.5	0.8	1.2	0.9	1.2
Post Office (%)	0.3	0.9	1.0	3.2	1.1	3.3

[a] Overhead traffic was not estimated in these areas.

TABLE 3 ESTIMATED 1982 CHANGE IN TRAVEL COSTS RESULTING FROM ROAD ABANDONMENT, THE DISTRIBUTION OF ADDITIONAL COSTS BY TYPE OF TRAVEL, AND THE MILES OF ROAD ABANDONED

	Area 1		Area 2			Area 3
	Solution 1	Solution 2	Solution 1	Solution 2	Solution 3	Solution 1
Miles abandoned	5.25	3.75	9.25	6.75	5.25	17.75
Change in travel costs from previous solution ($)	29,822	25,698	39,179	78,436	76,668	58,146
Percentage distribution of additional costs by—						
Households	28.4	34.4	14.2	15.6	40.1	7.0
Overhead traffic	0	1.5	—[a]	—[a]	—[a]	—[a]
Farm travel	38.4	56.3	74.1	69.7	45.2	60.3
Farm timeliness penalty	6.5	5.0	5.6	4.3	4.7	9.8
School buses and post office	26.7	2.8	6.1	10.4	10.0	22.9

[a] Overhead traffic was not estimated in these areas.

surfacing costs from the higher traffic levels. The increase in variable maintenance costs on roads inheriting the traffic from the abandoned roads exceeds the variable maintenance cost savings on the abandoned roads in four of the seven solutions. Fixed road maintenance and net land rental values are a function of miles of road abandoned, while the bridge maintenance savings are a function of the number and size of abandoned bridges and not of traffic levels.

Table 5 gives the estimated benefit-cost ratios of the five abandonment solutions. In urbanized Area 1, the benefit-cost ratio for the first abandonment solution was 0.88; that is, the traveling public spends $0.88 in additional travel costs for each $1.00 saved in maintenance and investment costs when the 5.25 mi of road were abandoned. In the second abandonment solution in the urbanized area, the benefit-cost ratio was 1.01. The additional roads abandoned in this solution had higher traffic levels than those abandoned in the first solution. The abandonment of the roads in the second solution would force the traveling public to incur additional travel costs approximately equal to the maintenance and investment cost savings from abandoning these roads.

In the largely rural Area 2, the benefit-cost ratio of abandoning the first set of 9.25 mi was 0.39, but the ratio climbed to 1.73 and 3.47 for the next 6.75 and 5.25 mi of abandoned roads, respectively. The major reasons for the low ratio in the first solution were the low traffic levels and the high cost of rebuilding and maintaining the bridges on these roads. The benefit-cost ratios increased as additional sets of roads were abandoned because each additional set of roads considered for abandonment had more traffic than the previous set of roads. Moreover, only 11.5 percent of the roads in Area 2 were paved roads. Thus, the traffic from the abandoned roads was rerouted onto gravel or oiled roads that have high vehicle travel costs and high variable maintenance costs.

TABLE 5 BENEFIT-COST RATIOS FOR SIX SOLUTIONS

Area	Solution	Benefit-Cost Ratio
1	1	0.88
1	2	1.01
2	1	0.39
2	2	1.73
2	3	3.47
3	1	0.61

TABLE 4 ESTIMATED ANNUAL MAINTENANCE AND INVESTMENT COST SAVINGS FROM ABANDONING SELECTED ROADS BY STUDY AREA

	Area 1		Area 2			Area 3
	Solution 1 ($)	Solution 2 ($)	Solution 1 ($)	Solution 2 ($)	Solution 3 ($)	Solution 1 ($)
Road costs						
Variable maintenance	–1,275	3,952	–1,036	–2,727	–4,727	1,647
Fixed maintenance	12,258	8,471	20,957	17,001	14,516	42,174
Resurfacing	26	–176	–41	–50	29	0
Reconstruction	6,141	7,019	10,194	14,819	–8,900	8,893
Bridge costs						
Maintenance	1,284	583	10,159	1,781	2,529	3,120
Reconstruction	8,441	4,191	57,807	12,516	17,115	19,618
Net land rental value minus land reconstruction costs	7,184	1,437	2,663	1,943	1,512	19,313
Total	34,059	25,477	100,703	45,283	22,074	94,765
Average savings per mile of abandoned road	6,487	6,794	10,887	6,709	4,205	5,339

In Area 3, the benefit-cost ratio for the abandoned roads was 0.61. Area 3 has lower traffic levels and a relatively high percent of paved roads. Thus, the traffic rerouted from the abandoned gravel roads to paved roads had lower vehicle operating costs, and the paved roads inheriting the additional traffic had relatively low maintenance costs.

The benefit-cost ratios reported in this paper are lower than the benefit-cost ratios for the same set of abandoned roads that were reported in Baumel et al. *(11)*. The reasons for the lower ratios are the following:

1. Road reconstruction and paved resurfacing costs in this analysis are estimated on a 45-year life cycle. In the earlier report, these costs were estimated on a one-time investment basis.
2. In this paper, bridges are reconstructed every 45 years. No bridge reconstruction costs were included in the earlier analysis.
3. In this analysis, no resurfacing costs were charged to gravel roads. Annual maintenance costs include sufficient gravel to maintain an adequate gravel surface. In the earlier analysis, gravel roads were resurfaced every 20 years in addition to the resurfacing contained in annual maintenance costs.

