TRANSPORTATION RESEARCH RECORD

574

Planning and Programming for Transportation

5 reports prepared for the 54th Annual Meeting of the Transportation Research Board

TRANSPORTATION RESEARCH BOARD

NATIONAL RESEARCH COUNCIL

Washington, D. C., 1976

Transportation Research Record 574
Price $2.60
Edited for TRB by Marianne Wilburn

Subject areas
11 transportation administration
81 urban transportation administration
82 urban community values
84 urban transportation systems

Transportation Research Board publications are available by ordering directly from the board. They may also be obtained on a regular basis through organizational or individual supporting membership in the board; members or library subscribers are eligible for substantial discounts. For further information, write to the Transportation Research Board, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competence and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The views expressed in this report are those of the authors and do not necessarily reflect the view of the committee, the Transportation Research Board, the National Academy of Sciences, or the sponsors of the project.

LIBRARY OF CONGRESS CATALOGING IN PUBLICATION DATA

National Research Council. Transportation Research Board.
Planning and programming for transportation.

(Transportation research record; 574)

1. Transportation planning–Congresses. 2. Urban transportation policy–Congresses. I. Title. II. Series.

TE7.H5 no. 574 [HE193] 380.5'08s [388.4]
ISBN 0-309-02488-9 76-25116

CONTENTS

EFFECTIVENESS OF NEAR-TERM TACTICS IN REDUCING VEHICLE MILES (KILOMETERS) OF TRAVEL: CASE STUDY OF LOS ANGELES REGION

William T. Mikolowsky, William L. Stanley, and Bruce F. Goeller,
Rand Corporation

An analysis of near-term transportation alternatives for the Los Angeles region that uses the policy-oriented urban transportation model developed by the Rand Corporation is presented. The predicted effect on regional vehicle miles (kilometers) of travel of various levels of bus-system improvements, car-pooling incentives, and economic disincentives (distance surcharges or increased gasoline prices and parking surcharges) is given. Changes in personal mobility as reflected in changes in the total number of person trips also are included. The analysis indicates that a number of transportation management alternatives are available that could reduce vehicle miles (kilometers) of travel in the Los Angeles region by 20 percent or more while minimizing adverse impacts on personal mobility.

•IN 1972, the Rand Corporation undertook the development of a comprehensive methodology that could be used to predict the regional impacts of alternative air pollution control strategies (including strategies that could cause significant reductions in automobile use). This methodology was developed initially as part of the San Diego Clean Air Project (1) and subsequently was applied in a similar study of the Los Angeles air quality control region (LA AQCR) performed for the Environmental Protection Agency (EPA) (2). Most recently, the original methodology again was modified extensively for application in the Los Angeles region under the sponsorship of the Southern California Association of Governments (SCAG) (3).

SOUTHERN CALIFORNIA ASSOCIATION OF GOVERNMENTS SHORT-RANGE PROGRAM

The recently completed study sponsored by SCAG was performed as an element of the SCAG short-range program. The short-range program came about mainly because of a desire to improve air quality in the Los Angeles region by 1977 so that EPA requirements could be satisfied (4). In addition, gasoline shortages observed in late 1973 and early 1974 emphasized the need to develop plans for conserving petroleum resources. These requirements evolved into a specific goal of reducing vehicle miles of travel (VMT) (vehicle kilometers of travel) by 20 percent from that currently forecast for 1977. This VMT (vehicle-kilometer-of-travel) reduction was hoped to be accomplished while retaining or improving personal mobility, particularly for the underadvantaged.

The LA AQCR, which has an area of nearly 8,700 miles^2 (22 620 km^2), encompasses parts of 6 southern California counties, including the entire greater metropolitan Los Angeles area. The people of the region, nearly 10 million in number, are today largely dependent on the private automobile for their transportation needs. Basically, the only

Publication of this paper sponsored by Committee on Taxation, Finance, and Pricing.

major alternatives to the automobile are the publicly owned bus systems that operate in the region and that attract slightly more than 2 percent of the daily weekday person trips. The bus systems now cover roughly 16 percent of the area of the region and serve about 68 percent of the population. Most individuals within the region who commute to work by automobile do so alone; the average automobile occupancy for work-related trips is only about 1.13 occupants/vehicle. The automobile commuter is particularly reliant on the well-developed regional freeway system.

In the study for SCAG, we sought near-term transportation tactics that not only would offer the commuter an alternative to the automobile but also would tend to increase average automobile occupancy. We felt that the mobility provided by the extensive regional freeway network should be exploited in the formulation of these tactics.

