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Abridgment

Optimal Speed Limit: A New Approach

JAMES M. JONDROW, MARIANNE BOWES, AND ROBERT A. LEVY

The private optimal speed for a driver and the optimal speed limit imposed by a government are two different things. An individual can determine his or her optimal driving speed by comparing the costs of increased speed (greater gasoline consumption and greater probability of an accident) with the benefits (reduced travel time). A driver's private optimum speed does not, however, take into account any damage that his or her extra speed may do to others. This is an external cost of speed, which provides a rationale for government regulation of highway speed. In this paper we present a method for calculating the optimal speed limit. It starts with the privately chosen speed and then adjusts it to account for external costs. One advantage of this method is that it is based on the driver's judgment about the value of his or her life rather than on an externally imposed estimate. After deriving a formula for the optimal speed limit, we use it in a simple numerical example that provides (a) an estimate of the optimal speed limit; (b) an estimate of the cost per life saved of a suboptimal speed limit, which can be compared with the costs of other ways of saving lives; and (c) an understanding of the types of information needed to improve estimates of the optimum.

In this paper we describe one rationale for government regulation of driving speed--externalities; that is, the costs imposed by one motorist on others. We also demonstrate that acceptance of this rationale leads to a method for calculating the optimum speed limit. As do all such calculations, our calculations depend on two uncertain parameters, the values of time and life. We show how to calculate the optimal speed limit without imposing outside judgments about these parameters. Someone's judgment must be used; we use that of the individual driver, which is inferred from the drivers' behavior. To demonstrate the methodology we make an illustrative calculation of the optimal speed limit for one type of road, uncongested freeways.

EXTERNALITY

The method is based on a crucial distinction: between the optimal speed limit (imposed by a government in the social interest) and the optimal speed for an individual driver.

An individual determines his or her optimal driving speed based on the private or internal costs (increased fuel use and increased possibility of an accident) and benefits (reduced travel time) of driving faster. The driver takes no account of the damage his or her extra speed may do to others (the external cost of speed). Society, however, must consider all costs, internal plus external, which is the major rationale for a speed limit.

ASSUMPTIONS

The formula for the optimal speed limit is derived from a simple economic model of driver behavior. [A more detailed analysis is given elsewhere (1)]. The model uses the following major assumptions:

1. A driver is rational; that is, given the necessary information, he or she would drive at the optimal speed;
2. The driver possesses the knowledge necessary to determine his or her private optimum speed or, at least, his or her knowledge is as good as the government's; and
3. There is a single representative driver, which implies that there is no variation in optimum speeds among drivers.

Deriving the Private Optimum Speed

Figure 1 shows how the private and social optimum speeds are determined. The marginal benefit curve shows the benefit of increased speed. The equation for this curve is derived from the total benefit of trip time (which is negative because trip time is a cost):

$$\text{Dollar benefit of trip time} = -V_T(D/S) \qquad (1)$$

where

V_T = value of time (\$/h),
D = trip distance, and
S = speed.

The marginal benefit of speed is the derivative of benefit with respect to S:

$$\text{Marginal benefit of speed} = V_T D/S^2 \qquad (2)$$

The curve that shows private marginal cost depends on the cost of gasoline and the increased probability of an accident. The equation is given by

$$\text{Private marginal cost} = [V_L b + P_G c]\, D \qquad (3)$$

where

V_L = the amount necessary to compensate a driver for an increase in the probability of a fatal accident;
b = the increased probability , per mile, of a fatal accident as speed increases 1 mph;
P_G = the price of gasoline; and
c = the increase in gasoline use, per mile, as speed increases 1 mph.

The private optimum is determined by the intersection of marginal benefit and marginal cost. Mathematically, this involves the equating of marginal benefit and cost and the solving of Equations 1 and 2 for S. S_p, the optimum speed for an individual driver, is the solution value of S:

$$S_p = V_T^{0.5}(P_G c + V_L b)^{-0.5} \qquad (4)$$

The private optimum depends directly on the value of time and inversely on the value of life and gasoline price, as well as on the increased gasoline use and fatality rate per mile of speed.

Deriving the Social Optimum Speed

To obtain a formula for the social optimum requires adjusting the earlier formula for marginal cost to account for externalities. The total effect of an increase in a driver's speed on the fatality rate is b + b', where b' is the effect on other people and b is the effect on the driver. Then (shown as an upward shift in marginal cost in Figure 1) marginal cost increases to $P_G Dc + V_L D(b + b')$, and the optimal speed is reduced to

$$S_s = V_T^{0.5}[P_G c + V_L(b + b')]^{-0.5} \qquad (5)$$

Figure 1. Social and private optimum speed limits.

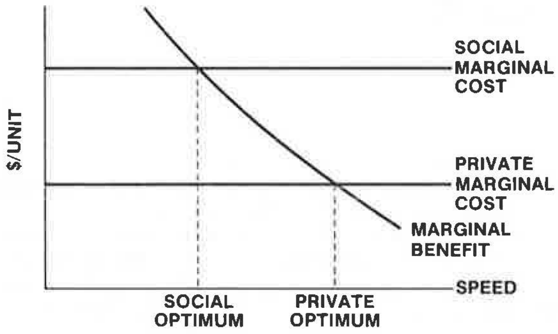

Table 1. Estimates of private and socially optimal speeds.

		Speed (mph)	
Value of Time ($/h)	Value of Life ($/life)	Private Optimum	Social Optimum
5	100 000	60.8	60.3
5	1 000 000	53.4	50.3
5	10 000 000	29.4	24.9
10	100 000	86.0	85.3
10	174 256	85.0	83.8
10	1 000 000	75.5	71.1
10	10 000 000	41.5	35.2
15	100 000	105.4	104.5
15	1 000 000	92.5	87.0
15	1 716 697	85.0	78.0
15	10 000 000	50.9	43.2
20	100 000	121.7	120.7
20	1 000 000	106.8	100.5
20	3 259 137	85.0	75.6
20	10 000 000	58.8	49.9

Numerically Calculating the Optimal Speed Limit

We now have formulas for the private optimal speed and the optimal speed limit. To make numerical calculations, we need values for the parameters. It is not too difficult to find data on gasoline prices or on the relations between driving speeds and fatality rates (2) and driving speed and gasoline mileage (3-5). The value of time and the value of life, however, are uncertain.

One strategy is to calculate the optimal private speed and the optimal social speed by using alternate values for life and time, which leads to the results in Table 1. The social speed limit varies greatly within the table, from 30 mph to more than 120 mph. To determine the optimal speed limit one would have to choose the most likely values for time and a life, a task that involves massive uncertainty.

We propose an alternative method, one that avoids imposing the value of a life from outside the driver's behavior. Our method uses the driver's private optimum (which we assume equals the average speed where there is no speed limit) and the other parameters to make inferences about the value drivers place on their own lives and to derive the optimal speed limit.

To illustrate our method, suppose the private optimum speed is 85 mph (roughly the actual, unrestricted speed on the German Autobahn). Our method involves restricting attention to the cases in Table 1 that are consistent with a private optimum of 85 (cases 10, 15, and 20). Note the drastic reduction in the range of socially optimal speeds. Rather than assuming a value of life and then solving for the private and social optimum speeds, we assume a value for the private optimum and then solve for the implied value of a life and social optimum.

Application to the 55-mph Speed Limit

This section applies our model to a current policy question, evaluation of the 55-mph speed limit. We can use our model not only to calculate the optimal speed limit, which does take account of highway deaths, but also to answer the question: What is the cost per life saved of imposing the 55-mph limit if this differs from the socially optimal speed limit?

We answer this question in the following way. First, we compute the lifesaving cost of a suboptimal speed limit: the costs less the benefits, where the benefits exclude the value of saving lives. We then divide this figure by the number of lives saved.

If the private optimum speed is 85 mph, the optimal speed limit is 78 mph, and the value of a life is $1.7 million (from Table 1), we find that the lifesaving cost of having a speed limit of 55 mph rather than 78 mph is $3.2 million per life saved. [For the calculations, see elsewhere (1).] In our case, this not only exceeds the value individuals place on their own lives ($1.7 million) but also proves to be a more expensive way of saving lives than many other proposed lifesaving policies, for example, the installation of smoke alarms.

SUMMARY

We have developed a method for calculating the optimal speed limit. The conclusions of our work can be stated as follows.

To determine the optimal speed limit, two parameters are of crucial importance: (a) the speed in the absence of a speed limit and (b) the ratio of external costs to internal costs. We conclude that data-collection efforts should be focused on these two parameters, which would involve a major redirection of federal highway research.

If our crude calculations are at all indicative, the optimal speed limit is above 55. Maintenance of the 55-mph limit is an expensive way to save lives.

In our method, the value of a life does not directly enter the calculation of the optimal speed limit. The value of time enters with less importance than in usual calculations. In general, the information needed for the calculation is changed as well as the relative importance of different pieces of information.

What we have presented is a highly simplified model, without precise parameter estimates. What is needed is a more sophisticated model with the same emphases--the focus on externalities and the ability to use the vast amount of information embodied in observed speeds. Also needed are the data (especially on externalities) to apply the model.

REFERENCES

1. J.M. Jondrow, M. Bowes, and R.A. Levy. The Optimal Speed Limit: A New Approach. Center for Naval Analyses, Alexandria, VA, Jan. 1982.
2. D. Solomen. Accidents on Main Rural Highways Related to Speed, Driver, and Vehicle. U.S. Bureau of Public Roads, HS-001 191, July 1964.
3. E.M. Cope. The Effect of Speed on Automobile Gasoline Consumption Rates. Federal Highway Administration, HS-013 850, 1973.
4. Highway and the Petroleum Problem. Federal Highway Administration, FHWA Bull., Oct. 2, 1975.
5. A Report on Automotive Fuel Economy. U.S. Environmental Protection Agency, HS-013 917, 1973.

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Economics of Bus Rehabilitation

DOUGLAS S. McLEOD

The cost-effectiveness of bus rehabilitation versus new bus acquisition warrants close examination because of the rapid increase in the costs of new bus acquisition and the scarcity of financial resources for local transit systems. In 1980 and 1981 the Florida Department of Transportation conducted a study of the economic feasibility and implementation of bus rehabilitation within Florida. This paper reflects the economic research and findings of that study, modified to incorporate the Urban Mass Transportation Administration's early 1981 guidelines on bus rehabilitation. Economic analysis techniques are used to evaluate the cost-effectiveness of bus rehabilitation from national and local viewpoints. A mainline economic analysis is developed with appropriate economic input values. The paper concludes that, from the viewpoint of national and local transit interests, bus rehabilitation is a cost-effective alternative to new bus acquisition. Local transit operators should consider providing additional funds beyond the required federal matching share. However, local transit operators should obtain substantial federal funding assistance before undertaking a bus rehabilitation program. Because cost-effectiveness of bus rehabilitation is dependent on economic input values, sensitivity analyses and general equations are presented so that local transit operators have the option to use values that more appropriately represent their particular situations. Short-term updating procedures are provided.

The concept of bus rehabilitation is not new; to various extents, transit agencies have been rehabilitating buses for several years. However, due to the rapid increase in the costs of new bus acquisition, increasing vehicle requirements, and relative scarcity of financial resources for local transit systems, the cost-effectiveness of bus rehabilitation warrants close examination.

In part as a response to these factors, in February 1980, the Urban Mass Transportation Administration (UMTA), issued a notice of proposed rule making (NPRM) to financially aid comprehensive bus rehabilitation projects (1). In order to benefit from the rehabilitation program, the Florida Department of Transportation (FDOT) initiated a feasibility study for bus rehabilitation in Florida (2). Concurrent with completion of the FDOT study, UMTA issued its final rule on bus rehabilitation policy and procedures in January 1981 (3); however, with the change in federal administrations, this final rule was withdrawn and is being reassessed. The expressed purpose of withdrawing the rule was to make the bus rehabilitation program as flexible as possible by providing guidelines rather than a fixed rule. Nevertheless, the current administration believes that bus rehabilitation is a good concept, and UMTA is funding bus rehabilitation projects by using the "withdrawn final rule" as a guideline. This paper reflects the research and findings conducted for the FDOT bus rehabilitation feasibility study (2), based on UMTA's 1980 NPRM on bus rehabilitation (1) and modified as appropriate to incorporate UMTA's 1981 bus rehabilitation guidelines (3).

To determine appropriate levels of investment between the acquisition of new buses and rehabilitation of existing buses, the following economic factors should be considered:

1. Initial capital investment costs,
2. Service lives,
3. Salvage values,
4. Operation and maintenance costs, and
5. Appropriate discount rate.

Consideration of the relative worth of a rehabilitated bus versus a new bus, which reflects qualitative differences, may also be appropriate.

In the following sections, UMTA's bus rehabilitation guidelines are evaluated from an economic viewpoint and mainline values are determined for the economic parameters listed above. National and local maximum acceptable bus rehabilitation costs are presented, sensitivity analyses of the economic parameters are performed, and short-term updating procedures are provided.

ECONOMIC SUMMARY OF UMTA'S BUS REHABILITATION GUIDELINES

Of the five key economic inputs needed to evaluate cost-effectiveness of bus rehabilitation versus new bus acquisition, only two inputs were addressed in the UMTA guidelines: initial capital investment costs and bus service lives. UMTA's estimated cost of a new bus did not include the cost of a lift for the elderly and handicapped (3, p. 9862). The current new bus cost provided in the UMTA guidelines is $120 000; this cost will increase due to inflation.

The need for structural improvements is UMTA's primary basis for evaluating the feasibility of bus rehabilitation; however, as a general guideline, buses should be at least 12 years old or should have accumulated 500 000 miles (3, pp. 9864-9865). No clear guidance is given as to the extended service life of a rehabilitated bus; however, the minimum extended service life of a rehabilitated bus is 5 years, and examples of extended service lives of 5, 8, and 10 years are cited (3, p. 9862).

In the NPRM (1, p. 9244), UMTA stated that its initial experience with bus rehabilitation indicated that the capital cost of bus rehabilitation should not exceed 50-60 percent of the cost of a new bus over a 12-year service life in order to ensure a worthwhile return on local and federal investments. UMTA used the 60-percent value as an input in the bus rehabilitation funding formula. Essentially, by introducing the 60-percent value, UMTA recognized the worth of a rehabilited bus as 60 percent of the worth of a new bus after accounting for different service lives. In the subsequent UMTA guidelines a 70-percent value was used (3, p. 9864); however, the meaning of these values appears to have changed. In the latter document, the value was used as a funding cap to approximate the median cost of bus rehabilitation (3, p. 9862). Nevertheless, by incorporating the 70-percent value in the guidelines, UMTA implicitly recognized the worth of a rehabilitated bus as 70 percent of the worth of a new bus after accounting for different service lives.

Salvage values for new and rehabilitated buses were not addressed in UMTA's guidelines. In the NPRM, UMTA requested comments regarding operating costs of new versus rehabilitated buses; however, the subsequent guidelines did not provide operating and cost differentials. Discount rates were not considered in the UMTA documents. Thus, the guidelines implicitly assumed no salvage values, no difference between the operation and maintenance costs of new and rehabilitated buses, and a zero-percent discount rate. The key economic inputs used or implied by the UMTA guidelines are summarized in Table 1.

The funding formula used by UMTA is, "The full cost of rehabilitation may not normally exceed seventy percent (70%) of the average annual amortized value of a new bus (based on a 12-year life), multiplied by the number of years the bus life is pro-

Table 1. Key economic input values of UMTA guidelines.

Economic Input	Value
Initial capital cost	
New bus	\$120 000[a]
Rehabilitated bus	\$35 000-\$70 000[a]
Bus service life	
New	12 years[b]
Rehabilitated	5-10 years
Bus salvage value	
New	\$0
Rehabilitated	\$0
Cost differential for operation and maintenance of rehabilitated versus new bus	\$0
Discount rate	0 percent
Worth of rehabilitated versus new bus	70 percent

[a] Changes over time. [b] Minimum value.

Table 2. Mainline bus rehabilitation economic input values and national analysis.

Item	Value
New bus cost	\$125 000
Bus service life	
New	12 years
Rehabilitated	8 years
Bus salvage value	
New	\$25 000
Rehabilitated	\$10 000
Cost differential for operation and maintenance of new bus versus rehabilitated bus	\$4 000/year
Discount rate	10 percent
Worth of rehabilitated versus new bus	80 percent
Maximum acceptable rehabilitation cost	\$73 065

jected to be extended" (3, p. 9864). For 5-, 8-, and 10-year extended rehabilitated bus service lives, UMTA would recognize maximum bus rehabilitation costs as \$35 000, \$56 000, and \$70 000, respectively.

UMTA regards bus rehabilitation projects as capital expenditures and, as in the acquisition of new buses, would participate on a funding-share basis of 80-percent federal, 20-percent local (3, p. 9865). For an 8-year extended service life, UMTA would recognize a maximum bus rehabilitation cost of \$56 000, of which \$44 800 would be borne by UMTA and \$11 200 by the local transit agency. UMTA would participate in additional costs of handicapped accessibility features and would consider participating in additional costs of new equipment (3, p. 9865). Analysis of these additional costs is beyond the scope of this paper.

BASIC ECONOMIC INPUTS OF BUS REHABILITATION

To evaluate the cost-effectiveness of bus rehabilitation versus new bus acquisition five key economic parameters should be considered. This section addresses these parameters, inflation, and other economic considerations and presents justification for values used in the subsequent economic analysis. The values used for the mainline economic analysis are presented in Table 2.

Initial Capital Investment Costs

Based on the analysis conducted for FDOT, the estimated average cost of new Advance Design Buses (ADBs) without lifts for the elderly and handicapped was \$125 000 in the second quarter of 1980. This cost does not include delivery charges, local inspection, or other non-manufacturing-related costs. Thus, an estimate of \$130 000, as well as UMTA's figure of \$120 000, is used in the sensitivity analysis. These new bus costs will increase over time due to inflation.

Levels of rehabilitation and associated commercial costs for Florida buses in the second quarter of 1980 are presented in the table below.

Level	Degree of Rehabilitation	Estimated Cost (\$)
1	Comprehensive rehabilitation with new engine and transmission	74 000
2	Comprehensive rehabilitation with remanufactured engine and transmission	64 000
3	Rehabilitation of parts as needed	54 000

No data are available regarding the projected cost of rehabilitating buses over time; however, the cost of rehabilitating buses will probably increase at approximately the same rate as the cost of new buses because of the similar work and materials involved.

Service Lives

The service life of a bus is its length of operation. With rehabilitation, a bus's service life can be extended. Generally, in Florida, UMTA's 12-year criterion for a new bus will be met prior to the 500 000-mile criterion; therefore, the 12-year criterion is used throughout the remainder of this study.

New Bus Service Life

In response to UMTA's NPRM, some northern transit operators stated that their buses' service lives were less than UMTA's 12-year standard because of climate. Concern was also expressed that the buses of certain manufacturers have shorter service lives than others and that the service lives of new ADBs may not equal that of the older, new-look buses.

In Florida, the 12-year standard appears reasonable. Although heat causes greater strain on air conditioning units and corrosive effects are caused by the proximity of Florida's major urban areas to the ocean, Florida's buses do not encounter the effects of northern climates. Furthermore, more than 30 percent of Florida's current bus fleet has been in use at least 12 years. A 12-year service life is used in the mainline economic analysis. For sensitivity analysis, 10- and 15-year new bus service lives are also considered.

Rehabilitated Bus Service Life

In response to UMTA's NPRM, leading bus rehabilitation companies and transit experts stated that an 8-year extended service life for rehabilitated buses was more reasonable than the 5-year value often illustrated. A 10-year extended service life was also suggested as practical. In response, UMTA stated that use of the 5-year extended service life in the NPRM was for illustrative purposes only; in the subsequent guidelines, extended service lives of up to 10 years were illustrated.

To extend the service life of a bus by at least 5 years, a comprehensive rehabilitation process is required, including mechanical rebuilding, electrical work, and body work. In the FDOT study, three levels of bus rehabilitation were evaluated. The FDOT study concluded that a 5-year extended service life value may be appropriate for a level 3 program and an 8-year value appropriate for a level 2 program. The difference in scope between levels 1 and 2 was considered too insignificant to alter the extended service life of 8 years for a level 1 program.

Given the projected extended service lives and costs, a level 2 rehabilitation program was deemed the most cost effective. Thus, the FDOT economic analysis concentrated on a level 2 program with an 8-year extended service life. Extended service lives of 5 and 10 years were analyzed in the sensitivity analysis.

Salvage Value

Salvage value is the value of an investment that remains at the end of the study period. Although the service life of a new bus may be 12 years, a bus still has value at the end of that period. It can be resold, used for spare parts, or held for use in case of emergency. In 1980 the estimated salvage value of new buses after 12-15 years was $25 000, and the salvage value for rehabilitated buses was $10 000. A $20 000 value for rehabilitated buses and $0 value for both types of buses were also employed in the sensitivity analysis.

Operation and Maintenance Costs

Operation and maintenance costs as well as initial capital expenditures should be considered in economic analyses of transportation projects. In fact, for transit-related projects, total operation and maintenance costs usually exceed initial capital costs. However, for the purpose of economic analysis, the difference in costs rather than total costs is important.

There is relatively limited experience and documentation on operation and maintenance costs of ADBs versus rehabilitated, new-look buses. Nevertheless, it is widely accepted that operation costs for lighter, new-look buses are less than for ADBs. Available data reflect that the fuel efficiency of an ADB is 0.5-1.0 mile/gal less than for an air-conditioned, new-look bus. Consider a 0.5-mile/gal decrease in fuel efficiency at 30 000 miles/year, with a fuel cost of $0.90/gal; an ADB would then cost $963 more per year to operate than would an air-conditioned, new-look bus.

Tires and brakes on new-look buses last longer. Because the seating capacity of a new-look bus is 10-12 percent greater than that of an ADB, transit agencies may need fewer buses to meet peak-hour transit demands.

It is also widely accepted that maintenance costs for new-look buses are less than for ADBs, largely because new-look buses are less sophisticated and established maintenance techniques and controls exist. Maintenance labor costs are less because it is easier to replace parts and repair the buses and less training is needed. The cost of parts is less and brakes are easier to maintain. The new-look buses are reported to be more reliable. The Detroit Department of Transportation (DDOT) operates more than 200 ADBs and has rehabilitated 79 buses. DDOT reported that the annual preventive maintenance cost for an ADB exceeds that required for a rehabilitated bus by $3370/year.

Even with limited experience and data for operating ADBs and rehabilitated buses, indications are that the ADB is more costly to operate and maintain. Based on the data presented in the preceding paragraphs and on level 2 rehabilitation specifications, an annual operating and maintenance differential of $4000 is a reasonable expectation ($3370 DDOT maintenance differential and $963 fuel differential, rounded to $4000). This value has been used for economic analysis. Savings of $0 and $2000/year are used for the sensitivity analysis.

Discount Rate

The discount rate allows economic analysts to bring back future benefits and costs to their present worth. The discount rate represents the average rate of return on private investment, before taxes and after inflation. In many benefit/cost analyses, the value of the chosen discount rate is crucial. A high rate diminishes the present value of future benefits and costs; however, a low rate overstates these benefits and costs. Suggested values for the discount rate range from 4 to 15 percent. The guidelines for highway and bus-transit improvements adopted by the American Association of State Highway and Transportation Officials (AASHTO) recommend a 4-percent discount rate (4). The discount rate most widely used by federal agencies is 10 percent, as prescribed by the Executive Office of the President, U.S. Office of Management and Budget (5). UMTA has required use of the 10-percent rate in evaluating programs and projects subject to its jurisdiction.

Although the discount rate is essential to economic analyses, it is seldom used in accounting. The opportunity cost of capital (the discount rate) is not considered in depreciating items. In many ways UMTA's funding formula, which includes use of average annual amortized costs, more accurately represents an accounting analysis than an economic analysis. Implicit in UMTA's guidelines is the use of a zero-percent discount rate, which results in an underestimation of the economic benefits of a bus rehabilitation program.

The mainline economic analysis in this study employs a 10-percent discount rate to comply with the U.S. Office of Management and Budget's directive. However, strong cases can be made for lower discount rates. In the sensitivity analysis of this paper, 0-, 4-, and 7-percent discount rates are considered.

Inflation

Although inflation may be of great concern to transportation and other interests, general inflation should not be included in benefit/cost analyses because all benefits and costs are estimated in constant dollars--the general purchasing power of the dollar at the time of decision. If, however, the cost of an item is increasing faster than the general rate of inflation, it may be appropriate to take into account the difference between the item's inflation rate and the general inflation rate.