SUMMARY AND CONCLUSIONS

The basic purpose of the study was to develop guidelines for local supervisors and engineers in evaluating local rural road investment or disinvestment proposals and to provide information to state legislatures in developing local rural road and bridge policies.

Three case study areas of 100 mi^2 each were selected in Iowa for this analysis. Study Area 1 has a high agricultural tax base, a high percentage of paved roads, and a large number of nonfarm households with commuters to Cedar Rapids and Waterloo. Study Area 2 has a low agricultural tax base, hilly terrain, a low percentage of paved roads, and a large number of bridges. Study Area 3 has a high agricultural tax base, a high percentage of paved roads, and few bridges. The major conclusions from the study were as follows:

- The major sources of vehicle miles on county roads are automobiles used for household purposes and pickup truck travel for farm purposes.
- Farm-related travel represents a small percentage of total travel miles but a high percentage of total travel costs.
- In areas with a large nonfarm population, a small number of low-traffic roads on which the increased vehicle travel costs of the rerouted traffic will be less than the maintenance and investment cost savings can be abandoned.
- In areas with a small rural population and a large percentage of gravel roads, abandonment of roads with no property accesses and high bridge maintenance and reconstruction costs will result in additional travel costs that are sharply lower than savings in maintenance and investment costs. However, if the bridge maintenance and reconstruction costs are relatively low, the additional travel costs incurred from rerouting the traffic over gravel roads tend to be greater than the maintenance and reconstruction savings from abandonment.
- In areas with a small rural population and a high percentage of paved roads, a relatively large number of miles of county roads with no property accesses can be abandoned on which the savings from abandoning the roads will exceed the additional travel costs.

The public policy implications of these results are as follows:

- There are limited potential cost savings from abandonment of local rural roads with no property accesses in areas with a large nonfarm population.
- There are high potential cost savings from abandonment of roads with no property accesses in areas with a small rural population and a core network of paved roads.
- There are potential savings from abandonment of roads with no property accesses that have high bridge costs in areas with a small rural population and a large share of gravel roads. However, more roads might be abandonment candidates if some gravel roads are resurfaced to create a core paved network. This alternative was not explored in this analysis.
- There can be substantial legal costs and damage awards associated with road abandonment. The possibility and extent of such costs depend on the state laws in effect in the various states. Because these costs vary widely from case to case, it was not possible to include these costs in the benefit-cost ratios in this study.

Present laws in some states may preclude any possibility of road abandonment even though all costs considered, including the shifting of road costs from the public to private sector, indicate a net benefit from such abandonments. In fact, it may require changes in state laws, along with a major change in public policy and acceptance, before any of these changes could and would be implemented and accepted. Some of the areas that need to be addressed are the following:

1. Adequate methods of compensation for those adversely affected by road abandonment.
2. Exemption of local government authority from legal action upon completion of established guidelines.
3. Legislative consideration to strengthen existing laws regarding road abandonment.
4. A method of educating the public of the benefits and costs of alternative road system changes to enhance the quality of the public input into the policy-making process.

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Condition Assessment and Improvement Needs of Locally Maintained Arterial and Collector Highways in Wisconsin

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A study has been conducted of the existing condition and the need for improvement of locally maintained arterial and collector highways in Wisconsin. The analysis required the collection of significant additional roadway condition data. Emphasis was placed on gathering information on pavement surface condition, drainage, and alignment and other geometrics. A 955-mi sample was surveyed initially. Existing conditions were analyzed and needs were projected for the 21,540-mi locally maintained arterial and collector system. The second phase of the study involved data collection and analysis for an additional 8,500 mi during 1986. Results of the condition assessment showed that on the average pavement conditions are similar to those of state trunk highways. However, the arterials and collectors that are maintained locally have poorer geometrics compared with those of state trunk highways. More than 3,500 mi have poor pavement conditions, 2,500 mi have poor alignment or drainage, and 2,900 mi have shoulders less than 2 ft wide. Existing federal aid funding for repairs is inadequate to meet projected future needs. Approximately $60 million annually of additional state and local funds will be necessary to address the projected needs of these vital Wisconsin highways.

The primary purpose of this work was to study the current and prospective improvement needs for arterial and collector streets and roads under local jurisdiction in Wisconsin. The goal was to identify the improvements required to have the whole of the state and local arterial and collector highway system provide an acceptable level of total highway service. Study results were also to be used to examine the adequacy of resources currently devoted to the rural secondary and urban systems. Recommendations were to be completed in time to incorporate them, as necessary, into the 1987–1989 Department of Transportation (DOT) budget proposal.

Arterial and collector highways maintained by local governments in Wisconsin have been a significant link in the state's highway network. Funding to improve these highways traditionally has been a combination of federal-aid secondary programs, federal-aid urban programs, and local funds. Current state aids from the transportation fund have also been used for funding improvements. The Surface Transportation Act of 1982 held these two federal-aid programs to previous levels of funding even though revenues collected for the trust fund increased significantly. This fact, coupled with the erosion by inflation of the purchasing power of highway revenues, has exaggerated the revenue gap. Subsequent policy discussions have raised further concern over future funding and perhaps even the existence of these categories of federal support.

In Wisconsin, the local government's ability to provide adequate funding for this highway network has been severely strained. At the same time, pavements have continued to deteriorate and traffic volumes to increase on these highways. Local governments have expressed serious concern over their future abilities to address improvement needs.

In response to these concerns, the Wisconsin DOT initiated a needs study to determine the condition of locally maintained arterials and collectors, and to assess the need for improvements. The study was to establish alternatives and funding levels to be considered in developing the 1987–1989 Wisconsin transportation budget.

There was virtually no data on the pavement condition of roadways off the state trunk highway system. Therefore, the first step in the study was to determine the condition of arterials and collectors maintained by local governments. Future needs for improving these highways were to be projected based on this condition information. The study was begun in fall 1984, and was to be completed with recommendations by fall 1986.

ORGANIZATION

A steering committee of 43 members, representing the Wisconsin DOT and local governments, directed the needs study. The committee members were primarily professionals and technical staff rather than elected officials.

The steering committee was organized into three subcommittees; the Wisconsin DOT provided staff support. Specific responsibilities of the subcommittees were as follows:

1. *Standards and Guidelines* Subcommittee. Identify data requirements; establish alternative threshold and improvement levels; and analyze and assemble alternative needs study results.
2. *Road Inventory* Subcommittee. Determine and select a valid sample; develop inventory methodology and procedures.
3. *Program and Financial Management* Subcommittee. Develop alternative management and financial programs.

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First the steering committee reviewed and affirmed the overall purpose of the study. It was agreed that the study should document existing arterial and collector roadway conditions, then develop improvement needs in terms of miles and costs to maintain this system in the future. Although the committee agreed that the condition study should be objective and would be unlikely to provoke controversy, the committee recognized that reaching a consensus on the level and distribution of future needs might not be possible. Therefore, as a minimum, the steering committee decided to develop a range of alternatives for consideration by the Wisconsin DOT, local associations, and the Wisconsin legislature.

STUDY METHODOLOGY

Scope

The steering committee first determined the basic scope of the study and approach. In Wisconsin, local governments of counties, cities, villages, and towns are responsible for maintaining 95,646 mi of roadway. Table 1 presents the distribution of this mileage. There are 21,540 mi functionally classified as arterials and collectors. This includes 10,669 mi currently on a federal aid system. Although the committee expressed considerable interest in condition assessment and improvement needs estimates for local roads, the scope of the study was restricted to include only arterials and collectors. This includes the federal aid system and most of the county trunk highway system. The rationale for this critical decision was that more than two-thirds of these miles are eligible for federal aid, and that concern over the future of the federal-aid program was a major emphasis in initiating this study. Furthermore, state responsibility for improving the arterial and collector system is potentially much greater than state responsibility for improving local roads. Therefore, it was determined to include only arterials and collectors; the methodology developed may prove useful for a future study related to local roads.

This study used the state functional classification system assigned to a section of road for distributing state transportation aids. The functional classification categories are the same as those used by FHWA, but the definitions have been modified slightly to reflect Wisconsin's specific characteristics.

The study does not include an assessment of bridge condition and needs. All bridges have already been inspected, inventoried, and rated. A program for rehabilitation and replacement is funded with federal, state, and local money. The committee believed that bridge needs are being addressed and should not be included in this study.

Concept

In Wisconsin, transportation aid funds from the Wisconsin DOT are distributed directly to local governments. Although these funds may be used for maintenance, construction, or other purposes, including highway improvement work, it is generally accepted that they be used for basic maintenance and low-level improvements. This transportation aid represents between 20 and 30 percent of the total local expenditures for roadway maintenance and improvement. Currently, there are no additional separate seate funds targeted for highway improvements. Although the distribution of existing transportation aids is obviously a subject of continuing interest and discussion, the steering committee decided it would not address that issue. The focus of the study was to identify improvement needs on the arterials and collectors and to formulate alternatives for additional funding for these improvements.

The report of the steering committee was to be available by fall 1986. Considering the size of the study and the work required, a careful work plan was required. Results of this study would identify improvement needs on a portion of locally maintained highways. These needs obviously had to be balanced with other statewide transportation needs. To assist in final analysis, it was determined that this study should use methodology similar to existing state highway planning procedures. This policy, which would allow comparison with the needs of the state trunk highway system, was considered essential in the decision-making process.

The steering committee also decided that to the extent possible existing data collection and analysis procedures would be used. Development of new methodology, though perhaps advantageous, was limited because of the restricted time schedule for this study. Therefore, the study methodology paralleled procedures for the development of the state highway plan and improvement programming.

TABLE 1 FUNCTIONAL CLASSIFICATION AND JURISDICTION OF LOCALLY MAINTAINED HIGHWAY

	Functional Classification[a]					
		Collectors				
Jurisdiction	Arterials (mi)	Major[b] (mi)	Minor (mi)	Subtotal (mi)	Local (mi)	Total (mi)
County	1,089	10,218	4,536	15,843	4,388	20,231
City	1,235	847	166	2,248	8,677	10,875
Village	116	148	80	344	3,008	3,334
Town	81	974	2,050	3,105	58,156	61,206
Total	2,521	12,187	6,832	21,540	74,106	95,646

[a]January 1, 1985, system data.
[b]Includes urban collectors.

Existing Data

Significant data on the local road system existed in Wisconsin DOT files. Data on mileage, location, jurisdiction, surface type, and function classification are currently on file. This information is collected and updated by district staff annually. Such basic geometric information as lane width, roadway width, right-of-way width, and actual or estimated traffic count is also included in the file.