In 1972, the average cost of a new bus was $40 500. By the end of the second quarter of 1980 the average cost was $135 000, which represents an increase of 3-1/3 in the cost of a new bus. In the same period, the consumer price index nearly doubled; therefore, the cost of new buses increased considerably faster than did the U.S. general price level.

The buses of 1972, however, are not comparable with those of today. The modern ADB is built to entirely new specifications, including special provisions for the elderly and handicapped. In view of these changes, the increase in bus costs versus the twofold increase in the general price level appears less excessive. Nevertheless, data indicate that the cost of comparable buses has been increasing faster than the general rate of inflation. Not only has the cost of new buses increased at a faster rate than general inflation but so have fuel and maintenance costs. The difference between transit's increasing cost rate over time and general inflation can be approximately accounted by subtracting the difference from the standard discount rate. Although subject to discrepancies between price trends of different transit costs, the lowering of the discount rate is easy to use and will generally not distort economic results for a few years. Although the mainline economic analysis uses a 10-percent discount rate, it is reasonable to decrease the selected standard discount rate by no more than 5 percent to account for transit's real inflation rate. Discount rates of 0, 4, and 7 percent, as well as the 10-percent standard, are presented in the sensitivity analysis.

All cost figures used in this analysis are based on 1980 second-quarter values. As stated previously, general inflation should not be included in an economic analysis; however, at the actual time of decision, the cost of a new, comparable bus will have risen. This change in cost should be considered at that future time in determining whether to rehabilitate a bus or to purchase a new one. For instance, a local transit operator may be considering rehabilitation of buses in December 1982, at which time new buses may cost 25 percent more than the estimate of $125 000 used in this analysis. To account for the change in prices, the local transit operation should increase its maximum acceptable rehabilitation cost (presented in this text) by 25 percent. Although subject to increasing error, this procedure would be reasonably accurate in the short run.

Rehabilitated Versus New Bus Worth

UMTA's funding formula implicitly assumes that, after accounting for differences in service lives, a rehabilitated bus is worth 70 percent (60 percent in the NPRM) of a new bus. Certainly, the more expensive ADBs have qualities superior to new-look buses or they should not be produced. A good assumption of an ADB's minimum qualitative advantage over a new-look bus is the difference in cost. Data from 1976 to 1980 indicate differences from 74 to 87 percent, which gives an average of approximately 80 percent. Thus, the value of a new-look bus could be roughly 80 percent of a new ADB. The mainline economic analysis assumes that a rehabilitated bus is worth 80 percent of a new bus after consideration of service lives. Because the recognized worth of a rehabilitated bus in comparison with a new bus is such an important consideration, the sensitivity analysis includes 60-, 70-, and 100-percent values.

MAXIMUM ACCEPTABLE BUS REHABILITATION COSTS BY USING BASIC ECONOMIC INPUTS

By using the national maximum acceptable rehabilitation cost general equation (Equation 1) and second-quarter 1980 cost data, on a national basis, bus rehabilitation should be funded up to $73 065/bus (see Table 2) or at a level of approximately 58 percent of the cost of a new bus. The level of $73 065 is approximately 1.3 times greater than the acceptable rehabilitation level of $56 000 (for an 8-year extended service life) used in UMTA's guidelines and approximately 2.8 times greater than the acceptable rehabilitation level illustrated in UMTA's bus rehabilitation NPRM. This indicates that, although UMTA is considerably closer to recognizing an optimum rehabilitation level, as illustrated by UMTA's examples, UMTA is not giving adequate recognition to the economic worth of bus rehabilitation. Furthermore, UMTA's maximum acceptable rehabilitation cost of $56 000 for an 8-year extended bus service life does not reflect the cost to rehabilitate a bus; the commercial cost to rehabilitate a Florida bus was about $64 000. (If a 5-year extended service life were used, UMTA's recognized rehabilitation cost would be totally inadequate; for a 10-year extended service life, UMTA's recognized level may be adequate.) Thus, this analysis lends further credence to the reasons that local transit operators have for allocating funds to bus rehabilitation with no or only partial UMTA participation.

The general equation to determine the national maximum acceptable rehabilitation cost is as follows:

$$
\begin{aligned}
R = {} & (N \cdot W_{R/N} - S_N) + OM_{N/R}(\text{pwf-d-sl}_N) - S_n(\text{pwf}'\text{-d-sl}_N) \\
& - (N \cdot W_{R/N} - S_R)(\text{pwf}'\text{-d-sl}_R) - OM_{N/R}(\text{pwf-d-sl}_{N-R})(\text{pwf}'\text{-d-sl}_R) \\
& + [N \cdot W_{R/N} - (N \cdot W_{R/N} - S_N)(\text{sff-d-sl}_N)(\text{caf-d-sl}_{N-R})](\text{pwf}'\text{-d-sl}_N)
\end{aligned}
\qquad (1)
$$

where

R = national maximum acceptable initial cost of rehabilitating a bus,
N = initial cost of a new bus,
$W_{R/N}$ = worth of a rehabilitated bus versus a new bus,
S_N = salvage value of a new bus,
$OM_{N/R}$ = operation and maintenance cost differential between a new bus and a rehabilitated bus,
(pwf-d-sl_N) = uniform series present-worth factor for a given discount rate for the service life of a new bus,
$(\text{pwf}'\text{-d-sl}_N)$ = single payment present-worth factor for a given discount rate for the service life of a new bus,
S_R = salvage value of a rehabilitated bus,
$(\text{pwf}'\text{-d-sl}_R)$ = single payment present-worth factor for a given discount rate for the service life of a rehabilitated bus,
(pwf-d-sl_{N-R}) = uniform series present-worth factor for a given discount rate for the difference between new and rehabilitated buses' service lives,
(sff-d-sl_N) = uniform series sinking fund factor for a given discount rate for service life of a new bus, and
(caf-d-sl_{N-R}) = uniform series compound amount factor for a given discount rate for the difference between new and rehabilitated buses' service lives.

The values in Tables 1, 2, and 3, and other values not shown, can be obtained through use of the equation. The equation is based on economic analysis principles that incorporate present-worth concepts. A computer program has been developed by Environmental Science and Engineering, Inc., to calculate the maximum acceptable rehabilitation costs given appropriate economic input values.

SENSITIVITY ANALYSIS OF ECONOMIC INPUT VALUES AND RESULTING EFFECTS ON NATIONAL MAXIMUM ACCEPTABLE REHABILITATION COSTS

Although the inputs for the mainline economic analysis are soundly based, other values can be justified. The following sensitivity analysis provides transit interests and others with the option to use other inputs in determining appropriate national maximum cost levels for bus rehabilitation. Table 3 uses the mainline economic input values and varies these inputs one at a time.

As can be seen from Table 3, most cases result in maximum acceptable rehabilitation cost levels above what UMTA may recognize (assumed to be $56 000) and the cost of level 2 rehabilitation ($64 000). Table 3 also indicates inputs that have greatest impact on the national maximum acceptable rehabilitation cost. These inputs are the rehabilitated bus service lives (cases 5 and 6), bus salvage values (cases 7 and 8), operation and maintenance costs (cases 9 and 10), and rehabilitated versus new bus worth (cases 14, 15, and 16). Although some of the

Table 3. Sensitivity analysis of mainline economic inputs on maximum acceptable rehabilitation costs.

Case	New Bus Cost ($000s)	Bus Service Life (years)		Bus Salvage Value ($000s)		Operational and Maintenance Cost Differential of New Versus Rehabilitated Bus ($/year)	Discount Rate (%)	Worth of Rehabilitated Versus New Bus (%)	Maximum Acceptable Rehabilitation Cost ($)	Percentage of Mainline Maximum Acceptable Rehabilitation Cost (%)
		New	Rehabilitated	New	Rehabilitated					
National mainline	125	12	8	25	10	4000	10	80	73 065	
1	120	12	8	25	10	4000	10	80	69 933	-4.3
2	130	12	8	25	10	4000	10	80	76 197	+4.3
3	125	10	8	25	10	4000	10	80	79 460	+8.8
4	125	15	8	25	10	4000	10	80	66 947	-8.4
5	125	12	5	25	10	4000	10	80	47 575	-34.9
6	125	12	10	25	10	4000	10	80	86 430	+18.3
7	125	12	8	0	0	4000	10	80	99 637	-36.4
8	125	12	8	25	20	4000	10	80	77 730	+10.6
9	125	12	8	25	10	0	10	80	51 725	-29.2
10	125	12	8	25	10	2000	10	80	62 395	-14.6
11	125	12	8	25	10	4000	0	80	67 000	-8.3
12	125	12	8	25	10	4000	4	80	69 775	-4.5
13	125	12	8	25	10	4000	7	80	71 540	-2.1
14	125	12	8	25	10	4000	10	60	53 491	-26.8
15	125	12	8	25	10	4000	10	70	63 278	-13.4
16	125	12	8	25	10	4000	10	100	92 639	+26.8
17[a]	105	12	5	0	0	0	0	60	26 250	-64.1
18[a]	120	12	5	0	0	0	0	70	35 000	-52.1
19[a]	120	12	8	0	0	0	0	70	56 000	-23.4
20[a]	120	12	10	0	0	0	0	70	70 000	-4.2

[a] UMTA examples.

influence of the discount rate is masked in other variables, it had relatively little influence (cases 11, 12, and 13). Due to the importance of these inputs, distinct sensitivity analyses are presented in the FDOT bus rehabilitation study (2, appendix E). Those sensitivity analyses indicated that the cost-effectiveness of bus rehabilitation varies substantially depending on the assumptions made.

MAXIMUM ACCEPTABLE REHABILITATION COSTS AND FUNDING LEVELS FOR LOCAL TRANSIT OPERATORS

On a national basis, level 2 bus rehabilitation is a cost-effective alternative to the acquisition of new buses; however, UMTA will probably not recognize bus rehabilitation at an economically efficient level ($73 065). Therefore, local transit interests may find it worthwhile to devote some additional funds for bus rehabilitation even without federal funding participation.

For capital expenditure programs, UMTA contributes 80 percent and local transit operators contribute 20 percent of the cost. Similarly, when receiving money from salvage of a bus purchased with UMTA assistance, 80 percent returns to UMTA. Operation and maintenance costs are not based on the 80-20 funding percentage formula. Although UMTA participates in funding up to 50 percent of bus operation and maintenance costs, actual funding is usually considerably less. In Florida the operation and maintenance percentages are approximately 33.3 percent for UMTA and 66.7 percent for the local transit operators. This difference in funding percentage is significant in determining maximum acceptable funding levels for UMTA and local transit operators.

From a national viewpoint, the maximum acceptable rehabilitation cost ($73 065 for the mainline assumptions) represents the maximum cost at which it is economically worthwhile to rehabilitate buses. If funding percentages of 80-20 were used for all initial capital costs, salvage values, and operation and maintenance costs, then the maximum amount local transit operators should pay for rehabilitation would be $0.20 for every dollar of the maximum acceptable rehabilitation cost. For national mainline analysis purposes, this would amount to $14 613 ($73 065 x 0.20). However, in the case of operation and maintenance costs, for every dollar spent, local Florida transit operators on the average pay $0.667 instead of $0.20, which effectively alters the maximum acceptable rehabilitation costs for local transit operators. UMTA would recognize operation and maintenance costs, but these costs would not be as important as capital expenditure costs because of UMTA's lower funding participation rate. Thus, the maximum acceptable rehabilitation cost from a national viewpoint is not the maximum acceptable rehabilitation cost for UMTA and the local transit operators. Given the existing funding formulas to maximize their funds, UMTA would recognize a value less than the national optimal level, and the local transit operators would recognize a higher value.

Table 4 indicates local transit operator's maximum acceptable bus rehabilitation costs and corresponding funding levels for different recognized UMTA funding levels and operations and maintenance costs. The table values are obtained from the following general equations:

$$U = 0.8A \quad \text{if } A \leq B, \text{ or } U = 0.8B \quad \text{if } A > B \qquad (2)$$

and

$$L = 0.2A + 0.2(B - A - M) + XM \qquad (3)$$

where

U = UMTA's share,
A = UMTA's recognized maximum rehabilitation cost,
L = local transit operator's share,
B = national maximum acceptable rehabilitation cost for a given operation and maintenance cost differential,
X = percentage of operation and maintenance costs borne by local transit operators, and
M = present worth of operation and maintenance cost differential.

For example, assuming the 80-20 funding split for

Table 4. Local maximum acceptable rehabilitation costs and funding shares.

Case	UMTA Recognized Maximum Rehabilitation Cost ($)	Present Worth of Operation and Maintenance Costs Differential ($)	UMTA Rehabilitation Cost Share ($)	New Versus Local Transit Operator's Maximum Rehabilitation Cost Share ($)	Local Maximum Acceptable Rehabilitation Cost[a] ($)
Mainline	56 000	21 340[b]	44 800	24 579	69 379
1	56 000	10 670[c]	44 800	17 462	62 262
2	56 000	0[d]	41 380	10 345	51 725
3	35 000	21 340	28 000	24 579	52 579
4	35 000	10 670	28 000	17 462	45 462
5	35 000	0	28 000	10 345	38 345
6	70 000	21 340	56 000	24 579	80 579
7	70 000	10 670	56 000	17 462	73 462
8	70 000	0	41 380	10 345	51 725

[a] Value is column 4 plus column 5.
[b] Present worth of $4000/year, operation and maintenance cost differential for 10 percent discount rate for 8-year rehabilitated bus service life.
[c] Present worth of $2000/year, operation and maintenance cost differential for 10 percent discount rate for 8-year rehabilitated bus service life.
[d] Present worth of $0/year, operation and maintenance cost differential for 10 percent discount rate for 8-year rehabilitated bus service life.

capital investments, an UMTA recognized rehabilitation cost of $56 000, the national mainline maximum acceptable rehabilitation cost of $73 065, 66.7 percent of the operation and maintenance costs being borne by local transit operators, and an operation and maintenance cost differential of $4000/year between new and rehabilitated buses ($21 340 present worth), the UMTA share becomes U = 0.8 ($56 000) = $44 800, and the local operator's share becomes:

$$\begin{aligned} L &= 0.2(\$56\,000) + 0.2(\$73\,065 - \$56\,000 - \$21\,340) \\ &\quad + (0.667)(\$21\,340) = \$11\,200 - \$855 + \$14\,234 = \$24\,579 \end{aligned} \tag{4}$$

Thus, the maximum acceptable bus rehabilitation cost a local transit operator should accept is $69 379 ($44 800 plus $24 579).

As presented in Table 4, the maximum acceptable rehabilitation cost for local transit operators would be $69 379 for the mainline assumptions, of which $44 800 would be incurred by UMTA and $24 579 by the local transit operators. Of the local operator's share of $24 579, $13 379 is in excess of federal funding assistance. In other words, it would be cost effective for local transit operators to spend up to an additional $13 379 without federal assistance. Note, however, that the maximum amount local transit operators should spend to rehabilitate a bus is $24 579. Thus, as long as federal funds are available for acquisition of new buses, local transit operators should not begin a bus rehabilitation program without significant federal funding.

The local maximum acceptable rehabilitation cost of $69 379 and the local cost share of $24 579 are 55.5 and 19.7 percent of the cost of a new bus, respectively. These percentages should remain nearly constant for the next few years. As an alternative to the procedure of updating rehabilitation costs, the percentage values of 55.5 and 19.7 can be used. For example, if the cost of a new bus without a lift is $160 000 in February 1983, then the maximum acceptable rehabilitation cost to local transit operators would be $88 800 ($160 000 x 0.555) and the maximum funding share would be $31 520 ($160 000 x 0.197).

CONCLUSIONS

Significant values presented in this paper are highlighted in the following list:

1. $24 579 (maximum rehabilitation cost incurred by local transit operators),
2. $56 000 (UMTA guidelines' maximum acceptable bus rehabilitation cost for an 8-year extended service life),
3. $64 000 (level 2 rehabilitation cost),
4. $69 379 (maximum acceptable rehabilitation cost incurred by local transit operators), and
5. $73 065 (national maximum acceptable rehabilitation cost).

Based on the above values, from the national and local transit operators' viewpoints, bus rehabilitation is a cost-effective alternative to acquisition of new buses. Furthermore, it may be desirable for local transit operators to provide additional local funds above their normal federal matching share because UMTA may not recognize an economically efficient rehabilitation funding level and because of existing funding structures. Local transit operators, however, should not undertake a bus rehabilitation program without substantial federal assistance. Although this paper presents a mainline economic analysis, the cost-effectiveness of bus rehabilitation is sensitive to economic input values. Local transit operators may wish to use values more appropriate for their particular situations. Guidelines are provided to perform these specific analyses.

REFERENCES

1. Urban Mass Transportation Administration. Bus Rehabilitation Program Policy and Procedures. Federal Register, 49 CFR Part 640, Docket No. 80-A, Feb. 11, 1980, pp. 9244-9246.
2. Environmental Science and Engineering, Inc.; ATE Management and Service Company, Inc. Feasibility Study for Transit Vehicle Rehabilitation Center, Florida Department of Transportation, Gainesville, 1980.
3. Urban Mass Transportation Administration. Bus Rehabilitation Program Policy and Procedures. Federal Register, Final Rule, 49 CFR Part 640, Docket 80-A, Jan. 29, 1981, pp. 9862-9865.
4. A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements, 1977. AASHTO, Washington, DC, 1978.
5. Discount Rates To Be Used in Evaluating Time-Distributed Costs and Benefits. Executive Office of the President, Bureau of the Budget, Circular A-94, Rev., March 1972.

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Indirect and Spatial Impacts of Transportation Investment in a Less-Developed Country

A.G. HOBEIKA, G. BUDHU, AND T.K. TRAN

The overall impacts, especially indirect and spatial impacts, are rarely incorporated explicitly and evaluated quantitatively in transportation planning methodologies used in less developed countries. Such planning strategies that are used have resulted in an overemphasis of high-volume facilities to the detriment not only to the growth of rural regions but also to unwanted urban inmigration. In this study an attempt is made through the methodology of system dynamics to explicitly account for the diffused impacts of a given investment policy on the rural region itself and on the nation as a whole (i.e., in terms of shifts in population). Guyana is used for the case study to evaluate the impacts of three investment alternatives: (a) do nothing, (b) investment in roads only, and (c) investment in roads, drainage, and irrigation. The traditional economic analyses of net present worth and benefits/costs ratio are undertaken. However, the additional time-series information on production, income, unemployment, and migration provided by the modeling technique allowed for more astute decision-making in rural investment projects. The roads, drainage, and irrigation alternative provided the best overall impacts and is therefore recommended for implementation. The expected net present worth of this strategy at 10 percent interest rate is approximately G $13 million ($4.3 million U.S.) over a 20-year period. But even more important, it helps to reverse the severe urban inmigration over the analysis period—1980-2000.

In most less-developed countries, the overall impacts, especially indirect and spatial impacts, are rarely and not explicitly incorporated and quantitatively evaluated in their transportation planning models. The premise of transportation planning has been that travel demand is repetitive and predictable and that the transport system should be designed to meet this future demand. This strategy has resulted in an overemphasis on high-volume facilities to the detriment not only to the accessibility and growth of the rural agricultural regions but also to unwanted rural outmigration. In addition, the resultant benefits due to high-volume facilities were disappointing (1), since the concept of traffic volume (i.e., users benefits) used for the evaluation was more relevant to the industrialized countries that developed these methodologies. The value of passenger travel time saved and vehicle depreciation are questionable determinants of real benefits in countries that have high unemployment rates and low vehicles per capita.

Moreover, investments (and their impacts) are treated as if they are spatially neutral in the sense that only the region where the investments are made is affected. Empirical evidence, however, has attested to two trends from transport (especially road investments) in low-economic-activity regions: (a) transport has significant noneconomic impacts (for example, interregional migration and accelerated transfer of know how among others) and (b) transport is only one component (albeit a necessary one) for the development of a region. That is, transport-equal development is a misconception (1-4).

These findings have resulted in researchers calling for a more comprehensive approach to the evaluation of transport investments. Odier (5), in his discussion of benefits, states that road construction affects the nation as a whole and "efforts must be made to assess them as a whole, which result in the first place in the concept of the effects on national income, and in the second place in the customary classification into direct and indirect effects." Harral (6), of the World Bank, points out that

> The value of transport is measured by the degree to which it contributes to goals in other sectors of the economy, and that sound investment analysis requires a greater awareness of the interrelationships between transportation and the other sectors it serves.

Specifically then, the direct, indirect, and spatial impacts of transportation and related agricultural investments on the nation's production and shifts in population need to be evaluated if long-term benefits are to be realized. The system-dynamics methodology proposed in this paper has the capability to incorporate explicitly intrasectoral and intersectoral relations and feedback phenomena and thus may specifically address the above needs.

OBJECTIVES OF THE STUDY

There are definite linkages and feedback between the transport sector and the other main socioeconomic sectors in any region, and this feedback is even more pronounced, Hofmeier contends (7), in poorly accessible agricultural based regions. This study intends to explicitly incorporate the transport activity (variable) in a comprehensive system model and to study the impacts of various investment strategies in transportation and related agricultural inputs on the economy as a whole through the methodology of system dynamics.

Specifically, the objectives are as follows:

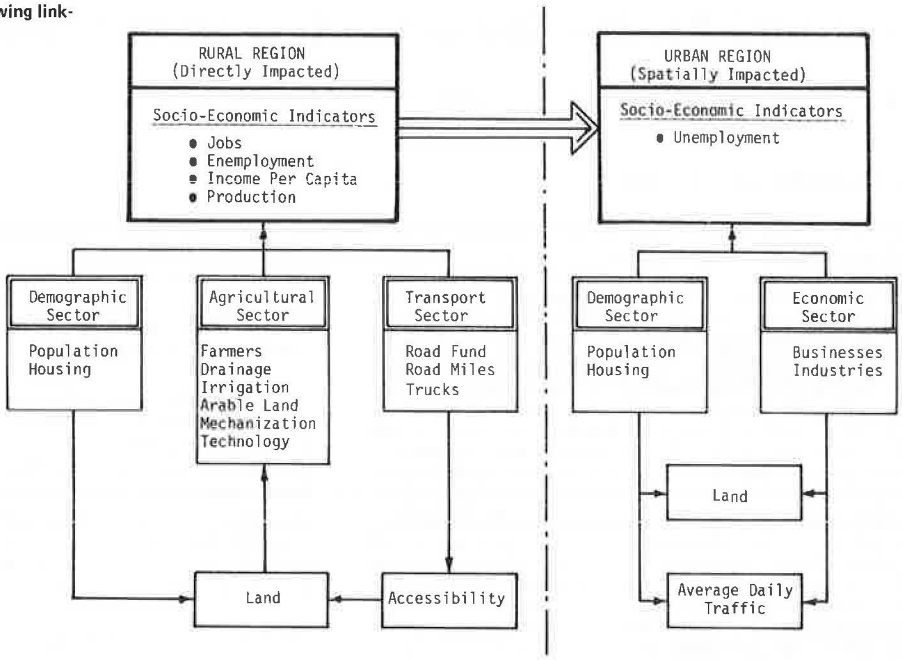
1. To develop computer simulation submodels for the main sectors of both the agricultural based region (directly impacted) and the urban region (spatially impacted);
2. To link the submodels to form a comprehensive model, thereby accounting for the intraregional and interregional relations and interactions of the different sectors of the economy; and
3. To apply the model to Guyana, an agricultural based, less-developed country, as a tool for strategic transportation planning to determine primarily the indirect and spatial impacts of proposed investment strategies.

SCOPE AND ORGANIZATION

Conceptually, an agricultural based economy depends on accessibility and mobility; that is, if the desired level of transport is not provided, the economy is likely to stagnate at a subsistance level and produce possible unwanted urban inmigration. Furthermore, a significant portion of a less-developed country's funds, at times, comes from foreign agencies, which request detailed feasibility studies to justify the loans. Thus, the proposed methodology should provide explicitly, the answers to questions of rate of return and prioritization of investments, impacts on production, employment, income, and migration, among others, for various policies.

The conceptual model is presented, then the model is calibrated with data from Guyana, and used to evaluate the socioeconomic impacts of three investment strategies both at the rural (or directly impacted) and the urban (or spatially impacted) re-

Figure 1. Simplified block diagram showing linkages of main sectors of economy.



gional levels. The direct impacts, i.e., road users savings due primarily to traffic flows, will not be considered in the feasibility analysis but will be used to determine the geometric and structural characteristics of the roadway facility to be constructed. This approach is taken because traffic flow per se is a poor surrogate to determine feasibility in rural development projects. Changes in production and the contribution to national goals are the main determinants of socioeconomic feasibility and implementation. The list below summarizes typical goals, policies, and impacts of a transport investment strategy.