Accident data on individual highway segments were not available from a centralized source. Data on roadway condition, drainage, and alignment also were not available.

Condition Assessment

The Standards and Guidelines Subcommittee reviewed the existing data and recommended the collection of additional data. The subcommittee considered the lack of existing pavement condition information a serious constraint. Improvements to highways under local jurisdiction are normally made only when surface condition has deteriorated significantly. Obviously, spot safety improvements are made and in urbanized or urban areas capacity improvements are also made. However, even in these cases priorities are assigned to roadway segments that also have poor surface condition. Therefore, it was determined that the needs study must collect additional pavement condition information. Table 2 presents a complete listing of data items used in the study, including not just items already available but also items that needed to be gathered in the field or generated in an office.

Because an emphasis on pavement surface condition was essential, the Standards and Guidelines Subcommittee evaluated various condition measurements. The Wisconsin DOT has recently developed one such procedure for surface condition evaluation called the pavement distress index (PDI). The PDI is based on a detailed survey of surface conditions. It measures the visible sign of pavement deterioration as determined by 10 distinct characteristics (cracking, rutting, flushing, distortion, etc.). These indications of deterioration, weighted and combined into a summary index of pavement structural adequacy, form the PDI. The PDI, which ranges from 0 (best) to 100 (worst), was developed under the guidance of experienced maintenance engineers to reflect existing judgment on severity of different surface distress conditions related to future highway life and rehabilitation needs. Data on the state trunk highway system have recently been completed. Because future maintenance and improvement needs will also be using this index on the state trunk highway system, the subcommittee selected the PDI as the measure of surface condition for this study.

The Wisconsin DOT has traditionally used the present serviceability index (PSI) in programming state roadway improvements. The PSI is a mechanical measure of surface roughness determined by an electromechanical meter mounted in an automobile. PSI is measured on a scale of 0 (worst) to 5 (best). Because of its traditional use and for objectivity, it was considered desirable to also collect PSI information in this local study. However, PSI data were collected on only approximately 20 percent of the sample because of minimum segment length and 50-mph travel speed requirements.

An alternative to the use of PSI was explored because of its need for equipment of limited availability and for an additional crew to survey the sampled segments. The pavement serviceability rating (PSR) as defined in the Highway Performance Monitoring System (HPMS) field manual *(1)* was selected. This item is a subjective measure of pavement condition recognizing not only ridability but also pavement distress. Values range from 0 (worst) to 5 (best). Because PSR is data collected by field personnel, it could be collected along with the PDI data. Because PSR data are less costly to collect than PSI data, correlation between PSR and PSI would be desirable for enhancing the use of PSR in future data collection efforts.

The importance of adequate drainage in long-term pavement performance is well recognized. Therefore, the subcommittee believed that some assessment of drainage condition was also essential in evaluating roadway conditions. The HPMS field manual describes an accepted procedure for assessing drainage

TABLE 2 DATA ITEMS FOR NEEDS STUDY

Data Available from Current Files	Office-Generated Data	Data Gathered by Field Inventory
County	Cross section	Pavement distress index
Section ID	Urban/urbanized code	PSR
Road name	Jurisdiction	PSI (rural only)
Termini	Surface type	Lane width (rural only)
Rural/urban code	Access control	Approach width (urban only)
Functional class	Shoulder type	Horizontal alignment (rural)
Federal aid system	Curb and gutter	Vertical alignment (rural)
Facility type	Divided roadway	Percent passing sight distance (rural)
Length	Average highway speed	Speed limit
AADT	Capacity	Drainage adequacy
Through lanes	Parking (urban only)	Urban location (urban only)
Shoulder width, right (rural only)	Future AADT	
	AADT volume group	
	Expansion factor	
	Pavement age	

adequacy; the HPMS rating scale was adopted because it could allow correlation with independent data.

Evaluation of safety was considered an important aspect in evaluating current conditions and future needs. However, adequate safety data on individual segments were not available. Records were scattered among various local agencies, and there appeared to be no practical way to collect accident data for each segment. After other indicators of safety were discussed, the subcommittee decided to use roadway geometrics. Because some assessment of horizontal and vertical alignments was necessary, and for the same reason stated for drainage, a rating scale for alignment similar to that in the HPMS manual was adopted by the subcommittee.

Sample Survey

A review of the data collection needs and the size of the system indicated it was necessary to collect data on a sample rather than on the entire system. The entire system contains 21,540 mi, and the inventory file breaks this into 29,936 individual segments.

A computer-aided random sampling process patterned after the HPMS procedure was used to select the sample. First the entire 21,540-mi system was stratified into several important categories. Obviously, the functional classification of arterials and collectors was important. The jurisdiction (maintenance authority) was also important. In Wisconsin, there are four types of jurisdictions—counties, towns, cities, and villages—that have various maintenance and improvement responsibilities. Because of their similarity, cities and villages were combined into one stratum. Conditions and needs were likely to vary by area type—rural, urban, and urbanized. Therefore, data collection should recognize rural (less than 5,000 population), urban (5,000 to 50,000 population), and urbanized (more than 50,000 population) areas. Samples were also chosen within certain traffic volume ranges; those categories having been selected to ensure that the sample adequately represented the entire system. A random sample of segments to be inventoried was selected for each unique combination of factors. The size of each sample differed in each case depending on the variability of traffic volumes within a particular stratum so that the sample data could legitimately be expanded to represent the entire mileage having that particular combination of factors.

Considering the possible stratifications of the data and various confidence and precision levels, sample size requirements for several options were developed. The committee determined that the minimum usable study would be to determine conditions and needs that would allow portrayal of highway needs on a statewide basis by jurisdiction and functional classification with a further statewide breakdown between rural, urban, and urbanized areas. It was believed that a confidence level of 90 percent and a precision of ±10 percent provided a reasonable compromise between sample size and usefulness of the data. The committee also believed the assessment of statewide needs would not provide sufficient detail required by local communities and decision makers to justify an additional improvement program. An expanded study is considered necessary to be able to adequately describe the needs and demonstrate the impact of this program. This option would allow determination of needs at the county level, but would not distinguish between individual towns and cities within the county. This expanded option would provide sampling of about one-third of the system and was considered a reasonable balance between cost and results.

A review of the data requirements in conjunction with staff availability indicated that a two-phase data collection effort was necessary. The statewide sample of approximately 1,000 mi could be collected during the summer of 1985. This effort would allow initial analysis in the fall of 1985 and early 1986 pending satisfactory results. It would permit sizing up the program on a statewide basis, but would not enable any needs-based funding distribution. It would also provide an opportunity to review a smaller set of data and make revisions before collection of 8,500 mi of data. The expanded sample of approximately 8,500 mi could then be collected in the summer of 1986. This would meet the project deadlines.

Data Collection

The initial 955-mi statewide sample data were collected in the summer of 1985. Originally all of the field work was to have been done by two Wisconsin DOT central office crews, but some districts volunteered to do part of the work within their district. All the field work, however, was coordinated by the central office. It was determined that two-man crews were required to efficiently and safely conduct the field inventory condition ratings. Because of the importance of pavement condition data to the study, the committee asked that experienced engineering and technical personnel be used to do the pavement rating work. Therefore, crews composed of an experienced engineer as crew chief and an engineering technician as an assistant were hired.

Central office and district crews were trained during a 3-day workshop on data collection. To provide uniformity in the statewide collection of condition data, central office engineers prepared a manual. Training included a step-by-step review of condition and pavement distress rating procedures in the manual, followed by field demonstrations. Preselected sections had previously been rated by Wisconsin DOT staff engineers.

Data collection efforts proceeded smoothly over a 3-month period. Total cost of the data collection for the 955-mi sample, including salaries, fringe benefits, travel, meals, motels, training, and computer charges, was around $80,000. Approximately 2,000 hr of effort were required. Crews were able to collect the required data on 24 segments of roadway in a 10-hr day. Because of the dispersion of the sample, an average of 8.62 mi of travel was necessary per sample segment.

Collection of data on approximately 8,500 mi of roadway was to be completed during the summer of 1986. Two-person crews from each of the eight district offices were to complete the inventory. All crew received training similar to the 1985 sessions. Total cost of the data collection effort for the expanded sample was projected to be $231,000. Ten crews of two persons each were expected to complete the inventory over a 3-month period. Sampling rates were expected to improve as a result of more experienced crews and the proximity of the 1986 sample segments. Travel to collect the required data was estimated to be reduced by about 15 percent.

Needs Assessment

The heart of the arterial and collector roads needs study was an assessment of the type and extent of physical improvement needs that would be required on locally maintained arterial and collector highways in Wisconsin to the year 2000. A computerized modeling procedure was developed to produce estimates of highway needs for three study periods: (a) 1986 or backlog, (b) emerging to 1990, and (c) emerging between 1990 and 2000. This modeling procedure was closely patterned after the procedure used in the development of the *State Highway Plan—2000 (2)* to assess required improvements on state trunk highways.

The study's highway deficiency analysis process compared various geometric and performance characteristics of segments of the locally maintained arterial and collector highway system against alternative sets of threshold condition levels to determine ranges of existing and future system deficiencies and the ranges of improvement programs needed to alleviate the identified deficiencies. Figure 1 shows the analysis process.

Deficiency Analysis Logic

The fundamental assumption of the arterial and collector highway needs analysis was that combinations of several key roadway conditions, when identified in a ranked order of consideration, indicate the level of physical improvement needed for any