1. Goals--increase rural income and decrease urban inmigration;
2. Policies--do nothing (maintain status quo), invest in transport, or invest in transport, drainage, and irrigation;
3. Direct rural impacts--traffic volumes, travel time, and vehicle depreciation;
4. Indirect rural impacts--production, income, and employment; and
5. Spatial urban impacts--Migration and traffic volumes.

SYSTEM DYNAMICS METHODOLOGY IN PERSPECTIVE

Traditional transportation planning approaches have not seriously attempted to quantify time lags (in the case of construction), feedback, and nonlinear behavior and spatial impacts that are invariably evident after project implementation. The system dynamics approach has the capability of not only using realistic statistical relations (linear and nonlinear) but also of incorporating causalities and feedback relations explicitly.

Ever since the development of system dynamics by Forrester in 1958 (known as industrial dynamics), the methodology has been applied increasingly to a wide range of socioeconomic problems, as documented by Roberts (8). However, except for the work of Drew and others (9), little use has been made of the methodology in the field of transportation planning for rural regions.

The steps involved in undertaking system dynamics analysis are as follows:

1. Causal loop diagramming,
2. Flow diagramming, and
3. Conversion of the flow diagrams into sets of simultaneous difference equations.

According to the theory of system dynamics, the relation between two variables is positive if both of them vary in the same direction; otherwise it is negative. Usually a dynamic model is composed of many causal relations that often close on themselves to form feedback loops. The significance of a feedback loop is in the behavior that the system exhibits. There are basically two types of behavior pattern that are of interest in a qualitative analysis: explosive and asymptotic. An explosive growth pattern is exhibited by positive feedback structures and an asymptotic growth pattern is normally seen from negative feedback structures. Detailed information on system dynamics can be found in Drew and others (8).

DEVELOPMENT OF CAUSAL MODEL

The hypothesis of the model formulation is that investment is not spatially neutral; that is, decisions taken in any of the regions (rural or urban) will eventually impact other regions of the country. The question is how far reaching and diffused would the impacts be? The degree of the spatial impact will depend on the baseline socioeconomic characteristics of the specific country under consideration. That is, in countries where there are significant regional disparities (in terms of job opportunities and incomes), there is a greater likelihood for shifts in population than in countries that have more equitable distributions of development. However, most less-developed countries can be typified as agricultural based or rural economies, in which there are a few or only a single well-developed urban center (generally the capital region), and the remainder of the nation experiences different levels of development as measured by population density and socioeconomic infrastructure such as schools, electricity, transportation, drainage, and irrigation. Furthermore, the urbanized centers are generally the attractors of population because of their relatively higher income per capita, better

Table 1. Basic statistics for study region.

Statistic	1970	1975	1980[a]	1990[a]
Rural				
Population[b]	30 000-35 000	NA	30 000-35 000	NA
Per capita income (G$)	260	NA	NA	NA
Total arable area (acres)	70 000			
Cultivated area (acres)	30 000	33 000	35 000	NA
Collector and farm roads (miles)	150	175	200	NA
Road expenditure (G$)	600 000	1 250 000	1 500 000	NA
Urban				
Population	396 900	NA	516 500	708 800
Jobs	95 514	NA	133 010	189 250
Land area (acres)	193 000			

Note: G$3 = $1 U.S. (1982).

[a] Projected values.

[b] Population for rural area given in ranges because of the difficulty in accounting for everyone in poorly accessible regions.

social infrastructure, and perceived greater job prospects.

Thus, the boundary of influence of the investment may be defined as the immediate region in which the investment is made and the regions that will possibly be affected by in- or out-migration as a result of the impacts of such investments. The boundary and the hypothesized socioeconomic characteristics and interactions of the impacted regions are illustrated in Figure 1.

The hypothesis of Figure 1 is that a poorly developed region (as measured by production level, income per capita, unemployment rate, and accessibility) will loose population to more-developed regions of the country, and this migration to urban centers defines the impacted system boundary to be studied.

The simplified block diagram shows the subdivision and main variables of the sectors of the impacted regions that interact dynamically to produce the regional socioeconomic characteristics, such as unemployment rate, jobs, income per capita, and production rate. It also implies that land availability is a constraint on regional growth and output.

The rural region (i.e., the region directly impacted through investments) is conceptualized as having three main sectors. The demographic sector (whose main components are population and housing) affects unemployment (through the labor force) and land availability (through housing), respectively. The agricultural sector (whose main components are farmers, drainage and irrigation, arable land, mechanization, and agricultural technical inputs) impacts production rate, yield per acre, job opportunities, and profitability. Finally, the transport sector (whose main variables are road funds, road network miles, and trucks) impacts regional accessibility and after-production loss.

The objective of the developed model is to investigate a strategy in transport and related investments in rural regions that provides the most beneficial indirect and spatial impacts. Furthermore, spatial impacts were defined as the shift in population due to differences in regional socioeconomic characteristics measured primarily by differences in unemployment rates. Therefore, the main interest in the urban region (i.e., zones to which population is attracted) is its perceived employment characteristics. As such, the urban region is aggregated into only the demographic and economic sectors--the main determinants of unemployment rates. The demographic sector, whose main components are population and housing, determines the labor force and housing stock of the region. The economic sector, whose main components are businesses and services, determines the job opportunities of the region. Both sectors impact land availability and traffic generated.

Figure 1 presented the simplified but definite linkages that exists between the major sectors of the economy. The important intersectoral impacts are recognized through the following variables: (a) agricultural land development rate, (b) after-production loss, (c) agricultural jobs, (d) urban-to-rural unemployment ratio, and (e) urban inmigration. The first three variables link the sectors of the investment region, and the last two variables link the rural region with the urban region, thus providing explicitly for the spatial impacts.

The synthesized conceptual model of the impacted regions provides the framework for collection of the appropriate data base and the development of the quantitative mathematical model for the economic analyses of a given investment policy.

CASE STUDY OF GUYANA

Guyana, a nation in South America, is chosen for the case study because (a) it is typical of less-developed countries in which accessibility is perceived to be a main constraint to accelerated economic growth; (b) large sums of money are annually allocated for the expansion of the transport sector; (c) the nation's professed economic destiny is in the development of the agricultural potentials; and (d) the data on Guyana were available for model validation.

Directly Impacted Rural Region

The area of influence lies between the Essequibo and Pomeroon rivers, which are 40 miles apart. This boundary encompasses a potential arable land area of 70 000 acres. There are 150 miles of collector and dirt farm roads that serve the current 30 000 acres of rice cultivation, which is the main economic activity of the region. During the wet seasons (twice per year), these roads become impassable and seriously affect the rice production and productivity of the region.

Spatially Impacted Urban Region

Georgetown is Guyana's hub. It holds a commanding position in regard to Guyana's social and economic activities. It is Guyana's political and cultural center and will undoubtedly remain the main center of activities for the future. Decisions taken in any region will affect Georgetown and its future socioeconomic activities.

For the purpose of this study, the urban or spatially impacted region is defined as the region that extends approximately 25 miles from the center of Georgetown (the capital of Guyana) along the Atlantic Coast and the Demerara River. This region accounts for more than 50 percent of the total population and production of the nation and is a net receipient of interregional migration.

The basic information of the two regions is given in Table 1 (10).

System Dynamics Model's Levels and Main Assumptions

The behavior of a system is the outcome of the feedback loops that underlie the structure of the system. Feedback loops govern actions and changes in the system from the simplest to the most complex. A feedback loop is a closed path that connects an action to its effects on the surrounding conditions, and these resulting conditions in turn come back as

Table 2. Hierarchical order of model structure.

Region	Sector	Level	Concept
Rural, Essequibo Coast[a]	Demographic	Population	Births, deaths, migration, unemployment, and housing demand
		Housing	Depends on population and consumes land
	Agricultural	Rice land cultivated	Determines productions and jobs; affected by road accessibility
		Farmers	Determine cultivation level
		Drainage and irrigation	Affect cultivation intensity and yield
		Tractors and harvesters	Affect cultivation intensity
		Road miles	Impacts of accessibility on land development
		Trucks	Impacts of transportation on postproduction loss
		Road fund	Financial constraint on road development
Urban, Georgetown[b]	Demographic	Population	Distribution of population to urban zones
		Housing	Growth is constrained by land availability
	Economic	Businesses, services and wharfs	Determine employment and land use

[a] Directly impacted by investments. [b] Spatially impacted by migration.

Table 3. Summary of model's main assumptions.

Multiplier	Influencing Variables	Influenced Variables	Direction of Influences
Urban immigration	Georgetown unemployment rate/rural unemployment rate	Rural migration	+/-
Rural housing construction	Rural households/houses	Rural housing construction	+
Agricultural land availability	Rural land fraction occupied	Rice land development rate	+/-
Farmers availability	Farmers/land areas cultivated	Rice land development rate	+
Drainage and irrigation	Rice land cultivated/water available	Rice land development rate	-
Husbandry	Agricultural technicians/farmers	Yield per acre	+
Mechanization	Rice land/tractor	Rice land development rate	-
	Rice land/harvester	Yield per acre	-
Road accessibility	Actual road density/desired road density	Rice land development rate	+
Road transport cost	Actual road density/desired road density	Farming cost of transport	-
Fertilizer availability	Fertilizer inputs	Yield per acre	+
Georgetown civic land availability	Georgetown civic land fraction occupied	Georgetown housing, business, and service structure construction	+/-
Urban labor force	Labor force/jobs	Georgetown housing, business, and service structure construction	+

Table 4. Predicted and observed values of rural population, cultivation, and roads.

Variable	1970	1975	1980[a]	1990[a]
Population				
Model	35 000	34 500	32 800	36 000
Observed	35 000	35 000	30 000-35 000	NA
Difference (%)		1.5	6-8	
Cultivation				
Model (acres)	30 000	33 100	35 000	44 800
Observed (acres)	30 000	33 000	35 000	NA
Difference (%)		<1	<1	
Roads				
Model (miles)	150	171	198	284
Observed (miles)	150	175	200	NA
Difference (%)		<1	<1	

[a] Forecast values.

information to influence further actions (11). Two kinds of variables dominate a feedback loop--levels and rates. Levels are the accumulation (integrations) that describe the state or condition of a system at any point in time. Rates are flows that cause the level to change and are generally associated with policies or decisionmaking in the system.

Before the mathematical model of a large and complex socioeconomic system is developed, it is first necessary to understand the behavior of the main components or levels of the system and then to link the components to form a representative model of the system. Table 2 gives a breakdown of the proposed rural transportation planning model (RURTRAN) in terms of (a) the regions represented, (b) the sectors of the regions, (c) the main components or levels that underlie the structure and determine the behavior of the regions, and (d) the concepts and hypothesized phenomena represented by the main components or levels.

Twelve levels have been chosen to develop the rural region (i.e., the directly impacted investment region), and five levels to represent the urban region (i.e., the spatially impacted region). The comprehensive model has a total of 277 simultaneous difference equations and its main assumptions are illustrated in Table 3.

Model Calibration

It is particularly important for a model this large, whose formulation is based on observed data, assumptions, and concepts drawn from demography, economics, agriculture, transportation and technology, to test the model's predictive ability over a sample period.

Calibration was attempted as follows: a set of variables (over a 10-year period) whose characteristics more or less determine the regional behavior were compared with the simulation output for the same period. Table 4 compares the model values and the observed values (data) for population, cultivation, and road miles. The differences between predicted and observed values are less than 10 percent and thus the model is accepted as adequately realistic.

Analyses of Alternative Investment Strategies

The traditional analyses that use benefits/costs and net present worth value will be undertaken because, for all intent and purpose, quantification in monetary terms is still the single-most desirable and used indicator of the impacts of the investments. But benefits from production instead of traffic

Table 5. Results of economic analyses of three strategies.

	Present Worth (G$)				
	Costs				
Strategy	Roads	Drainage and Irrigation	Benefits (G$)	Net Present Worth (G$)	Benefit/Cost Ratio
Do nothing	15 925 400		23 692 400	7 767 000	1.49
Roads only	23 739 400		26 453 700	2 714 300	1.12
Roads, drainage, and irrigation	23 739 400	17 868 400	55 121 500	13 513 700[a]	1.32[a]

Notes: G$3 = $1 U.S. (1982).
Results based on 20-year simulation at 10 percent annual interest rate and one crop per year.

[a] Given guaranteed drainage and irrigation, double cropping per year will result in increased benefits (by a factor of 1.6 to 2).

flows are evaluated for the given outlay. However, recognize also that the estimates of output are not based only on marginal reduction in transport costs. The development project, which embodies a variety of factors, is instead considered as removing a bottleneck to production so that discrete rather than marginal changes to production can occur. Thus, instead of a single numerical indicator for the value of the project, a set of socioeconomic characteristics are used in the evaluation process. Final evaluation is based on the following factors:

1. At the rural regional level--impacts on production and productivity; population, jobs, and unemployment rate; and per capita income.
2. At the urban regional level--impacts on urban inmigration (i.e., spatial impacts).

The following alternatives were analyzed.

Do Nothing

In a real-world scenario, nations never really completely neglect their rural regions. Whereas the desired level of investment may not be forthcoming, cognizance is taken of the contribution of these rural regions to the national economy. Funds are generally allocated to at least maintain the status quo and in some cases to also provide for minimum expansion of the economic infrastructure. The Essequibo Coast (i.e., the rural region in the study) falls in the category of receiving some funding every year, as shown in Table 1, and an average of $1 million Guyana/year for funding was used for this scenario (note G $3 = $1 U.S.). Further, a mile of new road was estimated at G $100 000 and G $5000/mile for routine annual maintenance. For this alternative the calibrated model was simply simulated for 20 years to year 2000, and the output was analyzed.

Investment in Roads

Roads influence the intensiveness and extensiveness of socioeconomic activities in Guyana. Accessibility by roads is, therefore, perceived as the main bottleneck to the expansion of the agricultural base of the region. A sum of G $20 million was assumed for road funds and the model was simulated to the year 2000.

Investments in Roads, Drainage, and Irrigation

There is no doubt that road is the main catalyst to the initial expansion of an agricultural region, but sustained and continued growth and productivity depend on other inputs of which dependable drainage and irrigation may be equally as important as roads. Simply put, dependable drainage and irrigation not only complement the farming infrastructure but maximize the benefits derived from improved access due to roads.

In this case the only modification made to the roads only alternative was the removal of the drainage and irrigation constraints and incorporation of the time lag needed to construct the increased drainage and irrigation capacity.

Analyses of the Outputs of the Three Investment Alternatives

Table 5 summarizes the results of the economic analyses (i.e., the impacts on product only) of the three investment strategies. All of the alternatives satisfy the feasibility criteria of net present worth and benefits/costs ratio. The do nothing performs best on benefit/cost ratio and roads, drainage, and irrigation performs best on the net present worth concept.

Analyses of Other Indirect Impacts

Table 6 provides a summary of the information on the main regional socioeconomic indicators at steady state (i.e., that point in time when the rural region's output stabilizes or further growth in production depends on inputs other than land area farmed or such economic infrastructure as roads, drainage, and irrigation). A close examination of Table 6 reveals the following impacts.

Within 10 and 13 years, respectively, the roads, drainage, and irrigation alternative and the roads only alternative sustain a population of 52 300. The do nothing case takes 20 years to sustain a much lower population of 48 000.

The 25-percent unemployment under the do nothing alternative seems much better than the other two investment strategies. This, however, is because of heavy rural outmigration, as shown in the time series data and also that, within 10 years, 16 100 jobs are provided by the other investment policies. Only 15 500 jobs are provided by the do nothing alternative in year 2000.

The rural regional income per capita, a measure of improvement in standard of living, has risen to $443 from $357 in 1985--as much as 24 percent in a mere six years of the comprehensive investment strategy.

Impacts on the Urban Region

Spatial impacts, as hypothesized in this study, are due primarily to population movements. The inflow of people from the rural region increases urban population, labor force, and unemployment rates. It creates additional stresses on the urban socioeconomic infrastructure of housing, schools, and trans-

Table 6. Steady state values for main socioeconomic indicators.

Indicator	Do Nothing	Roads	Roads, Drainage, and Irrigation
Steady	2000 or in 20 years	1993 or in 13 years	1990 or in 10 years
Rural roads (miles)	324	350	330
Rice land cultivated (acres)	51 800	53 300	53 000
Gross regional income (G$000 000s)	14.8	15.1	20.0
Population	48 000	52 300	53 200
Gross income/capita (G$)	308	288	382
Jobs	15 500	16 100	16 100
Unemployment (%)	25	29	29
Out migration (persons/year)	-46	310	310
Out migration in 1985[a] (persons/year)	311	-624	-624
Gross income/capita in 1985 ($)	357	375	443

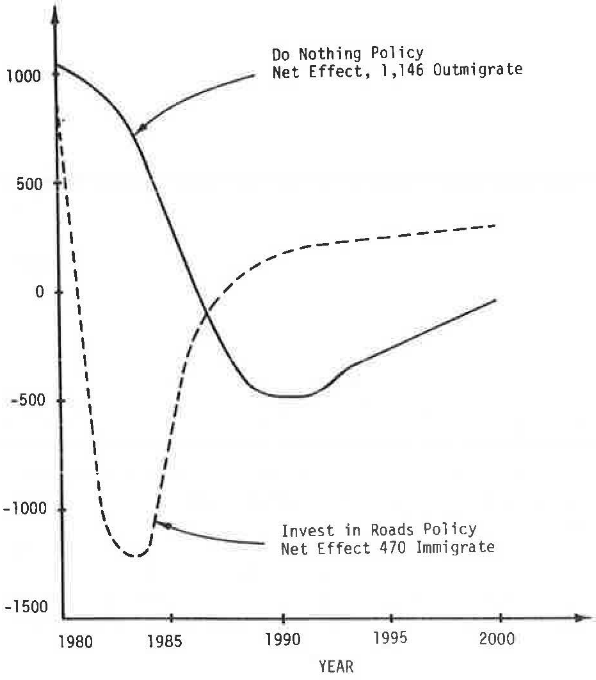
Note: G$3 = $1 U.S. (1982).

[a]Transient state values for 1985.

port. The overall urban inmigration rose from approximately 7000 persons in 1980 to approximately 13 000 persons in 2000; but of real significance here is that the Essequibo region has contributed to less than 3 percent for both investment policies, as opposed to as much as 15 percent for the do nothing alternative.

Figure 2 shows a trace of the behavior of migration over the analysis period from 1980 to 2000. The net effect of the do nothing alternative is that 1146 persons leave the rural region. On the other hand, the investment policies result in a net inflow of 470 persons to the rural region.

Figure 2. Trace of migration over analysis period, 1980-2000.



CONCLUSION AND RECOMMENDATIONS

A planning procedure that can assess the total efficiency of alternative rural investment strategies would be most useful. The concept of total efficiency is difficult to define and analyze. However, it must be faced if maximization of investment funds is to be realized. The system dynamics methodology and the developed model have the flexibility to incorporate indirect, spatial, and other possible impacts due to transport and related investments in rural regions of less-developed countries.

The additional information on income, unemployment rate, and rural outmigration, provided through the system dynamics approach, showed that the investment alternatives in roads only and roads, drainage, and irrigation provided the best overall impacts. The latter was superior in all respects and is therefore recommended for implementation in Guyana. The expected net present worth of this strategy at 10-percent interest rate is approximately G $13 million over a 20-year period. It should sustain a rural population of 52 000 persons at an average income per capita of G $400 annually. Even more important, it helps to reverse the severe urban inmigration over the analysis period, from 1980 to 2000.

REFERENCES

1. C. Edwards. Transportation Planning in the Developing Countries. Planning and Transportation Research and Computation, London, 1978, pp. 1-20.
2. B. Renaud. National Urbanization Policies in Developing Countries. World Bank, Washington, DC, Staff Working Paper 347, July 1979, pp. 1-10.
3. W.W. Shaner. Economic Evaluation of Investment in Agricultural Penetration Roads in Developing Countries, A Case Study of the Tingo Maria-Tocache Project in Peru. Institute in Engineering Economics Systems, Stanford Univ., Stanford, CA, Aug. 1966, pp. 54-65.
4. K.M. Gwilliam. The Indirect Effects of Highway Investments. Regional Studies, Cambridge Univ. Press Association, Cambridge, England, 1980, pp. 2-30.
5. L. Odier. The Economic Benefits of Road Construction and Improvements. Publications ESTOUP, Paris, 1963, p. 6.
6. C.G. Harral. Preparation and Appraisal of Transport Projects. Brooking Institute, Washington, DC, Oct. 1965, p. 2.
7. R. Hofmeier. Transport and Economic Development in Tanzania. Welform Verlaq, Munchen, 1972, pp. 10-20.
8. E.B. Roberts. Managerial Economics of System Dynamics. MIT Press, Cambridge, MA, 1978, pp. 1-30.
9. D.R. Drew and others. Bicol River Basin Development Program--Computer Simulation Model. U.S. Agency for International Development, Manila, Phillipines, Final Rept., Jan. 1975, pp. 1-10.
10. Selected Socio-Economic Data on Guyana. Ministry of Economics Development, Statistical Bureau, Georgetown, Guyana, Annual Repts., 1968-1978.
11. J.W. Forrester. Urban Dynamics. MIT Press, Cambridge, MA, 1961.

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Feasibility of Texas Highway Economic Evaluation Model for High-Occupancy Vehicle Projects

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The increasing importance of improving the efficiency of transportation facilities has resulted in the need for a systematic economic model to evaluate those kinds of projects. An important category of projects includes high-occupancy vehicle (HOV) projects, which encourage higher vehicle occupancy rates by restricting the use of some portion of the facility to some vehicle types or minimum number of occupants. This paper examines the feasibility of using the Texas highway economic evaluation model (HEEM) to evaluate HOV projects and recommends changes to the current model in three major areas, including the assumptions used in the model, the user cost calculations, and the method of allocating corridor traffic to specific routes within the corridor. The assumptions of the model examined include the percentage of trucks, the occupancy rates, and the value of time. The calculations for vehicle operating costs, including running costs and cycling costs, are examined, along with the vehicle types used in those calculations. The allocation of corridor traffic is an important aspect of evaluating HOV projects and other types of highway projects. The allocation method used in HEEM is compared with a method that minimizes the total user costs. The method involves determining the allocation such that the marginal user costs for each route in the corridor are equal. User cost equations are presented that can be used to allocate corridor traffic for any number of routes within the corridor. The cost functions are based on the user cost calculations in HEEM.

The near completion of the Interstate highway system and the increasing shortage of funds for future highway construction have caused state highway agencies to concentrate on upgrading and increasing the capacity of existing streets and highways. The projected shortage of funds has also forced the scaling down or deletion of many planned improvements on new and existing facilities. As a result, it has become increasingly important for highway agencies to estimate potential user and nonuser benefits and costs accurately from planned highway projects.

In recognition of this problem, the highway economic evaluation model (HEEM) was developed to measure the benefits and changes in mobility from a planned highway project. This paper examines a version of the model adapted for Texas and currently in use by the Texas State Department of Highways and Public Transportation (1).

HEEM provides for a streamlined and systematic approach for evaluating highway projects on a segment, route, or system basis in terms of a benefit/cost ratio, called an economic measure (EM), and mobility measure. EM for each project is the ratio of the present value of the estimated user benefits to the estimated construction costs. The user benefits are the sum of time savings, vehicle operating cost savings, and accident cost savings less the added (incremental) maintenance costs. Mobility is measured in terms of average daily speed for both the do-nothing and construct alternatives.

HEEM requires a relatively small amount of input data, including characteristics of existing and proposed highways, construction dates and costs, corridor traffic (current and projected), and key assumptions that the model provides but can be modified for a specific project evaluation if necessary. Table 1 (2) lists the current values of those key assumptions for Texas.

HEEM provides 33 different highway types that can be evaluated in the model along with the relevant specifications of speed, volume [average daily traffic (ADT)], cycles, accidents, and maintenance costs for each highway type. The model also provides the mathematical relations to calculate the user costs and EM. No knowledge of the relations are required to run the model.

Unfortunately, HEEM does not estimate a highway project's effect on air pollution as does other currently used procedures (3,4). Also, the model does not provide for the evaluation of fuel consumption and bus or other transit projects (as opposed to highway projects) as do procedures presented in the new American Association of State Highway and Transportation Officials (AASHTO) Redbook (5).