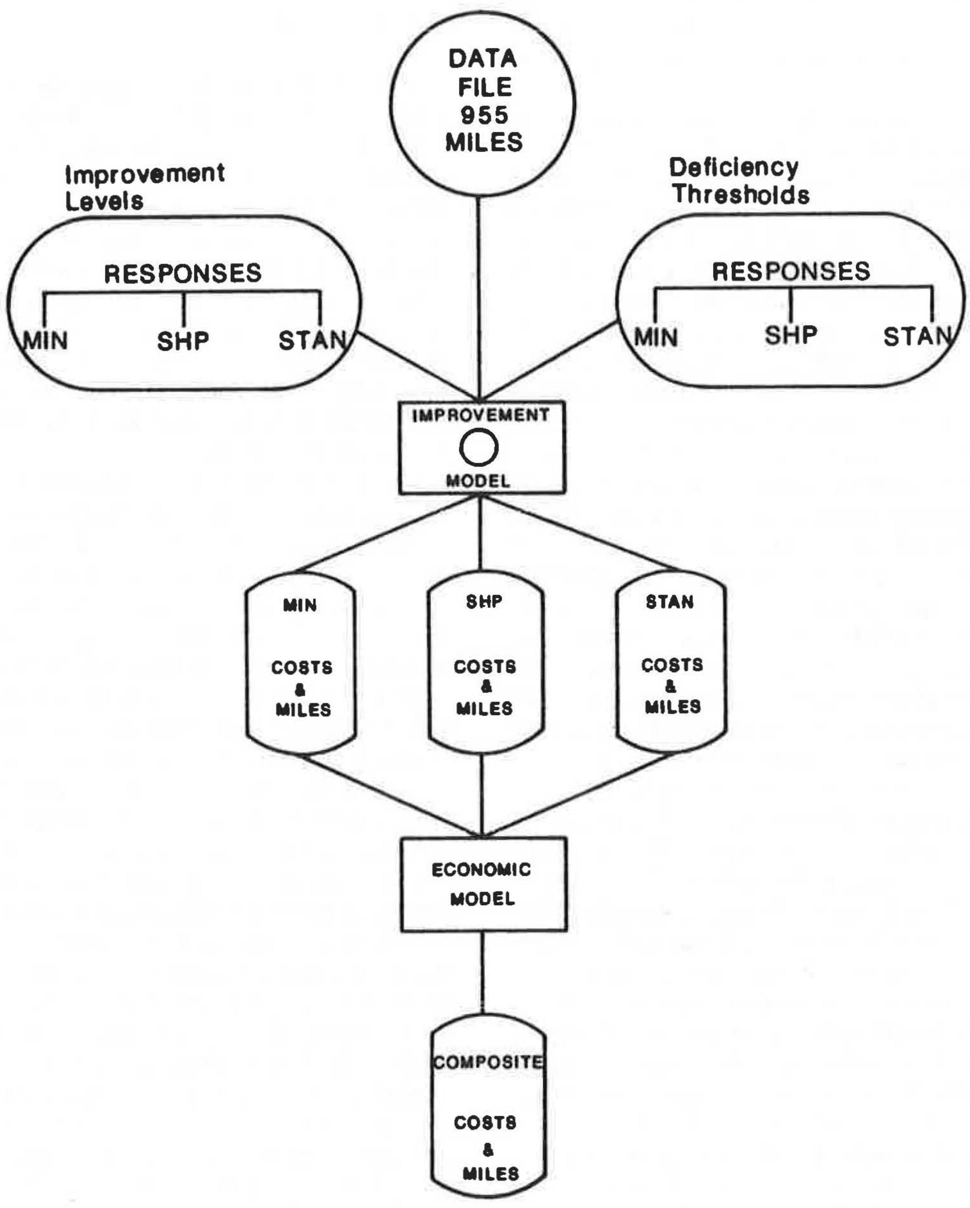

FIGURE 1 Deficiency analysis process.

given highway segment. If one or more of these key roadway conditions was at a less-than-satisfactory threshold level, then the highway segment in question was assigned to an improvement category. The threshold levels varied by definition for each alternative highway management strategy, but in every case those applied were consistent with accepted highway engineering principles. The specific design levels for each improvement category were correlated with the alternatives used to define each threshold condition level.

Highways are improved to alleviate deficiencies in capacity, pavement, or geometry. The deficiency analysis evaluated both existing and future conditions on individual segments of the arterial and collector highway system by examining these types of deficiencies. The source of the highway data analyzed in the study was the Wisconsin DOT's local road inventory file maintained by the Bureau of Environmental and Data Analysis, supplemented by additional data from the 955-mi inventory sample collected during the summer of 1985. The deficiency indicators used in the analysis are as follows:

Capacity
- 200th-hr volume-to-capacity ratio
- Number of lanes

Pavement
- Pavement serviceability rating (PSR)
- Pavement distress index (PDI)
- Bituminous road mix surface
- Gravel road surface

Geometrics
- Percent passing
- Lane width
- Shoulder width
- Shoulder paving
- Horizontal alignment
- Vertical alignment
- Drainage

The deficiency analysis logic differentiated between rural and urban segments by cross section type. Highway segments with rural cross sections have shoulders and ditches, whereas urban cross sections have curbs and gutters.

For any highway improvement need to be identified, the pavement deficiency indicators (PSR and PDI) had to be worse than the prescribed threshold conditions. Additional primary deficiency indicators of 200th-hr volume-to-capacity ratio and geometrics (alignment and drainage) were used to identify specific physical improvements. Unsatisfactory conditions in the other items listed were considered secondary indicators of need, which, when combined with an unsatisfactory primary measure, suggested the type of improvement required to adequately address those deficiencies.

To assess future needs, traffic volumes consistent with statewide forecasts for each target year (1990 and 2000) were developed for each highway segment. In addition, pavement conditions were deteriorated over the planning period by decaying the PSR and PDI values according to surface age and pavement type, based on the earlier state highway plan analysis of historic trends in pavement life on Wisconsin highways.

This process led to the identification of emerging traffic- and pavement-related deficiencies for 1990 and 2000. The process also updated pavement, geometric, and operating characteristics to reflect the improvements called for in each target year analysis.

Alternative Threshold and Improvement Levels

Each set of threshold and improvement levels represented an alternative or response that could be made to accommodate future travel demand (i.e., a planned quality of service for the locally maintained arterial and collector highway system). The following definitions are given to assist in understanding this concept.

Threshold—A level of roadway condition where a worse condition is considered to be unsatisfactory or deficient for that item.

Improvement level—The level of roadway condition associated with a new street or highway once an improvement project has been completed.

Improvement type—Improvement types considered in the analysis were as follows:

Resurfacing. Resurfacing or recycling of an existing pavement to provide a better all-weather surface and a better riding surface, and to extend the pavement life.

Recondition 1. Resurfacing plus widening of pavement or shoulder paving.

Recondition 2. Resurfacing or Recondition 1 plus shoulder widening with the improvement of an isolated grade, curve, or intersection, sometimes requiring right-of-way.

Reconstruction. Total reconstruction to improve maintainability, geometrics and traffic service, usually on existing alignment, and generally requiring additional right-of-way.

Capacity. Capacity expansion projects. Reconstruct existing two-lane facility to an expressway or freeway or add lanes.

Urban Recondition. Resurfacing plus drainage improvements.

Response—A compatible set of threshold and improvement levels that are used to estimate highway needs. Existing highway conditions are compared to the threshold levels to determine when a highway is deficient, whereas improvement levels specify the type of treatment required to correct the identified deficiencies.

Three alternatives or responses were considered:

Response STAN. Used existing county trunk highway standards in setting threshold and improvement levels for those factors for which standards were available. This was intended to be the highest level.

Response SHP. Used thresholds and improvement levels from the adopted state highway plan, which was being implemented for the state trunk highway system.

Response MIN. Used thresholds and improvement levels from the most austere alternative analyzed in the recent state highway planning process.

All improvement cost figures were calculated in terms of constant 1986 dollars. These costs were determined by applying a cost-per-mile rate based on state highway plan data and on a survey of local highway officials as to recent actual construction experience. These figures are illustrated in greater detail in Table 3.

Economic Analysis

Improving highway segments benefits highway users primarily by saving travel time, avoiding vehicle operating costs, and lowering accident rates. The benefits associated with the alternative threshold and improvement levels differ because they affect the condition and characteristics of a highway segment both before and after improvement. By comparing highway user benefits to highway improvement costs, the alternative producing the greatest increment of benefits over cost can be identified.

For each alternative (Responses MIN, SHP, and STAN), all rural highway segments projected to need reconditioning, reconstruction, or other capacity expansion were subjected to an analysis of the present value of the benefits and costs associated with such improvements. Benefits were analyzed using the Highway Investment Analysis Package (HIAP), a cost-benefit analysis model developed by the FHWA. Resurfacing was considered as the base option, and the analysis considered the incremental benefits and costs of improvements beyond resurfacing.

HIAP was used to estimate user benefits at the segment level. The actual cost-benefit analysis was performed for groupings of highway segments because the cost information available is best interpreted as an estimate of average cost. The segments were grouped based on the pattern of improvement levels called for by each of the study response alternatives. For each group, the response alternative that maximized the net present value of the improvements was identified. This response alternative was selected if its net present value was at least 5 percent greater than the Response SHP results for that group. Otherwise, the Response SHP was chosen. The combination of these selections formed a new alternative called the composite alternative.

Combining these elements into the composite alternative is more cost-effective than using any single response. The composite alternative has an additional $8.2 million in net present value (NPV). This increment represents a 170 percent increase over the NPV of Response SHP.

Because only limited traffic accident data were available for individual urban segments, the economic analysis has only been performed on rural highway segments. The annual NPV totaled $13.0 million for improvements to rural segments selected for the composite alternative. Response SHP was selected for all urban highways in generating the composite alternative. Because no benefits were assigned to improvements to urban segments, total benefits are understated.

RESULTS

Condition

Condition results are summarized in Table 4 by jurisdiction and functional classification. These data are based on the initial

TABLE 3 ANNUAL NEEDS TO 1990 LOCAL ARTERIAL AND COLLECTOR ROADS

Response Level	Length (mi)	Cost[a] ($)	Current Federal-Aid Programs ($)	Additional Local and State Funding Needed ($)
Minimum standards				
Arterials	19.7	5.8		
Major collectors[b]	180.3	16.7		
Minor collectors	140.4	20.2		
Total	340.4	42.7	24.5	18.2
SHP standards				
Arterials	70.7	16.7		
Major collectors[b]	186.2	23.3		
Minor collectors	210.6	35.2		
Total	467.5	75.2	24.5	50.7
Local standards				
Arterials	167.0	46.5		
Major collectors[b]	372.3	91.9		
Minor collectors	252.7	60.6		
Total	792.0	199.0	24.5	174.5
Composite				
Arterials	48.0	13.4		
Major collectors[b]	301.6	52.4		
Minor collectors	196.8	22.1		
Total	546.4	87.9	24.5	63.4

[a]Costs in millions of (1986) dollars.
[b]Includes urban collectors.

TABLE 4 CONDITION RESULTS 1985 WEIGHTED AVERAGES

	Pavement		Geometrics			Rural Cross Section Only		
	PSR	PDI	Alignment	Drainage	V/C Ratio	Percent Passing	Lane Width (ft)	Shoulder Width (ft)
Range of values	0–5	100–0	8–2	4–1		0–100		
Jurisdiction								
County	3.43	40	4.0	1.6	0.06	49.6	10.7	3.2
Township	2.93	50	4.7	2.2	0.02	36.2	9.9	1.8
City or village	3.59	42	2.7	1.4	0.21	65.4	11.0	2.5
Total system	3.38	42	4.1	1.7	0.07	47.9	10.6	3.0
Functional classification								
Arterials	3.65	41	3.1	1.4	0.23	54.6	11.0	4.4
Major collectors[a]	3.41	41	4.1	1.7	0.06	50.2	10.7	3.1
Minor collectors	3.21	43	4.3	1.7	0.03	42.6	10.4	2.6
Total system	3.38	42	4.1	1.7	0.07	47.9	10.6	3.0
State truck highways	NA	NA[b]	NA	NA	0.34	64.6	11.3	6.3

NOTE: NA = not available.
[a]Includes urban collectors.
[b]PCC = 39; BIT = 46.