As a result, projects that increase the efficiency of existing capacity, including priority treatment to high-occupancy vehicles (HOVs), cannot be evaluated by using HEEM. HOV projects have been receiving considerable attention in recent years and it is therefore of interest to consider modifying HEEM so that a systematic economic evaluation of HOV projects could be accomplished. Three major areas must be addressed in modifying HEEM to evaluate HOV projects. The first area is the appropriateness of the key assumptions (default values if not changed for specific projects) presented in Table 1 as they apply to HOV projects. The second area is the underlying user cost relation and the third area is the allocation procedure for allocating future projected traffic routes within the corridor.

ASSUMPTIONS OF MODEL

Buffington and others (6) examine each one of the key assumptions from HEEM in detail. One assumption is especially important in evaluating HOV projects, namely the percentage of trucks and a related issue, the occupancy rate.

A single statewide average percentage of trucks is assumed in HEEM for separating corridor traffic into two vehicle types, passenger cars and trucks. It is unclear what supporting evidence was used in arriving at the 8 percent statewide average and if the truck category includes pickup and panel trucks.

Table 2 presents data based on a selected random sample of 326 highway sections scattered over Texas and indicates that 8 percent is too low for a statewide average. These data compare favorably with national data, compiled by the U.S. Department of Transportation, as given in Table 3 (7). A related problem, evident in Table 3, is the wide variability in the proportion of single-unit trucks and multiunit trucks among highway types and location.

These problems are especially critical in evaluating HOV projects since the use of certain lanes are typically restricted to certain types of vehicles or vehicles that require a minimum number of occupants. A single statewide average would clearly be inappropriate. Instead, each highway project and each route evaluated in that project should be assigned a locally determined percentage of trucks, with single-unit trucks and multi-unit trucks separate. In the absence of a valid local estimate, estimates in Tables 2 and 3 could be used for conventional projects, and data from other HOV projects, such as the data reported by D. Baugh and Associates (8) could be used in the evaluation of HOV projects.

Table 1. HEEM's key assumptions for Texas.

Assumption	Description	Assumed Value in 1981
Truck percentage	Percentage of commercial truck traffic in typical traffic flow	Varies by facility default 8 percent
Value of time	Value of time lost due to congestion or circuitous travel	
Automobile	Average passengers per automobile at 1.3 persons/vehicle	$0.15/vehicle min
Truck	Average commercial truck	$0.28/vehicle min
Rate of inflation	Long-term rate of general inflation	8 percent
Construction cost-escalation rate	Long-term rate of construction cost escalation including inflation and the effects of higher environmental and design standards	8 percent
Discount rate	Minimum anticipated annual return of user benefits on dollars invested in highway construction projects	20 percent
Diversion route speed	Speed assigned to traffic diverted from a corridor that has reached capacity	
Rural		25 mph
Urban		15 mph

Table 2. Percentage of trucks on Texas highways by road system and location.

	Location					
	Rural		Urban		All	
Road	Percent	No.	Percent	No.	Percent	No.
Interstate highway	23.33	24	10.84	3	21.91	27
Loop highway	2.27	1	11.25	4	9.56	5
U.S. highway	17.68	116	2.86	1	17.55	117
State highway	15.26	56	10.37	1	15.50	57
Farm-to-market road	10.68	121		0	10.68	121
All	14.99	317	9.73	9	14.85	326

Note: Table is based on 1975 data collected from the Texas State Department of Highways and Public Transportation Roadway Information System File. Data excludes pickup and panel trucks.

Table 3. Percentage distribution of national vehicle miles of travel by type of vehicle, highway type, and location.

Type of Vehicle	Main Rural (%)	Local Rural (%)	Urban Streets (%)	All Roads (%)
Car	70.7	82.6	83.5	78.9
Bus	0.4	0.8	0.3	0.4
Single-unit truck[a]	19.1	15.5	14.8	16.4
Combination truck	9.8	1.1	1.4	4.3

[a] Includes panel and pickup trucks.

Not only must the distribution of vehicles be estimated with a reasonable degree of accuracy, but in order to calculate user time costs, the average number of occupants in each vehicle must also be estimated accurately. HEEM assumes an occupancy rate of 1.3 persons/car and 1 person/truck. The table below (9) gives vehicle occupancy rates for buses and passenger cars that operate in rural and urban areas. Transit buses are assumed to operate only in cities that have a population of at least 300 000.

	Occupancy Rate (persons/vehicle)		
Vehicle Type and Location	Avg	Peak Hour	Practical Maximum
Passenger car			
All trips including work and intercity trips	2.2	1.6	3.5
Intercity trips	2.9		
Bus			
Transit	9.0	18.0	25.0
Intercity	20.0		30.0

The assumed occupancy rate for passenger cars in HEEM is acceptable only for urban peak hours, especially since HEEM's calculations include nonpeak hours.

The occupancy rate in evaluations of HOV projects is especially important because one of the goals of such projects is to induce persons to use higher-occupancy modes of travel, including buses, vans, and carpools. The occupancy rates in HEEM cannot currently be adjusted except indirectly through the value of time assumption, which is assumed to be the same for all routes in the corridor being evaluated.

A constant occupancy rate is generally not appropriate for HOV project evaluations; therefore, HEEM should be modified to accept variable occupancy rates based on local estimates when available, otherwise estimates such as those in the table above could be used. Memmott and Buffington (10) provide some recommended occupancy rates for various HOV projects.

The occupancy rate affects user costs principally through the value of time calculations. Since time savings usually account for the greatest portion of user savings that result from a highway improvement, the assumed unit values of time used in calculating time savings is of utmost importance.

Initially, HEEM assumed, in 1975 dollars, a value of time of 9 cents/vehicle-min (assuming 1.3 persons/vehicle) for the average automobile and 18 cents/vehicle-min (assuming one driver and considering the value of equipment) for the average commercial truck. The assumed automobile value of time is almost identical to that recommended by Buffington and McFarland (4) as well as by Thomas (11) and Lisco (12), when adjusted to 1975 prices. Also, this value is near the upper end of the range of values recommended in the AASHTO Redbook (5). Therefore, after updating, HEEM's assumed value of time for automobiles is acceptable for time savings calculations if the amount of time saved, income level of occupants, or purpose of trip are not taken in account.

HEEM's initially assumed value of truck time is almost the same as that recommended by Buffington and McFarland (4) as well as by Adkins (13) for heavy multi-unit trucks. An average value of 16 cents/vehicle-min, as given in the table below, would be more representative of the average commercial truck. The distribution of average trucks is assumed to be 34.7 percent single-unit trucks and 65.3 percent multi-unit trucks.

Source	Value of Time in 1975 (¢/vehicle-min)		
	Single-Unit Truck	Multi-unit Truck	Avg Truck
AASHTO Redbook (5)	11.5	13.0	12.5
TTI study (4)	13.4	18.0	16.4

The AASHTO Redbook (5) recommends slightly lower values of truck time, based on a study by Wilbur Smith and Associates (14).

Since the values of time recommended by Buffington and McFarland (4) are based on truck and driver costs that prevail in the Southwest, a weighted average value of 16 cents/vehicle-min in 1975 prices would be preferred for evaluations of Texas highway projects. However, a superior method would be to treat each truck type separately, which would eliminate the necessity of calculating a weighted average. HEEM is not currently capable of incorporating additional vehicle types.

HEEM assumes a single value of time for cars. However, there is evidence in the literature to indicate that the value of time for passenger cars and buses varies with the amount of time saved per trip, family income, and the purpose of the trip (5,15,16). Thomas and Thompson (15) pioneered the research in this area in the late 1960s by using a revealed behavior approach. Their findings are based on a survey of motorists at sites in 10 states who faced a choice of a faster toll road or a slower free road. The value of time was based on how much money motorists were willing to pay in tolls to save a certain amount of time. They concluded that the value of time saved is a function of trip time saved, the motorist's family income, and trip purpose.

The AASHTO Redbook (5) gives a procedure for using the findings of Thomas and Thompson. Table 4 is based on that procedure, which divides both the amount of time saved and trip purpose into three different categories. As Table 4 shows, values of time can vary widely among the different categories and a single value of time may not be appropriate when these factors may differ significantly for different routes or over time for a single route.

USER COST CALCULATIONS

HEEM calculates user costs for time costs, accident costs, and vehicle operating costs. Operating costs are broken down into two categories, namely, running costs and cycling or speed change costs. The running costs, updated to March 1975, are based on those by Winfrey (18) and the AASHTO Redbook (5). The cycling costs are based on those used by Winfrey.

Figure 1 depicts the cost curves. The running costs for speeds below 25 mph are calculated by using a different equation than the running costs above 25 mph. There is a slight discontinuity at 25 mph as a result. The cycling cost equations estimate the cost of 10-mph cycles as a function of initial speed. This is as a linear function of average traffic volume by highway type and number of lanes. Cycling costs and average speeds can be adjusted for technical performance factors, such as shoulder and lane width, vertical alignment, and percentage of trucks.

Comparison of these operating costs to other estimates presents some difficulty because running costs and cycling are not generally separated in the same fashion as in HEEM. However, assuming 5.4 cycles/vehicle mile, HEEM's operating costs are roughly similar to AASHTO Redbook (5) costs for speeds below 25 mph. For speeds above 25 mph HEEM unit costs are more similar to operating costs recommended by Buffington and McFarland (4). The cycling cost component accounts for most of the difference in the combined costs generated from these data sources, which indicates the need for new cycling data, compiled for different highway types and traffic conditions, in order to estimate vehicle operating costs accurately.

Another problem is the limited vehicle types used in HEEM. The operating costs for all truck types are calculated on the basis of one truck type, assumed to be the multi-unit type. Difference in the operating costs of single-unit trucks and multi-unit trucks is considerable, especially at lower speeds. This becomes pertinent in calculating bus operating costs for HOV projects. One solution would be to use a weighted average of operating costs based on the distribution of trucks. However, the assumption of one set of weighted average unit costs for statewide use will yield vehicle operating cost estimates of varying accuracy. A superior method would be to revise HEEM to handle more vehicle types. The accuracy of the user cost calculations would improve and it would give the flexibility of handling unusual vehicle distributions, which is typically the case in HOV projects.

ALLOCATION OF CORRIDOR TRAFFIC

One of the most critical factors in HOV projects is the vehicle use of the restricted lanes. HEEM uses as an input the projected corridor ADT for a pro-

Table 4. Value of time as a function of time saved and trip type.

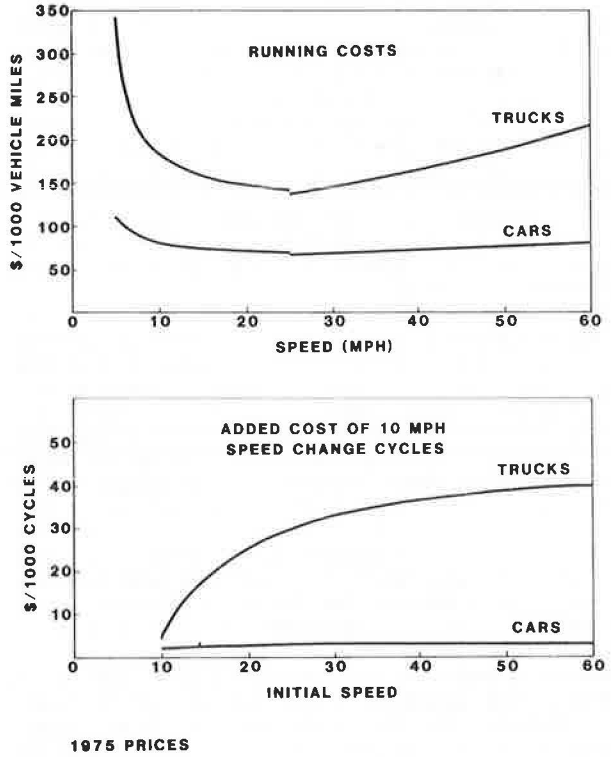
Time Saved	Trip Type	Value of Time per Traveler Hour ($)[a]	Percentage of Average Hourly Family Income[b]
Low time savings, 0-5 min	Work	0.47	6.3
	Personal business	0.01	0.1
	Social-recreational	0.05	0.7
	Weighted avg	0.18[c]	2.4
Medium time savings, 5-15 min	Work	2.42	32.5
	Personal business	1.12	15.0
	Social-recreational	0.87	11.7
	Weighted avg	1.47[c]	19.7
High time savings, 15-20 min	Work	4.06	54.5
	Personal business	4.31	57.9
	Social-recreational	2.24	30.1
	Weighted avg	3.54[c]	47.5

[a] Original values in Thomas and Thompson report (15) are updated to 1975 values by using the U.S. consumer price index.

[b] Based on 2080 working hours/year for the $15 500 average income of the $14 000-$17 000 range or $7.45/h. Use these percentages to adjust value of time factors proportionately when average family incomes are located outside the $14 000-$17 000 range.

[c] Arrived at by weighting individual values of time by trip purpose by following percentage of trip distribution (17): work trips = 36.7 percent, personal business trips = 40.8 percent, and social-recreational trips = 22.5 percent.

Figure 1. Vehicle operating cost-speed relation by vehicle type used in HEEM.



jected year and then calculates the projected ADT for each year up to the projected year by using either a constant growth rate or declining growth rate formula (19). The corridor traffic for each year is then allocated to the existing route, alternate route (if specified), and any excess is diverted to an unspecified circuitous route. The same allocation process is then repeated for the proposed route, the existing route (if it is not built over), an alternate route (if specified), and any excess is again diverted.

HEEM uses a very simple method to allocate corridor traffic--the route that has the highest ADT capacity receives all the traffic up to its congestion point or breakpoint, as it is referred to in the guide to HEEM (1). The breakpoint varies for most routes, but is is about 50 percent of capacity ADT on city streets and about 75 percent on rural streets. For rural divided highways and freeways the percentage is about 60 percent, compared with about 65 percent for urban expressways and freeways.

After the breakpoint for the highest capacity route is reached, all unallocated corridor traffic is then allocated to the next highest capacity route up to its breakpoint. This process continues until all routes being examined in the corridor have been allocated traffic up to the breakpoint. Traffic is then allocated to the highest capacity route up to its capacity, and the process continues in the same order as before until all routes have been allocated traffic to their capacities. Any additional unallocated traffic is then placed on the diverted route, which is severely penalized with an extremely low diversion speed of 15 mph in urban areas and 25 mph in rural areas.

It would be unlikely that this method would approximate actual traffic allocation. It would be especially unrealistic for HOV projects where the typical experience has been underuse of the HOV lanes compared with the unrestricted lanes (8).

The problem is how to allocate corridor traffic to approximate actual allocation within the limitations of HEEM's input data. Several sophisticated traffic demand models can be used to predict the traffic allocation given a projected corridor traffic, but the data requirements to calibrate the models are too large and expensive to be used regularly in evaluating highway projects and are certainly outside the capability of HEEM.

Another approach to the traffic allocation problem is to examine user costs. A basic axiom of microeconomic theory is that individuals seek to maximize utility. In reference to the use of transportation facilities in general, that would be equivalent to minimizing user costs. Most traffic demand models seek to minimize time or distance, but they are just components of user costs. In general, each motorist will choose the route and mode of travel that will minimize the perceived or expected individual user costs.

The problem is in accurately specifying the cost functions for each potential motorist in the corridor, which is clearly impossible. However, HEEM does provide average user cost functions that could be useful in approximating traffic allocation if the distribution of individual cost functions are fairly normally distributed. The reason for this is that persons on either end of the distribution will tend to be insensitive to changes in the average user costs for alternative routes. The allocation will be determined at the margin by motorists who are indifferent as to which route to choose, and, if those motorists are near the mean of the distribution, then an average cost function may approximate the allocation process.

Total user cost of corridor traffic is defined as the sum of user costs for each route in the corridor,

$$TC = \sum_{i=1}^{n} C_i(y_i) \tag{1}$$

where

TC = total corridor user cost;
C_i = total user cost for route i for a given ADT, y_i;
y_i = average daily traffic volume along route i; and
n = number of routes in the corridor.

Total corridor traffic equals the sum of the traffic for each route; therefore,

$$T = \sum_{i=1}^{n} y_i \tag{2}$$

Forming the Lagrangean,

$$L = \sum_{i=1}^{n} C_i(y_i) + \lambda\left(T - \sum_{i=1}^{n} y_i\right) \tag{3}$$

where λ is the Lagrangean multiplier.

Then, if we minimize L with respect to each of the y_i and eliminate the λ,

$$C_i'(y_i) = C_j'(y_j) \quad \text{for all } i \neq j \tag{4}$$

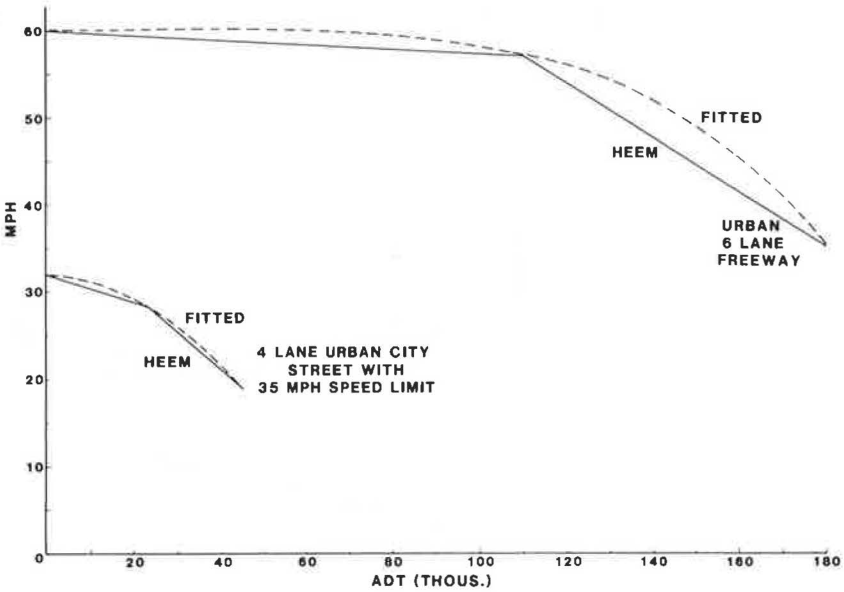
where $C_i'(y_i)$ is the marginal cost for i.

In order to minimize total user cost, the marginal cost for each route must be equal. For a given corridor traffic volume, an equilibrium will occur where the marginal motorist is indifferent as to which route in the corridor to take.

HEEM's user cost equations are not all smooth, continuous functions. Therefore, approximations are required in order to adapt this allocation technique to HEEM.

The speed-volume relation in HEEM is estimated with two straight lines, one running from the ini-

Figure 2. Approximation of speed-volume relation.



tial speed at 0 ADT to the breakpoint. The second line runs from the breakpoint to the point where the facility reaches capacity. The following function provides a good approximation to the relation,

$$f(y) = C - e^a y^b \quad (5)$$

where

y = ADT,
$f(y)$ = speed (mph) for a given traffic volume y,
$b = [\ln(C - E) - \ln(C - D)]/(\ln A - \ln B)$,
$a = \ln(C - E) - b\ln A$,
A = capacity ADT,
B = breakpoint ADT,
C = beginning speed (mph),
D = breakpoint speed (mph), and
E = capacity speed (mph).

Figure 2 compares the approximation by using Equation 5 with HEEM's speed-volume relation for two representative highway types.

As shown in Figure 1, the running costs are discontinuous at 25 mph. These equations can be approximated closely by using the following formulas, which are in terms of dollars per 1000 vehicle miles in January 1975 prices,

$$R_c = 194.3964 + 3.4337f(y) - 0.01926f(y)^2 - 61.7585\ln f(y) \quad (6a)$$

$$R_t = 413.2859 + 4.31590kf(y) + 0.00947[kf(y)]^2 - 119.7313\ln[kf(y)] \quad (6b)$$

where

R_c = automobile running costs,
R_t = truck running costs, and
k = avg speed of trucks/avg speed of cars, for a given traffic volume y.

Yearly running costs (RN) are

$$RN = (365 \cdot L \cdot y/1000)\ [(1 - r)R_c + rR_t] \quad (7)$$

where r is the percentage of trucks and L is the length in miles of route.

The cycling costs per 1000 cycles in January 1975 prices (depicted in Figure 1) are calculated by using the following formulas:

$$CY_c = 3.9499 - [13.8413/f(y)] \text{ cars} \quad (8a)$$

$$CY_t = 47.2458 - [428.198/kf(y)] \text{ trucks} \quad (8b)$$

The number of cycles per vehicle mile is given as,

$$NCY = [F + G(y)]/tpf \cdot N \quad (9)$$

where

tpf = technical performance factor used to adjust speed and cycling costs for abnormal conditions ($0 < tpf \leqslant 1$),
N = number of lanes,
F = 0.238 997 G = 0.000 183 for freeways and divided highways,
F = 5.1959 G = 0.000 190 for four-lane undivided highways, and
F = 2.2732 G = 0.000 355 for two-lane undivided highways.

For metered freeways, the number of cycles is assumed to stop rising at 3.1 cycles/vehicle mile, so the number or cycles for metered freeways can be approximated with

$$NCY_m = (F + cy + dy^3)/tpf \cdot N \quad (10)$$

where

$$d = G^3/[(3.1N - F)^2 - 3A^2G^2] \quad (11)$$

and

$$c = -3A^2 d \quad (12)$$

The yearly cycling costs (TCY) are then calculated,

$$TCY = (365 \cdot L \cdot y/1000)(NCY)\ [(1 - r)CY_c + rCY_t] \quad (13)$$

The total operating costs (TOC) are the sum of the running costs and the cycling costs,

$$TOC = RN + TCY \quad (14)$$

Time costs (VT) are calculated as,

$$VT = [21\,900 \cdot L \cdot y/f(y)]\ [(1 - r)(OC_c)(T_c) + (r/k)(OC_t)(T_t)] \quad (15)$$

where

OC_c = car occupancy rate,

Figure 3. Comparison of total vehicle user cost functions.

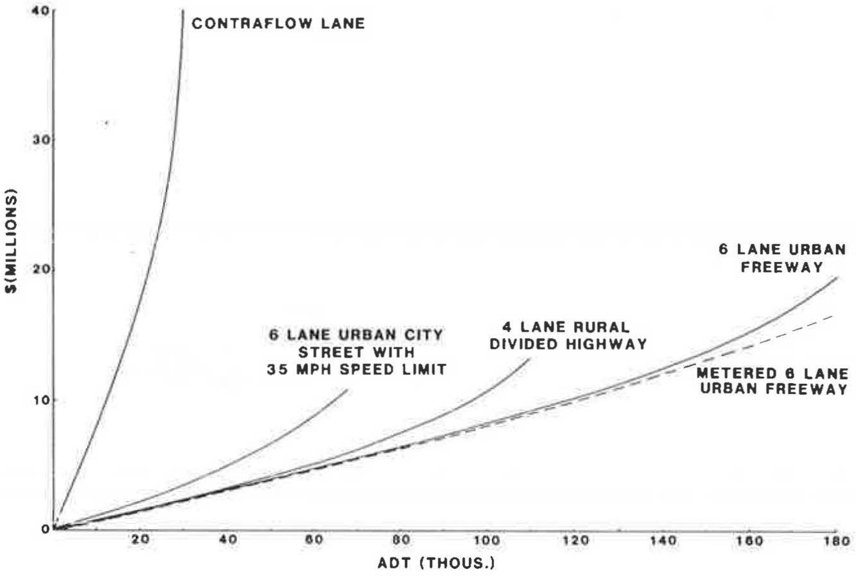
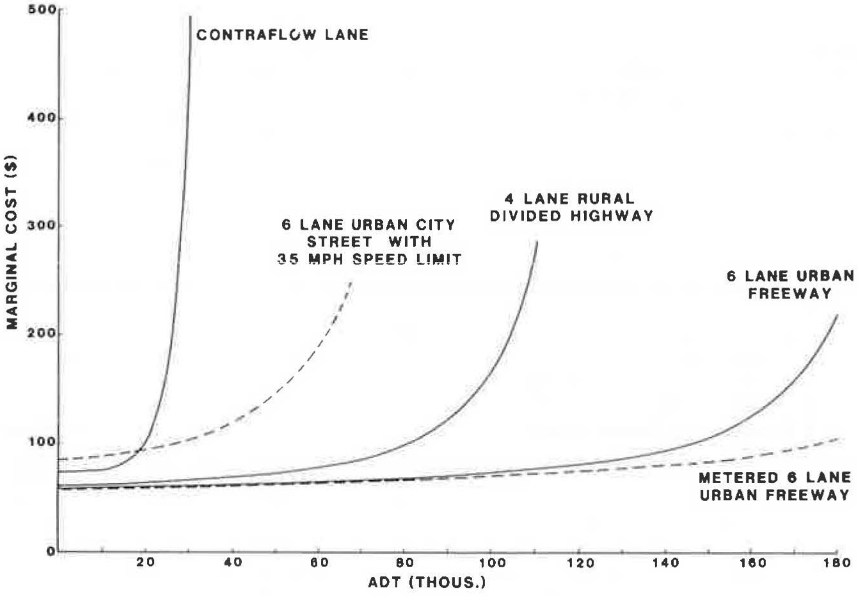


Figure 4. Comparison of marginal user cost functions.