955-mi sample collected in 1985. For comparison, state trunk highway average values are also given.

The condition of arterials was better than that of major collectors, which were better than minor collectors. The pavement condition, as expressed by the PDI, of the arterials and collectors was similar to that of the state trunk highway. Pavements on the town road system were in worse condition than those on the county and city systems. The alignment and drainage ratings showed the overall system to be in fair condition, with a significant number falling into the poor category. In the rural areas, the volume-to-capacity ratio did not indicate significant levels of need. The average rate of passing on the rural cross-sections was 47.9 percent, which compares to 64.6 percent on the state trunk highway system.

The lane width and shoulder width are additional categories where roads under study fell significantly below standards. Shoulder width in particular averaged 3 ft compared to an average of 6 ft on the state trunk highway system.

It is also useful to review the condition data for severe deficiencies. Table 4 lists the results of this analysis. A total of 3,507 mi had poor pavement surface conditions, defined as having a PSR less than 3.0 and a PDI greater than 70, which are the thresholds for the minimum alternative. There were 2,518 mi with either poor alignment or poor drainage. Narrow lanes (less than 10 ft) existed on 1,007 mi and narrow shoulders (less than 2 ft) were common on 2,989 mi. Passing opportunities were restricted to less than 30 percent on 5,772 mi.

Improvement Needs

The study's deficiency analysis produced estimates of the total number of miles and costs of highway improvements for each analysis year. The 1986 needs represented an existing backlog of need. The 1990 results represented needs that will be emerging by 1990. The 2000 results represented needs that will be emerging between 1990 and 2000.

Because the study is not intended to be a segment-specific project program but a system plan, the analysis results for the detailed physical improvement types have been combined into three general categories of highway facility improvements.

1. Surface improvements are primarily minimal or low-cost improvements, particularly surface renewal, which only serve to keep a highway segment operational. These include the specific improvement types of Resurface and Recondition 1.
2. Geometric improvements enhance primarily the safety and geometric characteristics of a highway segment. Although this type of improvement also normally increases the highway's capacity, the increased capacity is only incidental. These include the specific improvement types of Recondition 2, urban recondition and rural reconstruction.
3. Capacity improvements enhance payment condition, safety, and geometrics, but their primary purpose is to increase the traffic-carrying capacity of the facility.

In summary, more than 4,600 mi (22 percent) of roads needed immediate improvement and more than 12,000 mi (59 percent) of the system will need some improvement by the year 2000. A total cost of $1.76 billion will be needed for these improvements.

Roadway improvement needs are most often related in terms of annual improvement programs. It is therefore necessary to take backlog needs and combine them with projected future needs to develop an annual improvement program.

Obviously, annual programs will be quite sensitive to the manner in which the backlog is handled. The backlog for state trunk highways is handled by projecting their elimination by the year 2010. For consistency, the same procedure was used in developing annual needs for the arterial and collector roads. Therefore, the backlog was divided by 23 to provide an equal annual program in 1986 dollars. In addition to that, annual improvements that emerge for the years between 1986 and 2000 must also be added. Because there is a greater degree of certainty in projecting future needs for the near term, it was decided to project annual needs for the next 4 years (through 1990). This then becomes the sum of the backlog divided by 23 years added to the additional annual projects that indicate the

TABLE 5 CURRENT SEVERE DEFICIENCIES BY JURISDICTION

Deficiency	County (mi)	Town (mi)	City or Village (mi)	Total (mi)
Poor surface condition (PSR < 3.0; PDI > 70)	2,420	747	340	3,507
Poor alignment of drainage	1,536	807	175	2,518
Narrow lanes (<10 ft rural)	352	652	3	1,007
Narrow shoulder (<2 ft)	1,873	866	250	2,989
Restricted passing (<30% passing)	4,211	1,460	101	5,772

need for improvement during the years between 1986 and 1990. Table 5 lists these needs for the various alternatives. With the assumption of a continuing federal program at the current level, there is a range of additional state and local funding required between \$18 and \$175 million.

CONCLUSIONS

The use of analysis techniques developed for state trunk highway planning purposes has served well in developing condition assessment and needs estimates for improvement of locally maintained arterials and collectors. It was not necessary to develop new technology or analysis procedures. The use of a parallel analysis and planning process allows easy comparison of needs between the two systems and facilitates decision making.

Significant additional condition data were needed on roadways under the jurisdiction of local agencies, including pavement, alignment, and drainage condition data.

There was a significant need for improvements on arterials and collectors maintained by local agencies in Wisconsin. More than 22 percent needed immediate improvement and 59 percent will need improvement by the year 2000.

The existing funding provided by the federal-aid secondary and federal-aid urban programs is inadequate to address these needs. An additional \$63 million annually of federal, state, and local funds are needed.

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