OC_t = truck occupancy rate,
T_c = car value of time per person ($/min), and
T_t = truck value of time per person ($/min).

Accident costs (AC) are one given as,

$$AC = [365 \cdot L \cdot y \cdot H/(10^6) \cdot sf]\ [I + (Jy/1000)] \tag{16}$$

where

H = mean cost per accident,
I = intercept term for accident rate per million vehicle miles,
J = slope term for accident rate per million vehicle miles as a function of ADT (thousands), and
sf = safety factor used to adjust accident rate for abnormal conditions, such as shoulder and lane width.

Total user costs (TC) are the sum of operating costs, time costs, and accident costs,

$$TC = TOC + VT + AC \tag{17}$$

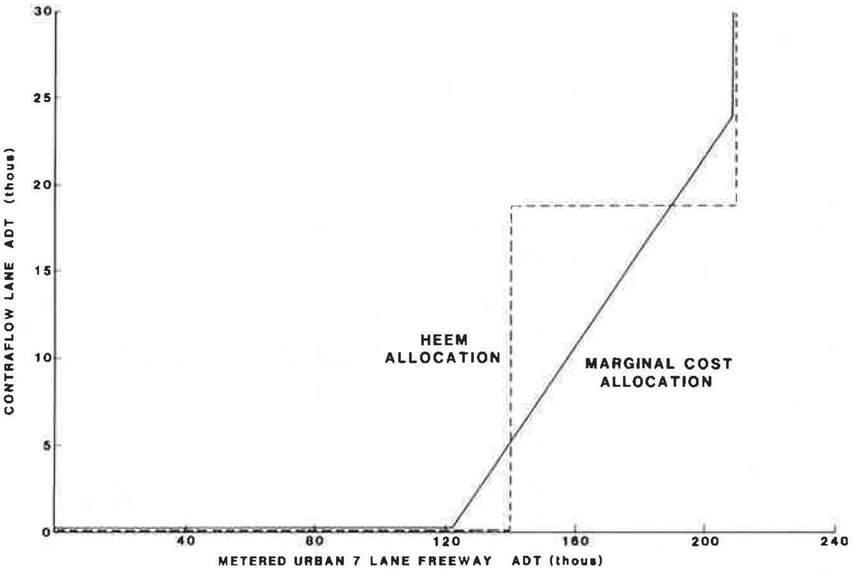
The shape of some representative total user cost functions is depicted in Figure 3. These curves are based on the 1975 default values for HEEM and the user cost functions presented above.

The marginal cost functions per person (MC) can be obtained by taking the derivitive of the total cost functions (Equation 17) with respect to the ADT volume and dividing by the weighted occupancy rate.

$$MC = (dTC/dy) \cdot \left\{1/[(1 - r)\, OC_c + rOC_t]\right\} \tag{18}$$

The marginal cost functions are sufficiently complex that an analytical solution is generally not possible; however, a solution can be obtained through iteration techniques, which can easily be performed in a computer program such as HEEM. Memmott and Buffington (10) give the marginal cost functions for the total cost functions, presented above, as well as a method for programming the allocation process by using marginal user cost functions. Figure 4 presents the marginal cost functions for the total

Figure 5. Comparison of HEEM allocation method with marginal cost-allocation method for a contraflow lane.



cost functions in Figure 3.

The marginal cost-allocation method is an equilibrium model, where the marginal costs for the last motorist on each highway in the corridor are equal. This would involve selection of the level of marginal cost such that ADTs for each highway in the corridor sum to the corridor ADT.

Figure 5 gives an example of the marginal cost allocation compared with the current HEEM allocation method. In this example traffic must be allocated between only two highways, a contraflow lane and a metered urban freeway. HEEM first would allocate all traffic to the metered freeway up to 140 000 ADT, then all additional traffic would be allocated to the contraflow lane up to 18 750 ADT, and this would continue until both reach their capacity.

The marginal cost allocation gives a much more uniform allocation, with the contraflow lane not being used until traffic on the metered freeway reaches about 120 000 ADT, then traffic allocates proportionately between the contraflow lane and the other freeway lanes until the unrestricted lanes reach capacity. This allocation would be much closer to what would be expected in actual application.

Another important aspect of the marginal cost-allocation method is that its usefulness extends beyond the evaluation of HOV lanes. It could be used in a great variety of highway projects where future traffic volumes must be allocated between two or more highway facilities. If relevant user costs are specified correctly, then this method should provide a reasonably good approximation of corridor allocation. It is certainly superior to using only travel time as the relevant variable, which is the method used in most other models, such as the Federal Highway Administration's highway investment analysis package (HIAP) (20).

CONCLUSION

Several modifications should be undertaken in order to modify HEEM to analyze HOV projects, including the following:

1. In the absence of a specific project estimate, the percentage of trucks default value should vary for relevant highway characteristics rather than by using one statewide average;
2. A variable occupancy rate for each corridor route should be added to the input data;
3. The number of vehicle types should be increased to improve the accuracy of the estimates for time savings and vehicle operating costs;
4. The value of time parameter should vary to account for trip time savings, family income, and trip purpose;
5. Vehicle operating costs should be updated to reflect actual expenses more accurately; and
6. The marginal cost-allocation method should be used to allocate corridor traffic volume.

The use of marginal user cost functions to allocate traffic has the potential to give a reasonably accurate estimate of future demand for a highway facility. Of course this method is sensitive to the specifications of the cost functions and the assumed values of the parameters, but it does not require the amount of data other methods require. The calculations are relatively simple and derived from minimizing user costs.

The marginal cost-allocation method is especially valuable in, but not limited to, evaluating HOV projects because the use of the facility is of critical importance. This method, along with other changes recommended for HEEM in this paper, should give government agencies a fairly reliable economic model to use in evaluating HOV and other highway projects.

Several other areas of the current HEEM model could possibly be improved, but these are outside the scope of the paper. These other areas are covered in detail by Buffington and others (6). However, HEEM provides a solid framework to use in looking at the desirability of a particular highway project and, as improvements are made over time, it should provide a reliable systematic method for evaluating not only conventional highway construction projects but also the increasingly important HOV projects and related methods to increase the efficiency of transportation facilities.

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responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views and policies of the Texas State Department of Highways and Public Transportation or the Federal Highway Administration.

REFERENCES

1. Guide to the Highway Economic Evaluation Model. Texas State Department of Highways and Public Transportation, Austin, Feb. 1976.
2. Deriving HEEM's Assumptions for Texas. Texas State Department of Highway and Public Transportation, Austin, Discussion Draft, Feb. 1976.
3. D.A. Curry and D.G. Anderson. Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects. NCHRP, Rept. 133, 1972, 127 pp.
4. J.L. Buffington and W.F. McFarland. Benefit-Cost Analysis: Updated Unit Costs and Procedures, Texas Transportation Institute, Texas A&M Univ., College Station, Res. Rept. 202-2, Aug. 1975.
5. A Manual for User Benefit Analysis of Highway and Bus Transit Improvements, AASHTO, Washington, DC, Feb. 1977.
6. J.L. Buffington, W.F. McFarland, and J. Rollins. Texas Highway Economic Evaluation Model: A Critical Review of Assumptions and Unit Costs and Recommended Updating Procedures. Texas Transportation Institute, Texas A&M Univ., College Station, Res. Rept. 225-8, Jan. 1979.
7. Highway Statistics, U.S. Department of Transportation, 1974.
8. D. Baugh and Associates, Inc. Evaluation of Freeway High-Occupancy Vehicle Lanes and Ramp Metering. U.S. Department of Transportation, Vol. 1, Aug. 1980.
9. Energy Efficiencies of Urban Transportation. Technical Study Memorandum No. 9, Alan M. Voorhees, and Associates, Inc., McLean, VA, May 1974.
10. J.L. Memmott, and J.L. Buffington. The Evaluation of High Occupancy Vehicle Projects in the HEEM. Texas Transportation Institute, Texas A&M Univ., College Station, Res. Rept. 225-24, Jan. 1982.
11. T.C. Thomas. The Value of Time for Passenger Cars: An Experimental Study of Commuters' Value. Final Rept., U.S. Bureau of Public Roads, Vol. 2, May 1967.
12. T.E. Lisco. The Value of Commuters' Travel Time--A Study in Urban Transportation. Department of Economics, Univ. of Chicago, Ph.D. dissertation, June 1967.
13. W.G. Adkins, A.W. Ward, and W.F. McFarland. Value of Time Savings to Commercial Highway Vehicles. NCHRP, Rept. 33, 1967, 74 pp.
14. Wilbur Smith, and Associates. Bus and Truck Roadway Systems and Truck Travel Restrictions. U.S. Department of Transportation, Vol. 1, Feb. 1975.
15. T.C. Thomas and G.I. Thompson. The Value of Time Saved by Trip Purpose. Stanford Research Institute, Menlo Park, CA, Oct. 1970.
16. T.C. Thomas and G.I. Thompson. Value of Time Saved by Trip Purpose. HRB, Highway Research Record 369, 1971, pp. 104-117.
17. Executive Office of the President. The Potential for Energy Conservation. Office of Emergency Preparedness, Washington, DC, Oct. 1972.
18. R. Winfrey. Economic Analysis for Highways. International Textbook Co., Scranton, PA, 1969.
19. J.L. Memmott and J.L. Buffington. Predicting Traffic Volume Growth Rates Resulting from Changes in Highway Capacity and Land Development. Texas Transportation Institute, Texas A&M Univ., College Station, Res. Rept. 225-23, Jan. 1981.
20. Multisystem, Inc. (modified by W. Smith and Assoc.). Highway Investment Analysis Package (HIAP): Vol. II, Tech. Manual. Federal Highway Administration, June 1979.

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Impact of Highway Improvements on Property Values in Washington State

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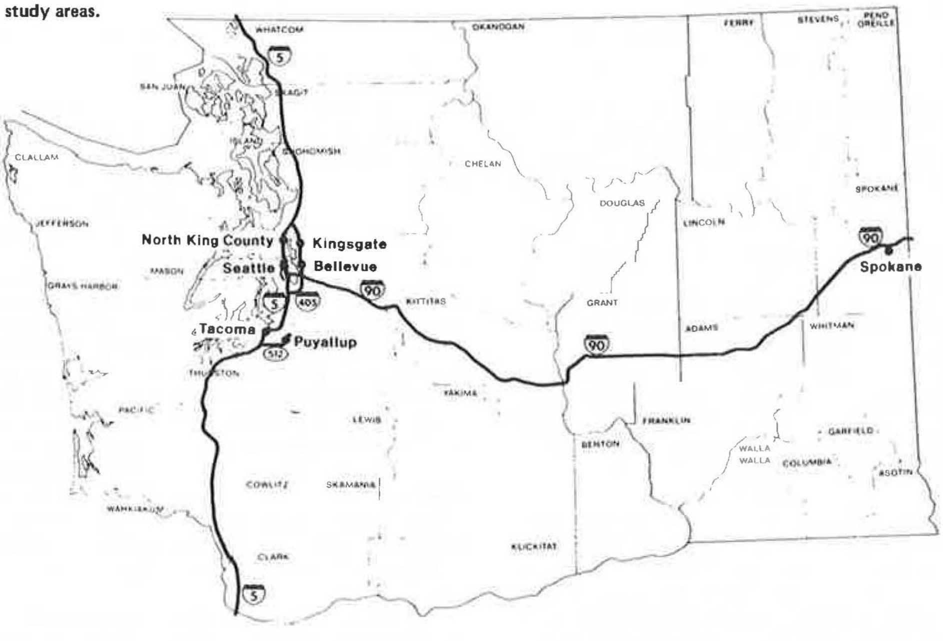
The purpose of the study is to examine the effects of major highways on the value of surrounding properties. The study applied several tested theoretical techniques to a data base derived from 9359 sales records and interviews with owners of homes and businesses. In each of five study areas, hedonic pricing techniques, with all variables kept constant except those under examination, produced a quality-adjusted price index. This index for the years during which a highway was opened was then compared with an index for a comparable area not affected by highway change. Owners' perceptions concerning highway impacts, gained from 383 interviews, were also analyzed. Improved access to residential areas provided by highway construction resulted in property appreciation 15-17 percent greater than comparable properties that lacked such access advantage. Even where highest noise level readings occurred, accessibility-induced property appreciation more than offset noise-induced depreciation. Highway noise had little effect on commercial, industrial, or residential properties greater than 600 ft from the highway. Extensive care ensured accuracy and data reliability. For example, each property sale was investigated to exclude any invalid transactions or sales where extensive improvements might influence appreciation. Validity to the 95 percent confidence level was the norm for hedonic regressions and related statistical computations. The results provide an accurate, reliable method for predicting the potential access benefits and noise costs in terms of relative changes in property value. This evidence will provide facts for detailed discussion during project planning.

The purpose of this study is to measure the effects of limited-access highways on property values. Transportation improvements of all kinds are being evaluated more carefully than ever during the planning stages. This attention to detail is well justified because the implications of such projects transcend the engineering disciplines and have environmental, social, and economic effects of major importance. In the economic area, one of the im-

Figure 1. Location of study areas.



pacts that is of great concern to the public is the effect of a highway on property values. This important issue arises in the preparation of the environmental impact statement and in the public discussions characteristic of our open planning process. Comparisons of beneficial and adverse effects require their quantification in terms of effects on property values. A major objective of this study is to isolate the factors of improved accessibility and of highway-generated noise from the myriad of factors that influence property values. Several theoretical developments allow refinement of previous studies and validation of their results. Reference is made to the studies by Anderson and Wise (1), Boyce and others (2), Gamble and others (3), Langley (4,5), Nelson (6), and Vaughn and Huckins (7). The research was designed to apply new theoretical techniques yet overcome difficulties noted in previous investigations.

OVERVIEW

This study analyzed the effects of a highway on the values of surrounding properties. Analysis of more than 9350 property sales provided real estate price trends in areas where a highway was constructed. These trends were then compared with those in similar areas that did not experience highway changes. A total of 383 in-depth interviews were conducted with residents of residential areas and business operators in a commercial and industrial study area (see Figure 1).

Where improvement in the accessibility of an area was substantial, property values appreciated significantly more rapidly. In Kingsgate, Interstate 405 resulted in a 12 percent appreciation; in the north King County study the appreciation that resulted from I-5 was 15 percent. In both areas, most residents used the highways for commuting to work and realized significant time savings. On the other hand, in Puyallup, few of the residents used WA-512 for commuting, so there was little or no effect of highway benefits on property values.

Unfortunately, some of the houses closest to the highways also suffer some negative effects because of adverse environmental influences. Highway noise levels caused a partly offsetting decrease in property values for those houses closest to the highway. This effect increased as the noise level increased above that in the surrounding neighborhood. The magnitude of this effect ranged from 0 to 7.2 percent in the areas studied, depending on the noise level and the character of the neighborhood involved. As incomes increase, people are willing to pay more for quiet surroundings and thus noise damages increase.

The net effect of these adverse and beneficial influences was positive for the areas where both effects could be quantified. This means that all houses in the areas appreciated because of the highway, but those closest to the highway did not appreciate to the same degree. A related study was done on the length of time involved in selling properties next to the highway and those further removed. There was no statistically significant difference in the amount of time houses were on the market prior to sale in the two locations.

In a study of commercial and industrial property, values were found to have appreciated almost 17 percent more than in a control area that was not influenced by highway change. Interviews in this area showed that the managers of the firms in the area were, for the most part, well aware of the benefits provided by the highway. The owners of land in the area tended to underestimate the appreciation in property values due to the highway.

Interviews were also carried out in residential areas. In general, residents' perceptions of both the benefits and adverse effects of the highway were fairly accurate. However, those people who live closest to the highway were not as aware of beneficial effects of the highway, and these people also estimated that the negative effect of noise on property values was almost twice as large as it actually was.

METHODOLOGY

Two courses of action are available to determine any beneficial access effects from a highway. It is possible to carry out a cross-sectional study of residences in significantly different locations and relate the various property values to some measure of the accessibility of the location. The alternative is to examine time-series data of property values in a particular area for a number of years, before and after a highway is opened, and compare the trends with those in an area that is relatively unaffected by changes in the highway system during the same period.

The former method requires a measure of accessibility such as the percentage of employment within a given travel time to the central business district (CBD) as postulated by many urban models. This is a reasonable measure of accessibility only where all employment is in the CBD. For more realistic urban areas, it is necessary to use more complex measurements of accessibility that take into account the attractiveness between various zones as well as the travel costs between these zones. Because of the large area that must be included in studies of this type, expense may rule out studies of individual houses and force studies of census tracts. Finally, the necessary measurements of accessibility are generally only available at wide intervals, and this makes prediction of the accessibility effects of a particular highway improvement difficult.

The alternative method, which was selected for this study, examines the time pattern of property values based on hedonic pricing. This technique evaluates quality changes in products by separating a commodity into its various characteristics and studying the contribution of each characteristic to the object's value. Dummy variables, variables that take a value of one in a particular year and zero otherwise, are the key to developing hedonic regressions that span several years. The use of data on individual houses makes possible the simultaneous consideration of localized adverse highway effects such as noise or air pollution. Not only just the final effect on property values is observed but also the pattern of change before the values again stabilize. Finally, this method examines property values in the period before the highway is opened. This allows the researcher to check the specification of the model before the major change of the highway was introduced and to see if anticipation of the highway's opening caused property value to increase.

There are numerous different causes of property value changes when a highway is constructed. These various effects can work in opposite directions and can occur over different areas and times. In this study the beneficial effects are measured by examining the trends in property value in the affected area over a 10-year period starting considerably before the highway's opening. These trends are then compared with a general residential real estate index for comparable property, or an index in a control area, to discover any differences. The trends within the study area are first established by using multiple regressions to separate the value of a house into the value of the various components of that house. Once this is done, it is possible to establish the price trends when all the characteristics of a house are kept constant. Thus, price is a function of these characteristics, and multiple-regression techniques are used to find the effect that changing one feature has on price when all other aspects of the property are held constant.

The accuracy of the price measurements developed by this method depends on the accuracy of the specification of the regression equation that establishes the component prices. The specification used in this study avoids several problems that have hampered some recent studies. Nonetheless, it was desirable to check the specification of the regression equation by comparing the measurements generated with those created by a different method. Such an alternative method was provided by examining repeat sales on the same houses. By this means the various characteristics other than depreciation were constant, and the pure price changes could be measured. The results of the analysis of repeat sales were then compared with the prior measurements to ensure their reliability for the study area. Both of these were then compared with a control real estate price index to see if the highway had influenced the values of nearby homes. An improvement in accessibility due to the new highway was reflected in an increase in property values. A substantial increase in accessibility for the area raised property values by 12-15 percent.

A less desirable effect on property values is created by adverse highway influences that may affect certain houses. Noise is the most important of such adverse effects. Noise monitoring was done throughout the study areas. By using these data, hedonic regressions revealed that property values were hurt by noise. An alternative means of estimating property value damages without noise measurement is carried out by using more easily collected data on distance and elevation with respect to the highway and vegetative cover. Negative effects on property values must be compared with the positive effects of improved accessibility to discover the net effect.

A number of criteria were used to select the residential study areas. Areas that have a large number of houses in close proximity to a limited-access highway were considered essential for this study to enable assessment of any negative environmental effects. Also, it was desired that the houses be distributed so that they extended back from the highways about 1 mile. By using such areas, some houses are adjacent to the highway and others are sufficiently removed that they experience no negative effects but do enjoy the benefits of accessibility. To increase the reliability of the regressions, the houses should be single-family dwellings and relatively homogeneous. The houses should not be influenced by nonhighway negative environmental effects. The highways should have been opened fairly recently but should have been open long enough to allow property values to reach equilibrium. The study area should lie within a single political jurisdiction to avoid possible fiscal differences that may affect property values.

Kingsgate Study Area

The first study area selected, Kingsgate in King County, is located on the east side of Lake Washington across from Seattle, just north of the communities of Kirkland and Redmond and just south of Bothell. It is traversed by I-405, which was opened to traffic in this area toward the end of 1970. The direct distance of the houses from the nearest lane of traffic on I-405 ranges from a minimum of less than 100 ft to a maximum of 5900 ft. There is an interchange at the north boundary of the study area and another just south of the south study area boundary. The minimum street distance of a house from the nearest interchange is 2000 ft and the maximum distance is 11 000 ft. The gently rolling terrain varies a little more than 200 ft in elevation but with no undevelopable steep slopes. Some of the houses are completely exposed to the highway, and others are screened by trees. The area is predominantly occupied by single-family dwellings in the middle to upper-middle price range. The oldest houses in the platted areas studied were build in 1962. The major building expansion was begun in 1965. The Kingsgate data were collected from the following sources: (a) excise tax records, (b) assessor's records, (c) direct measurement, and (d) published indexes.

Excise Tax Records

In King County there is an excellent source of information on sales prices and dates since the 1-percent excise tax on real estate transactions is cross-indexed by location. Crucial information on prices and dates of sales was obtained from the excise tax affidavits that indicate the seller's payment of the 1-percent excise tax on all real estate transactions in Washington. This excise tax was established in 1951, so the affidavits were available for all relevant sales. The affidavits record not only the price and date of the sale but also the type of deed involved and the parties to the sale. This information assisted in restricting the sales obtained to those that were representative of the value of the property. This was done by eliminating all sales where the conveyance was neither a warranty deed nor a real estate contract. Sales between parties with the same last name were also eliminated. All valid sales between 1962 and July 1976 were obtained. This provided a data base of 4785 sales for the analysis that follows. The mean price in 1967 dollars was $23 012 with a range from $11 064 to $33 728.

Assessor's Records

Data collection centered around the real property records of the county assessor's office. For each piece of property, county assessor's records contain an extensive description of the lot and house. As explained earlier, a priori expectation dictate many of the variables to be collected here. These include the areas on the various floors, the year built, and the number of bathrooms. For others of the variables shown, the question was whether or not they were relevant in this particular area. Empirical evidence was used to make this decision. The qualitative variables were made amenable to the regression analysis by transformation into dummy variables. In addition, the assessor's records contain information on the sales that had taken place on each particular piece of property. The remaining data were collected directly through the use of assessor's maps and visits to the site.

Direct Measurement

Various attributes determined from the assessor's maps included the following:

1. The distance to the highway measured from the center of the lot to the nearest lane of traffic,
2. Interchange and other important distances,
3. Elevation with respect to the highway,
4. The presence of trees between the house and the highway, and
5. Whether or not the house was in a plat that provided swimming pools and recreation facilities in return for mandatory dues.

Thirty noise-monitoring stations were selected to provide a representative sampling for the area. Readings were taken at various distances from the highway, at different elevations with respect to the highway, and with varying vegetation covers. At least three readings were taken at each station during peak traffic hours. The mean of these readings was then recorded on assessor's maps and used to construct contour lines to represent equal noise levels. This allowed the determination of the noise level within 2.5 dB(A) at the center of each of the lots.

Published Indexes

The final group of variables represent temporal effects on prices. The consumer price index is derived by the U.S. Bureau of Labor Statistics to represent the trend in prices of all consumption goods for urban wage earners and clerical workers. The other price indexes are published by the Seattle Real Estate Research Committee (SRERC) and represent real estate price trends within the Seattle-Everett standard metropolitan statistical area, defined by the U.S. Bureau of the Census, and also within the more limited area on the east side of Lake Washington. Finally, the date of the opening of the Totem Lake Shopping Center was included because many residents expressed the belief that this factor had influenced their property values.

The data on prices, sales dates, and property characteristics were used to develop real estate price indexes for the study areas to measure access benefits. To assess the impact of the highway on property values, it was necessary to know the general trend in real estate prices during these years. Within King County SRERC computes price indexes for single-family residential properties in various areas. The SRERC index for properties on the eastside of Lake Washington was most comparable for the Kingsgate area--approximately the same distance from Seattle and the same age.

Data Analysis

The primary method of analysis used on the collected data involved regressions. This technique required selection of the variables that make a significant contribution to explaining the observed market prices. Variables such as the various floor areas and the age of the houses were selected on theoretical grounds. The empirical work later substantiated these choices. For other variables the choice was made empirically. Where the coefficient of the variable was not significantly different from zero, it was not included.

After the opening of I-405, the properties affected by the freeway appreciated in value at a considerably faster pace than did the average of other properties on the eastside of Lake Washington. Between the opening of the highway and 1975 the houses in the study area appreciated by an average of 12 percent more than did houses elsewhere on the eastside. (Tests show this to be best expressed as a percentage of the house value rather than an absolute amount that applies to all houses.) The full effect of the highway did not seem to take place immediately, but property values increased over several years. Also, increases in property value do not seem to anticipate the opening of the highway.

North King County Study Area

The second study area bordered I-5 north of Seattle. This relatively homogeneous lower-middle class neighborhood contains homes that are an average of 25 years old. I-5, which in this section has six through lanes with two more lanes in connection with exits or entrances, was opened in late 1965. Thus, most of the houses were built before the highway location was announced.

Although there is some undeveloped land in the area, the study was restricted to platted land with single-family residences. Highway access is provided at either end of the study area and at a midpoint NE 175 Street. As in Kingsgate, the terrain is gently rolling with less than 200 ft of elevation difference.

All valid sales beginning in 1958 and continuing through 1976 were collected. These yielded a data base of 2823 observations. Similar techniques were used to measure property value trends for this study area. SRERC has an index that represents real estate trends in north Seattle, north King County, and southern Snohomish County. This control index represents the general location and type of homes in the study area.

After the highway opened, homes near the highway appreciated considerably more rapidly than did those represented by the control index. Resale values dipped between 1969 and 1973. This aberration is easily accounted for because these are the years of the Boeing Company reductions in employment. Many Boeing Company workers choose to live in Kingsgate and in the north King County area because these locations are central between Everett and Renton, where the company has plants.

Such houses command a premium because of the accessibility that the highway affords. When Boeing cut its employment by well over half and there were substantial secondary employment cuts, many of the residents of such areas were forced to sell, and the premium for accessibility was reduced. After the slump the differential was reestablished. The differential, with the exception of the years of the downturn, appears to have been about a 15 percent appreciation because of the accessibility benefits. This appreciation does not appear to have taken place on the announcement of the highway but rather on the opening of the highway. The improvement in accessibility in this area was comparable to that in the Kingsgate area. The same destinations to the north and south are available, and similar time savings are allowed by the highway. It is encouraging that the results in the two areas are quite close.

Spokane Study Area

Another study area was selected along I-90 through Spokane. Here a major urban freeway passes through an area of older houses that were built long before the highway was opened. The average age of the houses is 50 years, but the highway was only opened in early 1959 to carry the traffic that had previously used Sprague Avenue. This was only one of a number of changes that may have affected property values in this area over the years. Nonetheless, this area of lower-class homes provided an increased range of socioeconomic neighborhoods being studied. A total of 745 observations were available for the study of negative proximity effects. The absence of a control index prevented analysis of access benefits for the Spokane area.

Puyallup Study Area

The final residential study area to be discussed is located in the southeast corner of Puyallup, where WA-512 has recently been built. Much of this area is still relatively undeveloped, with farm land or small residential acreages scattered among the more densely developed residential areas. The northwest part of the study area is older and more uniformly developed than the rest of the study area. WA-512 is a limited-access four-lane highway that was opened in December 1973. One of the main reasons for the study was to examine whether or not the houses located to the southeast of the highway appreciated more slowly because they had been isolated from the main part of the city. This was a concern that was frequently expressed prior to the construction of the highway.

Data were collected for sales that took place between 1965 and 1976. This provided a data base of 838 sales. In the Puyallup study area the property value trends derived were compared with a countywide index based on mean sales prices and with the trends in a control area in Puyallup. Both techniques indicated that, although study area properties may have appreciated slightly more rapidly than the control indexes, there was no statistically significant difference. This coincides with the interview data where few of the residents indicated that they used WA-512 to commute to work. Because the time savings for residents would thus be small, it is not surprising that the property value effects were not large.

Access Benefits

The results from these study areas seem to indicate that improvements in accessibility and time-savings can be reflected in residential property values. However, the magnitude of this effect depends on the magnitude of the improvement in accessibility, especially with respect to work trips. Where the improvement was substantial, such as when I-405 or I-5 were opened, property values increased by 12 percent or more. But when few of the residents saved time in their commuting trips, as with WA-512, property values appreciate little, if at all, because of the highway. In making forecasts of the effect of a change in the highway system, the accessibility improvement must be estimated. The forecast could then be estimated as equal to that in the study area with a comparable improvement or as an interpolation of the results in two study areas if the improvement lies between that in the two study areas.

Noise Damages

In addition to the access benefits described above, the residential studies also allowed estimation of any negative proximity effects. The measured noise levels were used to assign a noise reading to each house as described above. The effect of this noise on property values was then isolated from the effects of other differences in properties. There was sufficient noise data to obtain this estimate for Kingsgate, North King County, and Spokane. In Kingsgate the 12-percent appreciation due to accessibility improvement more than offsets the 7.2-percent reduction due to noise at the noisiest houses.

Tests indicated that in each of the study areas the effect of noise was best expressed as a percentage of the value of the home rather than a fixed, absolute amount. In addition, tests were performed to examine whether or not a given increase in noise had the same effect at different noise levels. The A-weighted decibel scale was designed to approximate human perception of noise, but it is possible that it might not approximate the level of annoyance caused by that noise. Alternative forms for the noise variable were tried, but the linear form proved superior in all three study areas.

It might be expected that wealthier individuals would be willing to pay more for quiet in their residences. The studies confirm this, because not only are the damages a percentage of the value of the house, but also the magnitudes of the percentages increase with increasing income (see table below). The result of this study could be used to forecast the effect in an area where a new highway was proposed.

Study Area	Avg Reduction for Each 2.5 dB(A) Increase in Noise Above Ambient (%)	Highest Noise Reading [dB(A)]	Avg Reduction from Highest Reading (%)
Kingsgate	1.20	70	7.2
North King County	0.75	75	6.0
Spokane	0.20	80	2.0

Several other factors were tested for possible relations to distance from the highway, including the following:

1. Length of time on the market,
2. Sales terms, and
3. Greater than average decline in sales price during downturns in the real estate cycle.

Careful analysis of data obtained from multiple listing records provided no evidence of any effects of the highway on adjoining properties taking the form of changes in price or of longer periods on the market.

Commercial and Industrial Study Area

The effects of a highway on property values in a commercial or industrial area were also studied. It was much more difficult to find acceptable study areas for several reasons. First, commercial and industrial establishments generally have such definite transportation requirements that it is almost impossible to find such areas where access is not good. This makes it difficult to find a study area that predated the construction of a highway.

It is also necessary to control for the difference in the structures on the land to isolate the highway effects. Specification of the regression equation is considerably more difficult than in the residential case. The data on characteristics are difficult to obtain due to considerations of confidentiality. The selected alternative was to find an area where there was a mixture of commercial and industrial establishments and vacant land. This portion of the study could then examine trends in undeveloped land prices without considering structural characteristics. Interviews with established firms obtained the owners' perceptions of the effect of the highway. However, selection of study area sites remained difficult because this mixture of vacant and developed land is uncommon in commercial and industrial areas. A final problem is the lack of commercial and industrial real estate price indexes to serve as a control. For this reason, an actual control area was necessary. Unfortunately, to be useful a similar mixture of undeveloped and developed land was required. Also, the control area had to be similar to the study area in location and character.

The study area that seemed to meet these restrictive conditions best was in Bellevue, east of I-405. This section of I-405 was opened in June 1972, but commercial and industrial establishments were already in the study area at this time. The study area contains a business park, numerous automobile dealers, and other extensive commercial development. Safeway and Coca-Cola are the two largest establishments in the area in terms of both area and dollar volume. Most of the manufacturing businesses are located in the northern part of the study area. Much of the northwest portion of the study area is served by several railroad sidings to the Burlington Northern line. A substantial amount of vacant land remains throughout the area.

The control area selected was further south along I-90. This Interstate highway provides transportation access to the area, but there were no major changes in the highway during the period studied. The control area is similar in character, with small shopping centers, light industry, and vacant land.

Due to the restrictions of confidentiality on assessor's records, data on the prices and dates of property sales were collected from the monthly publications of Monitor Real Estate Corporation of Seattle. Monitor records all sales in King County for which the legally required excise tax is paid. Sales are classified by type of zoning and vacant or nonvacant land. All sales of vacant land within the study and control areas between 1965 and 1977, inclusive, were collected. This provided 268 observations. Zoning information was obtained from the Bellevue Planning Department, and land areas and access information were obtained from assessor's maps. A majority of the land was zoned for either manufacturing or for retail and wholesale use, although three other general classifications accounted for approximately 20 percent of the sales. There was a wide range of land areas from about 20 000 ft^2 to more than 650 000 ft^2.

After controlling for parcel size, zoning, railroad and street access, and the year of the sale, the properties in the study area were shown to have appreciated significantly more than those in the control area after the highway was opened. In fact, the differential was 16.7 percent. The improved access for incoming goods and customers for the commercial establishments and incoming and outgoing goods for manufacturers and warehousing provides the motivation for the firms' location here. This results in the appreciation of property values. Noise did not appear to have any adverse effects on these properties. As before, in using these results for forecasting the effects of a new highway on property values, one must consider the degree of accessibility improvement that is anticipated.

Surveys

Another phase of the study involved personal interviews with the residents to discover their perceptions of the beneficial and adverse effects of having a major highway located nearby. Perceived effects were then compared with those revealed by the real estate market.

These interviews were conducted in person by a team of interviewers. This method was selected to obtain the desired high return rate and to ensure hearing the opinions of those residents who were disgruntled with the highway. It was desirable to have any residents present who commute to work and, where possible, to have both husband and wife present. For these reasons, a majority of the interviews were conducted on weekends and at night. Attempts were made to interview at least one adult in every house that abutted the highway and in a sample of houses more removed from the highway.

The first set of interviews was done in the Kingsgate area, where 240 interviews were conducted, 114 at abutting properties. The major portion of the interviews concerned potential beneficial and adverse effects of the highway on the residence. The first questions of this part referred to the awareness of highway benefits. The distribution of responses to the general question, "Are there benefits to you from having a highway nearby?" was quite revealing. In the impact area within 600 ft of the highway the interviewers explained that this question referred to benefits from having the highway in the area and not necessarily from having it within 600 ft. In spite of this clarification, impact zone residents reported benefits less frequently than did those who lived in the study zone more than 600 ft from the highway. In the impact zone, 82.5 percent thought there were benefits, which seems to be a substantial proportion until it is compared with the study zone, where 99.2 percent mentioned benefits. Since the locations of work and distance to highway access did not differ substantially between the areas, it appears that the same benefits were present for the two groups. Yet, the adverse effects in the impact zone were preventing approximately one-

Table 1. Residents' overall rating of freeway based on living conditions.

	Study Zone (n = 126)		Impact Zone (n = 114)		Total Sample (n = 240)	
Rating	No.	Percent	No.	Percent	No.	Percent
Very good	62	49.2	11	9.6	73	30.4
Good	52	41.3	47	41.2	99	41.3
Neutral	11	8.7	33	28.9	44	18.3
Bad	1	0.8	21	18.4	22	9.2
Very bad	0	0.0	2	1.8	2	0.8
Percentage of sample		53		47		100

fifth of those interviewed from being aware of such benefits.

The next questions in the interview concerned perceived adverse effects. The questioning was divided into two parts. First, people were asked which adverse effects, if any, they noticed, and then they ranked the importance of these effects. For this part of the interview no suggestions of possible effects were made by the interviewers. Second, the respondents were asked to evaluate the importance of effects suggested by the interviewer. Questioning here concerned the effects both inside and outside the dwelling.

Noise was the one adverse effect mentioned extensively. Within the impact zone, approximately three-fourths of those interviewed cited noise as the most-important adverse effect. Those further removed from the highway in the study area still mentioned noise in one-fourth of the cases. Air pollution was the other problem mentioned with the next greatest frequency, but noise was mentioned almost 10 times as often.

The questions to this point only revealed which effects were mentioned and not the relative severity of the problems. The next part of the interviews sought relative evaluations of the different effects. The first point about these responses is that the highway seems to have few adverse effects for those residents more than 600 ft from the highway, which agrees with the noise-monitoring results reported earlier. Only one respondent found any of the effects annoying inside the home. Less than 16 percent even notice the noise, and they did not find it annoying. Outside the home the results were comparable except for noise where about 5 percent now found the noise annoying. Thus, the measure of the adverse effects used earlier in this study appears to coincide fairly well with the responses.

The responses in the impact zone were perhaps surprising in that many people did not find the effects annoying. Inside the houses only about 5 percent of the residents found effects other than noise to be annoying or objectionable. Within the house, 16.7 percent found the noise annoying and 3.5 percent found it objectionable. Most respondents found the effects other than noise "not noticeable" and noise "noticeable but not annoying". Outside the home the effects were more important. The noise was annoying or objectionable to 35.1 percent of those interviewed, and 7 percent felt that way about air pollution. The other effects were perceived to be the same as those indoors.

The interviews then had the residents evaluate the beneficial and adverse effects together to find an overall rating of the highway's effect on their living conditions. For the entire sample the median and the mean of the responses were in the category good. In the study area the most common response was very good; however, the mean was half way between very good and good. In the impact area the most common response was good, but the mean was between good and neutral. There is a statistically significant correlation between measured noise level and overall highway rating, so noise is an important factor in people's evaluation of the highway. It is of special interest that those people who bought their houses without knowing of the highway plans rate the highway significantly worse (bad was the most frequent answer) than did those people in the impact zone who bought their houses knowing of the plans (see Table 1).

The part of the interviews that related most closely to the main body of this research concerned the perceived effects of the highway on property values. In the study zone, 46.8 percent thought that the highway had increased their property values compared with what they thought would have happened if the highway had not been constructed. No effect was expressed by 37.4 percent, and less than 2 percent thought that property values had been decreased by the highway. In the impact zone, 36 percent thought values had been hurt, 31.6 percent thought there was no effect, 19.3 percent were uncertain, and only 13.2 percent thought values had increased. Next, the residents were asked if they could estimate the dollar value of these property value effects. Only about two-thirds expressed their opinions, but this was a high enough response rate to allow some generalizations. The residents believed that the damages were approximately twice as large as those found in actual sales. This indicates that in evaluating highway impacts it is important to consider not only the anticipated actual effects on property values but also the anticipated perceptions of those effects.

Interviews were also conducted with the residents of the Puyallup study area. In many respects the results were comparable to the results in Kingsgate. Noise was considered to be by far the most significant adverse effect, and once again people's ratings of the adverse effects correlated well with the actual noise readings. However, few of the people interviewed used WA-512 to commute to work. Thus, the evaluation of the benefits of the highway was significantly lower than in Kingsgate. This fact also lowered the overall ratings of the highway in Puyallup.

As part of the Bellevue commercial and industrial study, the managers of a representative sampling of business firms were interviewed. A majority of the interviews were at retail establishments, but interviews were also conducted with all the large wholesale and manufacturing establishments. A majority of the firms chose to locate in the area because of transportation availability or customer accessibility. More than 72 percent of those interviewed thought that I-405 helped customer accessibility, and 45 percent thought it improved goods accessibility for their firm. More than 65 percent stated that highway use had increased the gross sales of the firm, and 55 percent thought that the highway also resulted in lower operating costs. A significant number of firms (27.6 percent) indicated that they would not have chosen to locate in the area if I-405 had not been in existence. The overall rating of the highway was between good and very good, and a majority of the firms thought that the effect had been major.

To examine people's perceptions of the effect of the highway on property values, interviews were also conducted with the owners of the vacant land in the area. Half of these individuals thought that I-405 had influenced the value of the property. Although there was great uncertainty as to the magnitude of this effect, the estimates averaged 7.5 percent, which underestimates the actual effect estimated from real estate sales. These individuals thought that the increases could be attributed for the most part to improved customer and employee accessibility.

APPLICATIONS

Possible applications of these results are many. The most-important use is in connection with impact statements and public involvement programs. This application provided the original motivation for the study. The results of this study have quantified the property value effects of a limited-access highway. This information can be used for generally assessing property value effects in similar locations when a highway is constructed. The effects on property value are a great source of public concern. This evidence will provide facts for detailed discussions on this topic.

There has been interest in partly financing highway construction by capturing part of the accessibility benefits through property taxes. The property value effects are caused by the user benefits from the highway and do not represent an additional benefit. If existing taxes on highway users are at an appropriate level, then an additional tax on property is not called for. If additional taxes are indicated, they could take either form with similar long-run effects. A related point is that care must be used in applying the results of the benefit side of this study to benefit/cost analyses. Double-counting would result if user benefits were fully evaluated and property value effects were added.

These same considerations do not apply to the adverse property value effects of noise. Noise represents an externality that must be considered in benefit/cost analysis in order to make efficient decisions. The distributional effects of these externalities might also provide a basis for the payment of compensation to the residents affected. Such compensation should be paid to the house owners at the time of the highway effects origination but not to those who purchase the house after the effects take place. Currently, the Federal Highway Administration requires that controls such as noise barriers be used to reduce highway noise to 70 dB(A) in residential areas unless exceptions are granted. This study might be used to show that, in some cases, compensation would prove less costly than the construction of noise-abatement devices.

Finally, this study might prove useful in making decisions between various transportation modes. Such a choice between modes must be based on all of the effects of the construction of each mode.

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REFERENCES

1. R.J. Anderson, Jr., and D.E. Wise. The Effects of Highway Noise and Accessibility on Residential Property Values. Federal Highway Administration, 1977.
2. D.E. Boyce, B. Allen, and others. Impact of Rapid Transit on Suburban Residential Property Values and Land Development; Analysis of the Philadelphia-Lindenwold High-Speed Line. Wharton School, Univ. of Pennsylvania, Philadelphia, Nov. 1972.
3. H.B. Gamble and others. Community Effects of Highways Reflected by Property Values. Institute for Research on Land and Water Resources, Pennsylvania State Univ., University Park, Final Rept., 1973.
4. C.J. Langley, Jr. Adverse Impacts of the Washington Beltway on Residential Property Values. Land Economics, Feb. 1976.
5. C.J. Langley, Jr. Highways and Property Values: The Washington Beltway Revisited. TRB, Transportation Research Record 812, 1981, pp. 16-21.
6. J.P. Nelson. The Effects of Mobile-Source Air and Noise Pollution on Residential Property Values. Pennsylvania State Univ., University Park, Final Rept., April 1975.
7. R.J. Vaughan and L. Huckins. Economics of Expressway Noise Pollution Abatement. Rand McNally, Chicago, 1975.

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Some Conventional and Not-So-Conventional Views of Congestion

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The purpose of this paper is to explore the extent to which the conventional treatment of highway congestion, as developed in the economic analysis of road pricing, provides an acceptable theoretical or practical foundation for policy. The conventional theory is first outlined, and it is emphasised that, although it is probably technically sound, it relates to highly abstract circumstances. The main body of the paper then develops two themes. First, a number of arguments are put forward that imply that, in quantitative if not qualitative terms, the conventional analysis of congestion seems unlikely to provide an adequate basis for the proper formulation of policy. Second, some reasons for regarding congestion as an effective allocative mechanism in its own right are given. Although the arguments in the paper are not developed sufficiently far to reach firm conclusions of an operational kind, there are clear indications that traffic management and related policies aimed at securing efficient use of existing highway facilities should proceed with care when valuing congestion savings and when assessing optimal congestion levels.

A great deal of money continues to be spent to relieve traffic congestion. A great deal of time is spent in traveling in congested conditions. Where does the appropriate balance lie? It is all too easy, certainly for the layperson, and maybe even for the professional, to accept the conventional wisdom that congestion is bad, and that it is unquestionably the task of transport planners to eliminate it. Recent concern on both sides of the Atlantic about securing better use of existing transport infrastructure through traffic management and related policies has highlighted the issue, but perhaps not adequately.

We queue in congested conditions in shops and banks. We wait for a library book to be returned rather than buy it. We wait for state hospital treatment as an alternative to paying the fees associated with the private sector. Has society got it wrong everywhere? Clearly not--and nearly all professional transport planners will possess a degree of familiarity with the main arguments that underlie the determination of the correct level of congestion that should be permitted on a highway facility.

However, what we hope to demonstrate is that the conventional wisdom of urban traffic congestion is nothing like as firmly founded as a textbook familiarity with the topic might imply. We express some doubts about the theoretical basis of the conventional argument, and even more about the value of its implications as a guide to policymaking in the real world. Congestion, indeed, may even have positive advantages as a device for helping to distribute scarce resources among different sections of society.

The aim of the final section of the paper is to assess the implications of the previous sections. It cannot offer a neat conclusion, but it does suggest that, although we understand a little about the way in which we should try to determine the extent to which society should tolerate congestion on its urban highways, we do not know enough to be sure that we have the right balance between expenditure of money on the one hand and expenditure of time of the other.

CONVENTIONAL WISDOM

Economic analysis of traffic congestion has been undertaken in a number of ways. One approach, as for example by Mohring (1), Kraus and others (2), and Wheaton (3), has its foundations in conventional economic theory. It is a largely algebraic application of the theory of consumer behavior to circumstances that are broadly consistent with those found on congested urban roads. A second approach, which differs more in emphasis than final form from the first, is characteristically graphical in its mode of thought, starts from a physical description of the development of congestion as traffic volumes increase, and only becomes an economic analysis when the time and other resource commitments consequent on tripmaking are aggregated into a measure of trip-generalized cost. For the most part, the second of the two approaches has received the greater exposure in the professional literature, and certainly in student textbooks, and it is this that we take as our starting point.

Early thinking on the economics of road traffic congestion is described by Pigou (4) and Knight (5), but the principal impetus to more recent work stems from the contributions of Walters (6-8) and Beckman and others (9). The account that follows draws particularly on the descriptions given by Else (10) and Johnson (11). Conventionally, the analysis is based on a number of rather restrictive assumptions, the result of which is a tractable problem, but one whose solution, it will be seen later, is not necessarily very valuable. The assumptions are as follows:

1. A homogeneous traffic flow moving in a uniform direction,
2. A single road with only one entry and exit point,
3. Resource allocation considered only with reference to the road itself (i.e., ignoring interactions with other sectors of the economy), and
4. A demand for the use of road space expressed as a demand for a number of vehicles to emerge per time period, with instantaneous adjustment of density over the whole road so that density is uniform at every point.

If we let

F = flow (vehicles emerging from the road/min),
D = density (average vehicles/mile at a given time),
S = speed (miles/min attained over the road),
T = time (journey time for any vehicle), and
L = length of the road (miles).

Then the following relations hold,

$$T = f(D) \tag{1}$$

$$F = DS \tag{2}$$

$$S = L/T \tag{3}$$

$$F = [D/f(D)]\,L \tag{4}$$

$$T = g(F) \tag{5}$$

Equation 1 states that T will depend on D [T = f(D)], as illustrated in Quadrant I of Figure 1, with $f'(D) > 0$, $f''(D) > 0$, and f(D) asymptotic to D_{max}, reflecting a maximum density, beyond which movement along the road sizes up entirely. At low levels of density, travel time is almost independent of density.

In equilibrium, the flow of traffic that emerges from the road (F) is equal to the product of traffic density and speed (Equation 2), speed in turn being defined by Equation 3. A combining of Equations 1, 2, and 3 enables flow to be expressed as a constant (L) multiplied by a ratio [D/f(D)], which in graphical terms is simply the slope, measured relative to the vertical axis, of a ray from the origin to any point on the f(D) curve in Quadrant I. This ratio is clearly at a maximum when the ray is tangential to f(D) ($D = D_1$), and is zero when either D = 0 or as D tends to D_{max}. Graphically, Quadrant II in Figure 1 constructs the relation between [D/F(D)] and D and Quadrant III shows the linear relation (Equation 4) between the density/flow ratio and flow itself.

The final step in developing the conventional, backward-bending relation between flow and travel time involves, algebraically, substitution of Equation 1 and its inverse into Equation 4. Graphically this can be achieved by noting that any technically feasible flow (F_2) in Quadrant III can be associated with two separate travel times (T_2' and T_2'') in Quadrant I, via the relation depicted in Quadrant II. Thus, the backward-bending relation T = g(F) in Quadrant IV can be constructed.

Thus far, the relations discussed are noneconomic, based on the physical characteristics of the road in question and the observed behavior of travel times as traffic density increases. However, to de-

Figure 1. Derivation of time-flow relation.

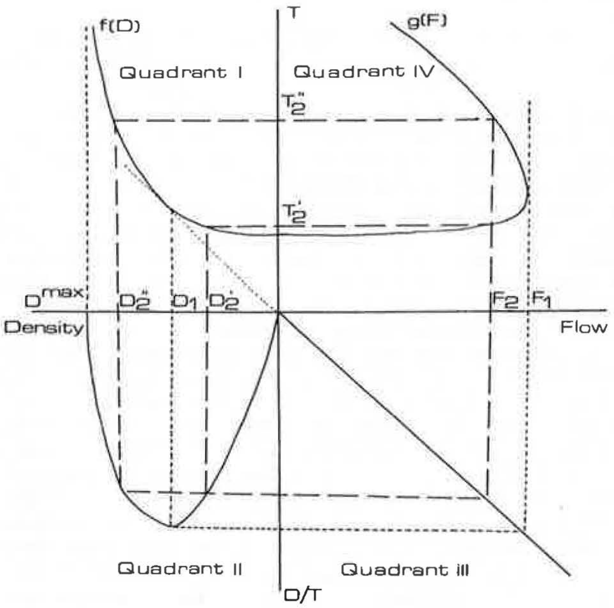
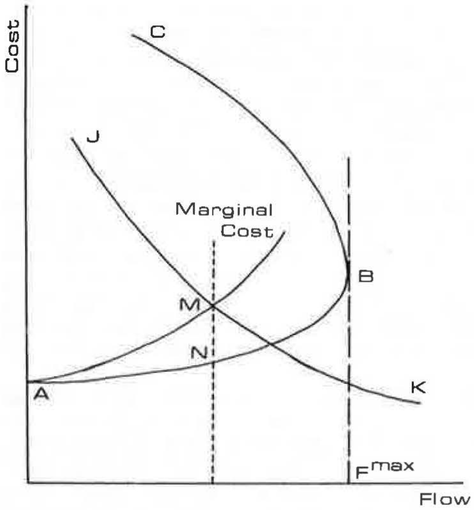


Figure 2. Cost-flow relation.



termine what flow of traffic will in fact be the output of the road, economic concepts are introduced. First, it is posited that travel cost will be a continuous, monotonically increasing function of journey time. This is meant to reflect the fact that travel time itself has an opportunity cost (a value) and that costs of travel such as fuel consumption and engine wear will also generally be greater as densities increase and speeds fall.

As a consequence, it is possible to reconstruct the relation shown in Quadrant IV as a similarly shaped relation between travel cost and flow (Figure 2). This may now be regarded as an average private cost curve. For any given value of flow, it shows the costs that accrue to the individual of being one component of the flow of traffic. In fact, for any given flow, one of two possible cost figures will arise, either one on the lower part of the curve (AB) or one on the upper part (BC). This rather counterintuitive possibility is explained as follows. Normally, as more traffic seeks to use the road, flow increases and so does cost (points in the range AB correspond to such situations). However, the strength of demand for use of the road space can be sufficiently great that density exceeds the density corresponding to maximum possible flow (D_1). In this case density is such that speeds decrease more than proportionately, and a flow less than the maximum results on the high cost portion (BC), of the cost-flow curve, the higher costs following from the greater time and resource costs associated with congested travel.

In formal terms, demand can be represented by a downward-sloping curve (JK), which implies that as the costs of travel fall, more people seek to travel. Thus, on which part of the cost-flow curve equilibrium is established depends on the precise position of the demand curve.

Given this formalization of the interaction between the demand for use of a road and its cost-flow characteristics, a number of questions conventionally follow. The first asks whether the volume of traffic that will choose to use the road is the correct one. The conventional answer is no. Assuming that the road can be viewed in isolation, economic efficiency in the use of resources requires that it is the intersection of JK with the marginal social cost curve and not the average private cost curve that should determine the appropriate level of road use. Some controversy exists over the definition of a marginal cost curve, as will be discussed later, but whatever attitude is taken in this latter respect, it can be concluded that, without the imposition of some structure of taxes, an incorrect level of traffic flow will in general result. This, combined with the personal frustrations of time spent waiting in traffic queues, leads to the conventional wisdom that congestion is a bad thing, which at least in some crude evaluations of the problem ought to be eliminated. This is another question that will be raised again later.

Finally, there is the problem of investment. Distortions in the market for the use of a service are likely to induce distorted responses in investment decisionmaking. Borins (12) and Wheaton (3) explore this topic, which is also one considered later.

DOUBTS CONCERNING CONVENTIONAL WISDOM

The conventional exposition of urban traffic congestion has been questioned both as a theoretical construct and, less directly, as a consequence of doubts about the validity of policy implications drawn from analysis based on that theory. This section will explore both aspects, starting with the empirical. Later some arguments will be put forward concerning possible advantages that stem from the presence of urban traffic congestion.

In considering the policy arguments that have developed from society's awareness of the disbenefits of increasing congestion over time, it is important to be clear about the scope of debate. In the previous section the assumptions adopted ensured that we were dealing with just a single type of road user, and that the costs considered were only those imposed by and on the road users themselves. Thus, no account was taken, for example, of the distinction between private and public transport nor that between the transport of passengers and goods. Also, the pollution effects of congestion were ignored, insofar as they impinged on anybody other than road users at the time of their travel. None of the wider effects that congestion might impose on society through influence on industrial location or urban structure were brought within the purview of the analysis either. To follow through, all the possible arguments on such issues must remain outside the scope of a short paper such as this.

There are problems enough merely within the range of consideration implied by the implementation of the policy implications of the conventional arguments. The remainder of this section will be developed largely on that basis. It concentrates on the points concerned with making better use of an urban road network of roughly the same scale as is already available for passenger transport. This amounts to the implementation of policies to shift cars from the places and times where congestion is currently excessive.

Under congested conditions, any tendency on the part of motorists to underestimate their own real costs of motoring or the costs they impose on others will encourage an excess of car use. In theoretical terms it is then very straightforward to argue that a tax given by MN in Figure 2, which will reduce traffic to the socially optimal level, should be imposed. In practice, however, such textbook conventional wisdom soon begins to lose some of its appeal. Even ignoring all the points raised in the previous paragraph, there are still difficulties. First, traffic conditions in urban areas vary widely according to time and location. The introduction of a flexible taxation system seems at present if not impossible, unlikely. Ignoring licensing and other rather coarse schemes such as that imposed in Singapore (13), the only flexible alternative appears to be some sort of vehicle-based metering scheme, presumably backed by modern computer technology, of the kind discussed, for example by Roth (14, chapter 5).

However, a scheme on those lines immediately highlights that a divergence between social and private costs is only a necessary and not a sufficient condition for the introduction of traffic limitation policies of the type under discussion. The running costs of such a scheme would be not inconsiderable and must, of course, be set against any savings in resource costs as a result of changes in patterns of car use (15). Economic costs are also likely to arise from trips previously made by car that are now suppressed or diverted to other modes. A commuter who arrives at work early may not effectively use the time between arrival and the conventional starting time. Also, it may very well be that the costs imposed by extra use of public transport in the peak hours alone would be considerably in excess of fares charged and so diminish the net benefits of any road pricing scheme.

The balance of costs and benefits in a road pricing scheme determines its desirability. The danger in the conventional textbook presentation of the argument is that, in the interests of clarity, it tends to relegate the very difficult task of performing the balancing calculations to a secondary role, which leaves the case for pricing as all too easy to accept as a basis for policy, no matter how actually implemented. For example, the financial support of public transport as a second-best approach to proper pricing is by no means self-evidently desirable, either as an alternative to the do-nothing alternative or to any other traffic-redistribution mechanism.

Evidence on the magnitude of potential benefits from traffic limitation is variable. Some early studies suggested considerable potential but made over-optimistic assumptions about potential traffic speeds in even a congestion-free urban environment (16, pp. 57-60). Present thinking, at least in the United Kingdom, is that only benefits of moderate size (say tens of millions of pounds per year, rather than the hundreds of millions considered earlier) might be available. In such circumstances, the costs side of the cost/benefit analysis needs detailed consideration--a blanket case for road pricing does not appear to exist.

Furthermore, one of the principal components of the benefit element in congestion pricing is the time saved by allowing faster journeys. But, such calculations assume that time savings, independent of their size, may be evaluated at the same unit rate. That this is the case is by no means clear. A recent study on the value of time (17) considered in some detail the question of the evaluation of small time savings. Some empirical evidence (18-20) appears to suggest that constant marginal valuations of travel time savings cannot be supported, but this has been disputed (21). The main arguments in support of nonconstant marginal valuation are that (a) small time savings may not even be perceived by the beneficiaries and (b) even if perceived, they may not be of as much use as larger time savings. Certainly both of these arguments are intuitively plausible, and, on balance, the conclusion of Voorhees and others (17) is that there is no theoretical reason to assume constant marginal values of time. Whether over a reasonable range valuation is approximately constant is an empirical question that does not appear to have been tackled. The correct evaluation of time savings is a matter that reaches beyond the topic of urban highway congestion. Nevertheless, the doubts that surround it again serve to undermine the conventional argument that the removal of congestion is clearly a good thing.

In addition to the empirical doubts about the support for policies aimed at removing congestion, questions have also been aimed at the theoretical basis of the conventional argument. In a recent paper, Else (10) suggested that the conventional analysis incorrectly defines the marginal social cost curve. Instead of considering the marginal social cost of an extra vehicle per unit of time to the traffic flow, what should be considered is the marginal cost of adding an extra vehicle to the road or, equivalently, the cost of adding to traffic density. Adoption of this approach suggests that the optimal flow will be greater than that yielded by the conventional analysis. It also follows from Else's approach that an optimum position on the backward-sloping part of the cost curve can be attained.

How well founded Else's criticisms are is at present a matter of controversy. Nash (22) has argued that they are for the most part unjustified, and that the redefinition of marginal social cost relative to numbers of vehicles rather than flow cannot be acceptable within the conventional theoretical framework of economics since all demands relate to flows, not stocks. Following this argument through supports the conventional position that a social optimum with flow at greater than the maximum is unattainable, and thus it seems that Nash has reestablished the authority of the conventional wisdom in this case.

One point, however, where Else's paper does make a valid criticism of established modeling procedures relates to the costs imposed by congestion on following traffic, outside the time period for which the basic analysis is undertaken. The concentration of conventional analysis on a steady state with no recognition of variability in levels of congestion is clearly highly abstract. Moreover, it incorrectly suggests a single optimal level of taxation. By adopting a more dynamically oriented approach, Else is able to show, in some simple cases, that the pattern of optimal congestion taxes should vary through the congested period, because a rise in peak traffic densities, through increasing the length of the congested period, causes delays to off-peak traffic.

Thus, the desirable tax structure is one that has a high level of taxation at the start of the heavy traffic period, which gradually declines as it proceeds.

Else is not the first person to criticize the conventional analysis of congestion for too easily suggesting solutions on the basis of too narrow a definition of the problems. Apart from the question of overflows into other time periods, there are also spatial overflows. The conventional analysis is always presented in terms of a single link but, from very early on, this was recognized as dangerous. Walters (7) presented a model that considered highway networks, although he recognized that, at that time, empirical progress with the model was impossible. This was followed by a later paper (23). More recently, and more practically, Wigan and Bamford (24) have investigated the effects of network structure on the benefits derivable from road pricing. The recent United Kingdom government paper (16) on Transport Policy warned,

> The relationship between traffic speeds and volumes, and the extent to which other traffic not subject to the traffic limitation measures responds to improved travel conditions, will depend on the particular traffic situation in individual towns. Generalisation on the proportionate reduction in traffic volumes required to produce any given congestion savings is therefore unwise. Wherever possible project and policy appraisals should be based on a transportation study model which simulates the complex interactions between traffic volumes and traffic conditions.

Finally, note that doubts about the practical value of the straightforward conventional theory as a guide to controlling the use of congested highway facilities must inevitably spill over into doubts about investment decisions designed to alleviate congestion. A number of authors (3, 12, 25) have developed models that show that, in circumstances broadly similar to those analyzed previously, the quantity and timing of investment will be incorrect when based on the responses of motorists paying the average private cost rather than the marginal social cost of their road use in congested conditions.

If cost/benefit analysis is used as the investment criterion, in conjunction with average cost pricing, Wheaton (3) argues that investment in roads will be greater than it should be, because a second-best investment criterion should be used with a non-optimal pricing policy. Without this, what results is that less of the cost of road use is paid through congestion (time) and more is paid in money terms (investment). This conclusion is based on the standard steady-state model.

Henderson (25), in a paper that concentrated more on the timing of journeys, and so moved outside the conventional framework, suggested that the optimal level of investment was lower in the taxed than in the untaxed case, more as a result of peak-spreading. In similar vein, Borin's paper (12) shows that the absence of marginal cost pricing will tend to bring forward the timing of investment programs, all other things being equal. Although the general qualitative thrust of all these papers is perhaps not undermined by some of the worries expressed earlier about the circumscribed range of models conventionally used, clearly their importance from a policy point of view is more open to doubt once the real effectiveness of introducing marginal cost pricing is questioned.

SOME ADVANTAGES OF CONGESTION AS A METHOD OF RESOURCE ALLOCATION

The tenor of the two previous sections has been such as to question the theoretical and particularly the empirical basis for the conventional view that the elimination of traffic congestion is a goal unquestionably worthy of pursuit. There is, however, a school of thought that goes further and puts forward the view that congestion is a positively helpful way of dealing with a resource-allocation problem.

One set of arguments that suggests some virtue in the presence of congestion is given by Nichols and others (26) and Smolensky and others (27). The analogy is drawn between congestion and queueing and it is suggested that, since queueing can be seen as a useful allocative mechanism, congestion can be also. Queueing essentially requires the consumer to provide an input of time as well as of money to obtain the good concerned. By implication, people queueing in banks or shops find it preferable to wait rather than, in the long term, to pay higher prices to expand service facilities to a scale that would effectively remove waiting.

The position is that in such circumstances queueing acts as a form of product differentiation, recognizing that the value of time to individual consumers varies. By offering a range of money-price, time-price combinations to consumers, welfare may potentially be increased by allowing each individual to choose his or her preferred combination. But it is by no means clear that this argument can help a great deal with the analysis of typical urban traffic congestion. The reason for this is that, where there is room for only one facility (a road whose congestion characteristics at any moment are shared by all users), only a single price-time combination can be offered. To provide different combinations at different times sidesteps the issue, as the services involved are now no longer the same, and, in any case, many people have little prospect of being significantly flexible in the timing of their demand for transport services. Only if there are parallel facilities offering essentially the same service could this argument by accepted.

A second set of arguments in favor of congestion having a role in the allocative process has a basis in the equity issue. Pricing through congestion of roads is seen as a way of achieving a more acceptable distribution of income. Sharp (28) discussed this issue, and more recently Richardson (29) has argued that conventional road pricing is very likely to be regressive between motorists (i.e., will serve further to distort the distribution of income away from one where all have equal incomes). Even when all road users are taken into account, when it is probable that there would be some benefit to low-income travelers, it is still not clear that the overall effect would be progressive, since it is likely to consist of losses by the middle-income group set against gains to those at the two extremes of the income spectrum. The formal apparatus of welfare economics does not provide a mechanism for assessing such a balance, apart from the empirical difficulties of quantifying the magnitudes involved.

A latter set of arguments that states that the regressive effects of road pricing is that pricing through congestion is likely to be progressive. Time, it is suggested, is distributed more equally than earned income. Thus, the opportunity cost of time (and thus willingness to queue) may be lower for those with lower wages, or no wages. Consequently, time prices act similarly to a tax that is proportional to wages. Thus, queueing can serve to vary the total subsidy involved in the provision of a public good by income class. Provided that the loss that results from queueing is less than the cost of administering an equivalent means test, congestion provides an efficient means of attaining an equity objective. Matters are not quite so straightforward, however. Barzel (30) demonstrates that, if income elasticity is high and price elasticity is low, it becomes less likely that the poor will be prepared to pay by waiting. At the extreme, this suggests that subsidizing, say, opera, is highly unlikely to have progressive results. For roads the position is less clear--we again have an essentially empirical issue that hinges on the relative magnitudes involved in each case.

SUMMARY

The intention of this paper has been to raise some doubts about the extent to which the control of congestion is understood, not as an engineering problem, but as a socioeconomic one concerned with making the most appropriate use of scarce resources.

Despite some doubts, the basic theory, as applied to a highly simplified situation, seems to be technically correct. What is much less clear, however, is the extent to which the acceptance of this analysis as a basis for policymaking in the real world is justified. Even if, qualitatively, its implications are correct, there are significant quantitative uncertainties. Given that governments, local and national, are still pouring considerable sums of money, both through subsidies and investment, into the relief of congestion, it is desirable to change this state of affairs. There seems to be ample scope for the transport economist, the transport planner, and the transport engineer to contribute to a debate that has a long and, in places, distinguished pedigree, but where the outcome is as yet considerably outstripped by the importance and complexity of the problems that must be solved.

REFERENCES

1. H. Mohring. The Peak-Load Problem with Increasing Returns and Pricing Constraints. American Economic Review, Vol. 60, 1970, pp. 693-704.
2. M. Kraus, H. Mohring, and T. Pinfold. The Welfare Costs of Non-Optimum Pricing and Investment Policies for Freeway Transportation. American Economic Review, Vol 66, 1976, pp. 532-547.
3. W.C. Wheaton. Price-Induced Distortions in Urban Highway Investment. Bell Journal of Economics, Vol. 9, 1978, pp. 622-632.
4. A.C. Pigou. The Economics of Welfare, 1st ed. MacMillan, London, 1920.
5. F.H. Knight. Some Fallacies in the Interpretation of Social Cost. Quarterly Journal of Economics, Vol. 38, 1924, pp. 582-606.
6. A.A. Walters. Track Costs and Motor Taxation. Journal of Industrial Economics, Vol. 2, 1954, pp. 135-146.
7. A.A. Walters. The Theory and Measurement of Private and Social Cost of Highway Congestion. Econometrica, Vol. 29, 1961, pp. 676-699.
8. A.A. Walters. The Economics of Road User Charges. World Bank, Washington, DC, Occasional Staff Paper, No. 5, 1968.
9. M.J. Beckmann, C.B. McGuire, and C. Winsten. Studies in the Economics of Transportation. Yale Univ. Press, New Haven, CT, 1956.
10. P.K. Else. A Reformulation of the Theory of Optimum Congestion Taxes. Journal of Transport Economics and Policy, Vol. 15, 1981, pp. 217-232.
11. M.B. Johnson. On the Economics of Road Congestion. Econometrica, Vol. 32, 1964, pp. 137-150.
12. S.F. Borins. The Effect of Pricing Policy on the Optimum Timing of Investments in Transport Facilities. Journal of Transport Economics and Policy, Vol. 15, 1981, pp. 121-133.
13. P.L. Watson and E. Holland. Road Pricing in Singapore: Impacts of the Area License Scheme. World Bank, Washington, DC, 1977.
14. G. Roth. Paying for Roads: The Economics of Traffic Congestion. Penguin Books, Harmondsworth, England, 1967.
15. J.M. Thomson. Modern Transport Economics. Penguin Books, Harmondsworth, England, 1974.
16. Department of the Environment Transport Policy. A Consultation Document, Vol. 2. Her Majesty's Stationery Office, London, 1976.
17. Martin and Voorhees Associates. Theoretical Considerations. Institute for Transport Studies, Univ. of Leeds and Transport Studies Unit, Oxford Univ. Value of Time Project, Working Paper 3, 1981.
18. I.G. Heggie. A Diagnostic Survey of Urban Journey to Work Behaviour. In Travel Time and Travel Choice (I.G. Heggie, ed.), Oxford Univ. Press, Oxford, England, 1976.
19. D.A. Hensher. The Value of Commuter Travel Time Savings. Journal of Transport Economics and Policy, Vol. 10, 1976, pp. 167-176.
20. T.C. Thomas and G.I. Thompson. The Value of Time for Commuting Motorists as a Function of Their Income Level and Amount of Time Saved. HRB, Highway Research Record 314, 1970, pp. 1-15.
21. N. Bruzelius. The Value of Travel Time. Croom Helm, London, 1979.
22. C.A. Nash. A Reformulation of the Theory of Optimal Congestion Taxes--A Comment. Institute for Transport Studies, Univ. of Leeds, Mimeo, 1981.
23. A.A. Walters and M.E. Beesley. Some Problems in the Evaluation of Urban Road Investments. Applied Economics, Vol. 1, 1970, pp. 241-259.
24. M.R. Wigan and T.J.G. Bamford. The Effects of Network Structure on the Benefits Derivable from Road Pricing. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Rept. LR557, 1973.
25. J.V. Henderson. Road Congestion: A Reconsideration of Pricing Theory. Journal of Urban Economics, Vol. 1, 1974, pp. 346-365.
26. D. Nichols, E. Smolensky, and T.N. Tideman. Discrimination by Waiting Time in Merit Goods. American Economic Review, Vol. 61, 1971, pp. 312-323.
27. E. Smolensky, T.N. Tideman, and D. Nichols. The Economical Uses of Congestion. Papers of the Regional Science Association, Philadelphia, Vol. 26, 1971, pp. 37-52.
28. C. Sharp. Congestion and Welfare--an Examination of the Case for a Congestion Tax. Economic Journal, Vol. 76, 1966, pp. 806-817.
29. H.W. Richardson. A Note on the Distributional Effects of Road Pricing. Journal of Transport Economics and Policy, Vol. 8, 1974, pp. 82-85.
30. Y. Barzel. A Theory of Rationing by Waiting. Journal of Law and Economics, Vol. 17, 1974, pp. 73-95.

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Abridgment

Modeling Dilemma of Intercity Bus Transportation

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The operating strategies employed by intercity bus carriers to serve rural communities have remained an enigma to those attempting to model the bus industry. Intercity bus transportation has been a blending of local transit and trunkline corridor services. Economic and demand-based models generally lack sufficient detail for investigating service along specific routes. City-pair and rural transit models have each addressed only a part of intercity bus transportation. Models that bridge the gulf that separates local from trunkline services will probably employ some understanding of supplier strategies to describe bus service levels at intermediate rural locations.

The intercity bus transportation network in the United States is unique among public transportation modes. It serves not only the major urban centers but also many thousands of rural towns and hamlets in every part of the country. Service levels at cities and travel needs of intermediate rural communities have been integrated by carrier management strategies. The result has been a regulated subsystem that exhibits a balance of resources and demands.

LEGACY OF REGULATION

A significant product of the regulatory environment has been the institutionalization of internal cross subsidies by using profitable services and routes to offset losses incurred on those routes that bear little passenger traffic. In this way many rural routes have been preserved where local travel demand alone has not supported service.

Infusion of direct governmental subsidies into the rural transit systems over the past two decades has generally not gone to aid intercity bus transportation. Recently some states have begun to offer direct assistance to private intercity carriers--operating subsidies, bus acquisitions, and station improvements. To the extent that direct subsidies have relieved private carriers of supporting unprofitable routes, the delicate regulated balance maintained through cross subsidies has possibly been disturbed. States need to engage in detailed planning efforts that will guide prudent use of any direct subsidies to the intercity bus system. Whereas the regulatory perspective has sought balance on a systemwide basis, policies of direct subsidization will likely be on a specific route-by-route basis.

NEED FOR BETTER MODELING

The lack of effective modeling of intercity bus transportation to date is remarkable when we consider that more than 300 million trips are taken annually by intercity bus riders in the United States (1). Federal corridor studies have focused on long-distance movements between large metropolitan areas, usually in a multimodal context, and small, intermediate service points are overlooked. State and local planners have, on the other hand, generally studied city transit problems and small isolated rural systems. The interregional traffic movements have remained separated from local transportation analyses, possibly as a reflection of the effects of strong jurisdictional boundaries and specific funding restrictions.

The intercity bus transportation network relies on rural passengers and package express from small communities. Although the route network ties together the major cities and capitals of the country, more than 30 percent of the system users are believed to be rural residents (1). Knowledge of rural service levels offered by intercity bus carriers is especially important when evaluating the potential for additional bus service or the likely impacts of discontinued service.

Service to small communities can require substantial route deviation from the most direct path between metropolitan hubs. Any increases in distance, in turn, impose additional operating costs and create delays for long-distance travelers. Since 1973, the prices of fuel and labor have increased at rates that outpace increases in revenues (2). If this trend continues, more rural places will either lose service or be served less frequently as carriers try to trim costs.

Determinations of appropriate intercity bus service levels are made in adversary proceedings before a regulatory body. They are based, in large part, on (a) the financial health of the carrier over the entire system and (b) the intensity of local opinion. Quantitative measures of carrier operating strategies would be helpful in defining the relation of service frequency to local conditions. In contrast, regulatory commission hearings are often accompanied by emotional rancor and legal manipulations. Objective analysis of a carrier's rural service patterns would be useful in evaluating levels of service.

Unfortunately, the rural service strategies of individual intercity bus carriers are not well known nor are they easily quantified. Many service decisions are apparently derived from the gut feelings of company officers. This intuitive approach is one that can be understood only after many years of operating experience. Although the method may suffice the needs of individual companies on an ad hoc basis, it offers little in assisting transportation planners and regulatory professionals to understand carrier rural service strategies.

Designers of public transportation systems in rural areas should strive to work in harmony with existing regulated intercity transportation services. Doing this could avoid duplicative new public investments by seeking maximum social benefit through use of transportation services already in place. Overall, a better understanding of the workings of private providers of intercity public transportation could contribute toward effective allocation of limited public resources and would likely produce higher levels of service at lower cost. The programmatic impact could be reflected at the local, state, and federal levels of government.

Shortcomings of Previous Studies

Conventional modeling approaches have not been very successful in describing or predicting intercity bus services. Perhaps this failure has been due to the complex superposition of local and long-distance travel, as well as the local service aberrations that result from the regulatory process. Previous investigations of intercity transportation have generally used a demand-based projection of travel needs or employed a distributive technique (e.g., modal split analysis) to prorate estimated corridor traffic among competing modes.

However, demand for intercity public transportation in rural communities is often too low to support regular and frequent service. An extensive network of high-quality roadways and near-universal ownership of private automobiles have taken a toll on rural public transportation systems. Demand levels for bus travel have dropped so low in many rural markets that they are no longer economical to serve. The cost of operating an intercity coach may require an average load of 12-18 passengers just to break even.

Rural loads are typically far below this level. It is not surprising that Greyhound Lines claims it operates at a loss on at least 67 percent of its route miles (8,9). However, the rural routes must be viewed in the context of the total system and are beneficial to the carrier if they contribute to overall system profitability. Thus, factors other than rural route loads must be examined to adequately explain the observed service levels at intermediate service points.

Problems of Economic Approaches

It is possible to analyze the intercity bus industry by employing economic concepts (3). However, this type of analysis is not specific or direct enough to be applied at the individual route level of analysis needed at intermediate rural locations. Revenues and costs, for example, have been generally aggregated and used as a systemwide measure of performance (4).

Aggregated statistics do not permit identification of specific profitable and unprofitable routes. They also tend to obscure the location and presence of cross subsidies. A recent staff study by the Interstate Commerce Commission (2) concluded, but only through indirect means, that "cross subsidization exists within the industry". The picture is complicated because revenues and costs associated with charter, regular route, package express, and special services have been difficult to segregate from each other. These other bus services have become other possible sources of cross subsidization.

Clues to finding profitable and unprofitable routes might lie in the review of actual route load factors. Such information is usually considered proprietary, and carriers are often reluctant to divulge it except when in their self-interest to do so, as before administrative law proceedings of regulatory bodies. It would generally be inconclusive to make any determination of profitability at the route or service point level of analysis in cases of feeder traffic, heavy package express use, empty long-haul seats, or cross subsidization. Furthermore, costs, fares, and quantities of service are likely not to be determined by local market conditions but rather to be a reflection of overall system performance as weighed in the regulatory arena. For all of these reasons, it has become apparent that techniques associated with economics of the firm have only limited application at the route and service point level of analysis of an intercity bus system.

Elevator Principle of Demand

Local demand for service is a poor indicator of the frequency of intercity bus service. Many rural places produce few passengers yet receive daily service. For meeting occasional demands en route, buses generally have sufficient unused seating to accommodate those who may desire service.

Because of the fixed size of the bus, unused capacity through intermediate points may be unavoidable and caused by what some in the industry call the elevator principle (6). The analogy simply relates a declining load factor, often observed when a bus leaves an urbanized area and heads cross-country, to what happens with an elevator in a tall building when it loads at the ground floor and discharges persons floor-by-floor as it ascends. Lower load factors create room for those persons that board at intermediate points. Of course, the reverse effect is noted as buses approach urbanized areas (or the elevator descends to the ground floor).

At rural service points, demand is likely to be unknown prior to bus arrival. However, through experience, carriers have learned the times, days, seasons, and directions of heavy loadings and can dispatch extra bus sections accordingly. For example, the number of trunkline bus-miles operated in California by Greyhound Lines during 1979 exceeded the scheduled bus-miles (as shown in timetables) by 60 percent (5,7), which reflects heavy use of extra-section buses.

CITY-PAIR AND RURAL TRANSIT MODELS

The literature is replete with examples of city-pair demand modeling, ranging from direct applications of gravity principles to the sophisticated incorporation of specific travel attributes. For rural areas, by contrast, transit demand has often been estimated in the form of aggregate system use and based on demographic data to produce average trip rates per capita. Recent work by Burkhardt and Lago (10) introduced a level-of-service factor to the demand analysis for specific rural routes.

Unfortunately, neither the city-pair models nor the rural transit models have been adequate to furnish good estimates of intercity bus service at rural intermediate service points. City-pair models have focused only on larger cities and metropolitan centers. Rarely have they included towns under 2500 population. In California, for example, the median population of all towns served by intercity bus is 1100 persons. Intermodal comparisons that have included commercial air carriers have tended to exclude places under 10 000 population. Although omission of small places has permitted satisfactory demand projections to be made for air travel (11), intercity bus trips have been poorly represented. Perhaps this weak performance of city-pair models can be partly explained in the overlooking of short local trips and the amount of traffic contributed by rural intermediate service points.

Rural transit models have suffered at the other extreme and have not been able to incorporate long-distance trunkline bus traffic. They have been too localized with emphasis on small service networks, with little or no reference to the intercity bus system.

In summary, the need exists for new approaches in modeling those rural transportation services now provided by the intercity bus industry. Supply factors, as well as demand factors, are important to an understanding of an industry that can serve rural America and larger cities at the same time (12). The need for highest use of every available transportation resource is evident now as never before. Concerns about energy costs and availability and reductions in federal operating assistance give new emphasis to understanding and using the private sector and the intercity bus industry for meeting the future needs of rural mobility.

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REFERENCES

1. America's Number 1 Passenger Transportation Service. American Bus Association, Washington, DC, Annual Rept., 1978.
2. The Intercity Bus Industry: A Preliminary Study. Interstate Commerce Commission, May 1978.
3. E.A. Pinkston. The Intercity Bus Transportation Industry. Yale Univ., New Haven, CT, Ph.D. dissertation, 1975.
4. E.L. Ramsdell. Assessment of Motor Carriers of Passengers Statistical Data Filed with the Interstate Commerce Commission. Proc., Transportation Research Forum, Richard B. Cross, Oxford, IN, Vol. 19, No. 1, 1978, pp. 430-437.
5. B. Rotenberg. Total State of California Comparison of Mainline Operating Statistics for 1967, 1978, 1979. Exhibit C-15 in the Matter of Applications 57797, 57939, California Public Utilities Commission, San Francisco, CA, April 30, 1980.
6. K.A. White. What Dictates Levels of Intercity Bus Service to Nonurbanized Communities of Similar Size. Greyhound Lines, Inc., Phoenix, AZ, July 24, 1979.
7. R.C. Zelrick. Comparison of Schedule Miles Operated in California. Exhibit C-38, in the Matter of Applications 57797, 57939, California Public Utilities Commission, San Francisco, CA, May 1, 1980.
8. F.L. Nageotte. The Case for Nationwide Intercity Bus Deregulation. Greyhound Lines, Inc., Phoenix, AZ, 1980.
9. J.L. Kerrigan. Intercity Bus Lines: Competing with Uncle Sam. Indiana Business Review, Vol. 5, July-Aug. 1978, pp. 11-14.
10. J.E. Burkhardt and A.M. Lago. The Demand for Rural Public Transportation Routes. Proc., Transportation Research Forum, Richard B. Cross, Oxford, IN, Vol. 17, No. 1, 1976, pp. 498-503.
11. D.A. Schroeder. A Multiple Linear Regression Analysis of Intercity Air Passenger Travel to San Francisco and to Los Angeles. Univ. of California, Berkeley, Master's thesis, Sept. 1970.
12. D.L. Dean. The Frequency of Intercity Bus Transportation to Intermediate Service Points: A California Case Study of Carrier Strategies. Univ. of California, Davis, Ph.D. dissertation, 1980.

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Intercity Bus Riders in Texas

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This paper includes summary information obtained from an on-board intercity bus survey performed in selected locations throughout Texas. The purpose of the survey was to gain insight into the socioeconomic and travel characteristics of intercity bus passengers in Texas. The survey instrument was also designed to collect data on general attitudes concerning service and fares and to identify the features of the existing service that are most important in generating ridership. The first section of this paper presents the major findings of the on-board survey. Then the results are presented of a comparison between the results of this on-board survey and the results of an on-board survey conducted in Michigan in 1977. The most significant findings of the user survey were that mean trip length was longer than generally reported, that users are generally satisfied with current service, and that Texas intercity bus riders do not appear to be significantly different from those in other parts of the United States. A large portion (28 percent) of intercity bus riders do not have an automobile available for the trip. Trips are made infrequently (the median is 3 times/year). The most significant trip purpose is to visit friends (38 percent). Any improvement in service should focus on safety, on-time performance, and comfort.

The Texas State Department of Highways and Public Transportation, with funding from the Federal Highway Administration, contracted with the Texas Transportation Institute to conduct an extensive study of the intercity bus industry. The study was prompted by interest expressed by operators in the state. This paper reports the results of a portion of the study that concerned an on-board survey.

Although some information existed concerning intercity bus riders (1-4), there is reason to believe that intercity bus riders in Texas might have some unique characteristics. The reason for this belief is the generally healthier condition of the intercity bus industry in the Southwest (5). For this reason, it was decided to undertake an on-board study of bus passengers.

Since other on-board studies had been undertaken (1,4,6,7), it was also decided that a somewhat more extensive questionnaire would be used. The size of the questionnaire selected was both sides of one page. This length was thought to be brief enough to elicit a good response and also allow for the inclusion of some attitudinal questions not included in any previous survey. Both English and Spanish versions of the survey instrument were used because of the significant number of Spanish-speaking residents in the state.

A stratified sampling frame was selected because of regional differences within the state. [Previous studies (1,2,8) indicated that low-income persons are a significant part of intercity bus ridership.] The border area of the state is economically poorer than the rest of the state. Based on county economic characteristics, one region includes those counties along the border identified as having a lower economic base. The remaining counties were roughly divided in half.

Within each region survey points were further segmented by small [nonstandard metropolitan statistical areas (SMSAs)], medium (SMSAs less than 1 million) and large (SMSAs greater than 1 million) cities. Texas has approximately 1000 potential survey points, but only 25 points are in the medium or large category. The number of survey points in each strata are given in the table below.

	Survey Points		
Region	Small City	Medium City	Large City
North-east	4	2	1
North-west	2	2	0
South-west	2	1	1

Figure 6. Mode of travel from bus station.

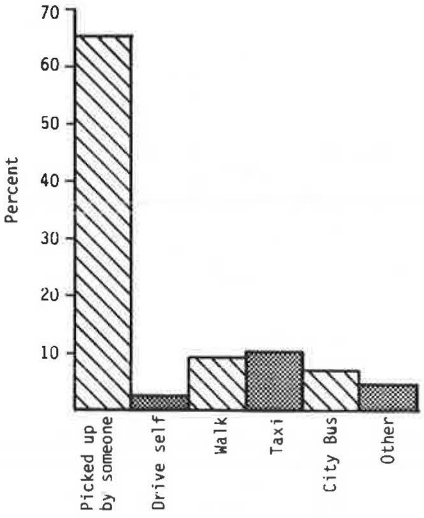


Figure 7. Trip purpose.

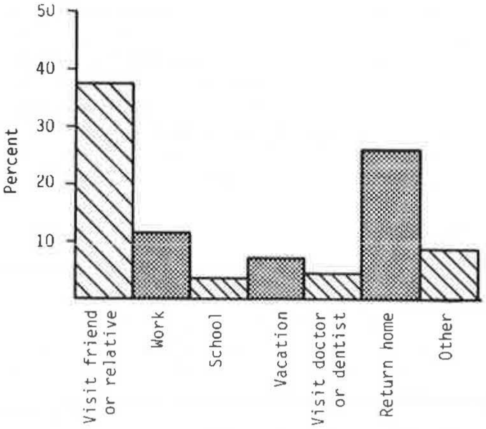


Figure 8. Alternative travel mode.

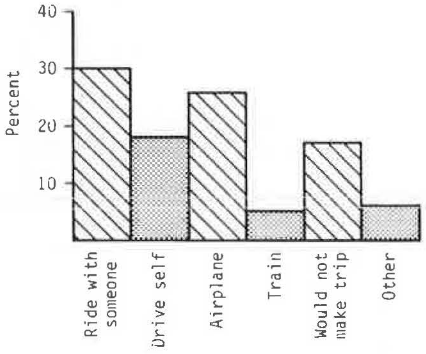
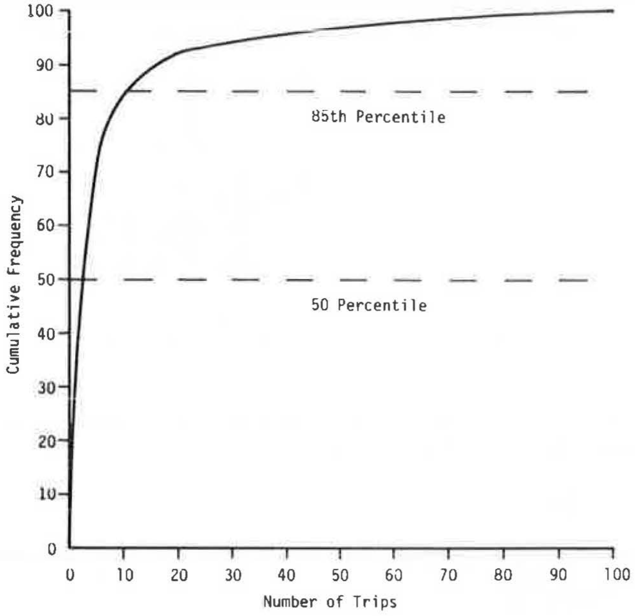


Figure 9. Number of intercity bus trips made by passengers in past year.



categories--those that have a choice of mode of travel and those that are captive and have no alternative mode of travel available. Passengers were asked how they would have made this trip if intercity bus service were not available. The responses are shown in Figure 8.

Forty-seven percent of the riders responded that they would have ridden with someone else or driven themselves. Twenty-five percent stated that they would have made the trip by airplane. This may have been the choice of those passengers making long trips, as 25 percent of the riders surveyed were traveling more than 600 miles. Seventeen percent of the riders stated they would not have made the trip if bus service had not been available.

Further analysis of data from those stating that they would not make the trip if intercity bus service was not available indicated that 45 percent owned a car that was available for the trip. Thus, the loss of bus service would appear to leave only a small number of persons without an alternative mode of travel.

Number of Intercity Bus Trips in Past Year

Figure 9 illustrates the number of bus trips made by the respondents within the past year. For this survey a round trip was counted as two trips. As indicated, 50 percent of the users had ridden three times or less and 85 percent had ridden fewer than 10 times.

As previously mentioned, almost 50 percent of the riders stated that the purpose of their trip was to visit friends or relatives for vacation or for a medical appointment. These trips are generally not made frequently. Thus, this may be the reason for the low number of trips made by bus in the past year.

Trip Length

Passengers were asked the origin and destination of their trips. From this information the length of each trip was calculated. Figure 10 shows the distribution of trip lengths for the passengers surveyed. Approximately 41 percent of the trips were less than 200 miles in length. However, 25 percent of the trips were more than 600 miles in length, and the average trip length was 498 miles.

The average trip length for intercity bus travel on a national level is reported to be 125 miles (9). However, there is reason to believe that the average trip length is actually longer than this due to the overcounting of passengers (10). Thus, the longer average trip found in Texas may not be as much of an anomoly as it appears.

Figure 10. Intercity bus trip length.

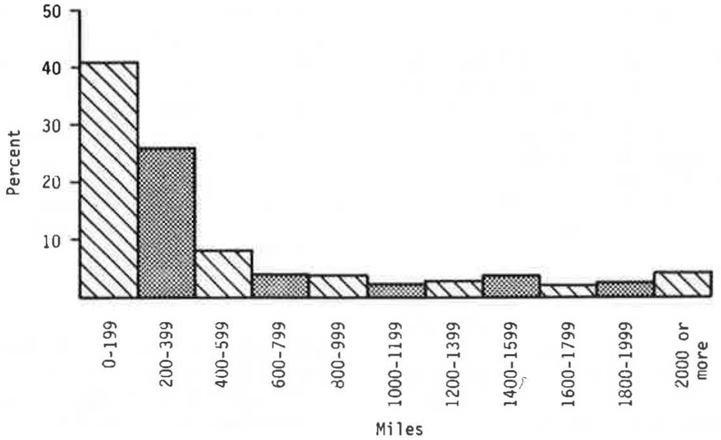


Figure 11. Passenger attitudes toward increased fares.

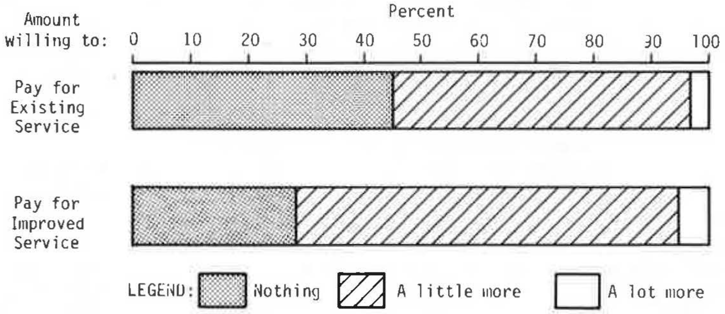


Table 1. Relative importance of various intercity bus features to users.

Feature	Overall Rating[a]	Significance Level[b]
Safety at bus station and on bus	4.44	Most
Leaving and arriving on time	4.38	
Leg room and comfortable seats	4.32	
Availability and cost of gasoline	4.13	Intermediate
Having express bus service	4.09	
Frequency of intercity bus service	4.05	
Bus fare	3.98	
Speed of bus trip	3.92	
Cost of owning car	3.90	
Location of bus station	3.87	
Riding in new modern bus	3.80	
Local city bus transportation at destination	3.67	
Food service at bus station	3.64	
Availability of air or train service	3.41	Least
Automobile parking near bus station	3.31	

[a] Each feature was rated on a scale of 1 (not important) to 5 (very important).
[b] To assess statistically significant differences in the responses, a Duncan's multiple range test for variable rank was performed to identify significantly different means. The responses fell into the three general significance levels shown in the table.

General Attitudes

The survey asked certain questions designed to identify attitudes concerning intercity bus service and fares and to identify those features that were important to users in their decision to use intercity bus service.

Service and Fares

Questions were asked concerning satisfaction with the existing bus service and attitudes toward the cost of the service. The response to the question "How would you rate your satisfaction with intercity bus service overall?" is summarized in the table below. As indicated, the overwhelming majority thought that the existing service is satisfactory. In fact, only 5 percent of the respondents were not pleased with the current service.

Level of Satisfaction	Response (n = 1024) (%)
Very satisfactory	41.8
Satisfactory	47.6
Not satisfactory	5.4
No opinion	5.2

Figure 11 shows the results of the questions concerning how much more users would be willing to pay for existing service and for improved service. Most riders surveyed indicated that they would be willing to pay a little more for both the existing service (51 percent), and for improved service (66 percent). Only a small number of persons would be willing to pay a lot more for either existing or improved service.

Important and Unimportant Features of Intercity Bus Service

This study attempted to identify those features of existing intercity bus service that were most important to the users in their decision to use the service. In essence, an attempt was made to document those features of intercity bus travel that should be emphasized in the planning and operation of the service.

The survey included the following statement: "A number of different factors are important in deciding to use intercity bus service. Please circle the number that best explains how important the following features are to you in deciding to use the intercity bus." Following that, 15 intercity bus features were listed; the user rated each on a scale of 1 (not important) to 5 (very important). These results are summarized in Table 1. The three most significant factors are within the control of operators.

To test for statistically significant differences in the responses, a Duncan's multiple range test for variable rank was performed to identify significantly different means. The Duncan method is a refinement of the protected least significant difference criterion for comparing ranked means on a pairwise basis. The Duncan method provides a reasonable tradeoff between type 1 and type 2 errors.

COMPARISON WITH MICHIGAN SURVEY

In order to ascertain whether Texas intercity bus riders or trips have any unique characteristics, the results of the survey were compared with the results of a 1977 on-board survey conducted in Michigan (1). The survey results were compared by using the Kolmogorov-Smirnov test (11), which is a nonparametric test for differences between two cumulative distributions. The two-sample test analyses the hypothesis that the two independent samples come from identical continuous distributions. The test is sensitive to population differences with respect to location, dispersion, or skewness.

The Texas on-board survey was compared with eight questions from the Michigan survey. Questions concerning age, sex, occupation, vehicle ownership, mode of arrival at the bus station, mode of departure from the bus station, trip purpose, and the number of intercity bus trips made in the past year were compared. All comparisons were made at a level of significance of $\alpha = 0.05$. If the null hypothesis was rejected, evidence was sufficient to conclude that the samples are drawn from different populations. As given in the table below, the null hypothesis was only rejected for occupation.

	Sample Population	
Question	Identical	Different
Age	X	
Sex	X	
Occupation		X
Vehicle ownership	X	
Mode of arrival	X	
Mode of departure	X	
Trip purpose	X	
No. of trips	X	

Note that the conclusion that occupations are different is dependent on the need to equate two different classification schemes. The differences between the two samples could be solely the result of the classification scheme. Therefore, the conclusion concerning differences in occupations is tenuous.

SUMMARY AND CONCLUSIONS

The most notable finding concerning intercity bus riders is that the average trip length is nearly 500 miles. This is significantly longer than generally reported elsewhere. The difference appears to be due to the way ridership data are reported by individual companies.

The on-board survey indicated that 89 percent of the users were satisfied with the service. Improvement of service for existing riders would, therefore, not be likely to result in increased ridership. Features of intercity bus service most important to users included safety, being on time, and comfort. User attributes were not shown to be different for riders in Texas and Michigan. The most significant attribute of intercity bus riders is their lack of an available automobile with which to make the trip.

ACKNOWLEDGMENT

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REFERENCES

1. Michigan Intercity Bus Study. Michigan Department of State Highways and Transportation, Lansing, Nov. 1977.
2. Census of Transportation National Travel Survey. U.S. Bureau of the Census, 1977.
3. J.E. Purdy and L.A. Hoel. An Evaluation of the Effect of Level of Service and Cost on Demand for Intercity Bus Travel. Virginia Highway and Transportation Research Council, Charlottesville, Sept. 1980.
4. R.L. Carstens; Engineering Research Institute, Iowa State University. Intercity Passenger Carrier Improvement Study. Iowa Department of Transportation, Ames, Aug. 1977.
5. Senate Committee on Commerce, Science, and Transportation. Intercity Bus Service in Small Communities. U.S. Congress, 95th Congress, 2nd session, July 1978.
6. Intercity Bus Transportation in Wisconsin. Wisconsin Department of Transportation, Madison, Vol. 1, Nov. 1976.
7. Intercity Bus Transportation in Oregon. Oregon Department of Transportation, Salem, Prelim. Rept., Feb. 1975.
8. The Intercity Bus Industry. Interstate Commerce Commission, Washington, DC, Prelim. Study, May 1978.
9. Transportation Facts and Trends. Transportation of America, Washington, DC, 16th ed., July 1980.
10. E. MacNeal. The Semantics of Air Passenger Transportation. Norfolk Port and Industrial Authority, Norfolk, VA, 1981.
11. M. Hollander and D.A. Wolfe. Nonparametric Statistical Methods. Wiley, New York, 1973.

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