ANALYSIS OVERVIEW

These thoughts, together with earlier work (1, 2), indicated that 3 types of tactics could be employed that might provide substantial VMT (vehicle-kilometer-of-travel) reductions in the near term. These are

1. Bus-system improvements (lower fares, increased frequency of service, and expanded service area);
2. Car-pooling incentives (preferential freeway treatment for car pools, computer matching to encourage formation of car pools, and exemptions from parking charges for car pools); and
3. Economic disincentives (distance surcharges and parking surcharges).

The effectiveness of each of these tactics was investigated in detail and, as we will discuss, the results form the basis of this paper. However, in the work for SCAG, the tactics were combined in different ways to form a number of alternative transportation strategies for the Los Angeles region. The strategies then were compared for their impacts on

1. Regional expenditures,
2. Transportation service,
3. Air quality,
4. Petroleum consumption, and
5. Households with different income levels.

For each category, a number of representative impacts were quantified. This comparison (3) then was used by local decision makers in formulating the short-range transportation plan for the Southern California region. The strategy judged most attractive by SCAG is now being implemented (5).

In this paper, we will show the effectiveness of the various transportation management tactics in terms of the resulting VMT (vehicle-kilometer-of-travel) reductions predicted by our analysis. When appropriate, the impact on personal mobility as manifested by a reduction in person trips (trips forgone) also will be shown. [The reader is cautioned, however, not to equate directly reductions in VMT (vehicle kilometer of travel) with improvements in air quality or reductions in gasoline consumption. The relationship in both instances is not straightforward, and the interested reader is urged to consult Mikolowsky et al. (3).]

POLICY-ORIENTED URBAN TRANSPORTATION MODEL

A key element of the overall Rand Corporation methodology is the policy-oriented urban transportation model originally developed as part of the San Diego clean air project (6, 7, 8). For the study discussed in this paper, extensive refinements were made to the original methodology primarily to allow a more detailed analysis of car-pooling incentives (3). We will begin by discussing the philosophy behind the transportation model; then we will show how it is used by providing a detailed example. All of the results presented later in this paper are based on the application of the transportation model to the Los Angeles region in the recent study for SCAG (3).

Philosophy Behind Rand Corporation Urban Transportation Model

The Rand Corporation urban transportation model is not a forecasting model in the sense that traditional transportation models forecast person trips, VMT (vehicle kilometers of travel), and the like on the basis of inputs that include physical descriptions (such as details of the highway network) and demographic descriptions of the region. Rather, to use the transportation model, one first must describe a base-line regional transportation system for the analysis year of interest. The base line includes forecasts of the number of weekday person trips, weekday VMT (vehicle kilometers of travel), frequency distribution of trip lengths, regional-bus-system description, characteristics of the highway network, and estimates of network capacity. We have termed this base line the reference case. The reference case is commensurate with current SCAG demographic and transportation system projections for the Los Angeles region through 1990 (9, 10). We have calibrated the transportation model to match closely the reference case for analysis year 1977 only, the year that currently is the deadline for full compliance with national air quality standards.

We emphasize that the transportation model is not simply a modal-split model. The transportation model adjusts the demand for travel in accordance with the service characteristics of the specified regional transportation system. For example, major improvements to the bus system not only may cause people to switch from the private automobile to the transit mode but also may induce new person trips on transit (trips not being made in the reference-case system). Alternatively, significant economic disincentives, such as a large gasoline tax, may cause some trips to be forgone and may increase car pooling and transit ridership. Thus the transportation model predicts many additional impacts such as total trips forgone; average trip times, speeds, and costs; and percentage of trips made in car pools.

How the transportation model is used to evaluate the effect of a given transportation management tactic can be illustrated best by an example.

Example Application—Effect of 25-Cent Bus Fare

Action by the Los Angeles County Board of Supervisors in early 1974 led to a temporary change in the fare structure of the bus systems operating in Los Angeles County. Before the change, the Southern California Rapid Transit District (SCRTD) base fare was 30 cents plus 8 cents for each additional transit zone crossed during the trip. A temporary supplemental subsidy provided by the board allowed a reduction to a 25-cent flat fare for all trips (Los Angeles County only). The transit district reported that, in November and December 1973, the SCRTD carried an estimated 500,000 passengers/average weekday. By March 1974, the effect of increased gasoline prices (and long lines at service stations) had increased ridership to about 550,000 passengers/weekday. By May 1974, after the 25-cent flat fare had been in effect for about a month, bus ridership increased to 630,000 passengers/weekday. Thus the near-term effect of the flat fare was to increase ridership by 15 percent. The flat fare plus the increase in gasoline prices that occurred during the 6-month period from November to May increased ridership by 26 percent. We will use the percentage increases for comparison because the transportation model is calibrated to the regional bus system not the SCRTD operations in Los Angeles County only.

We have used the transportation model to evaluate the effect of bus-fare reductions as a tactic for reducing VMT (vehicle kilometers of travel) in 1977. The reference-case bus system was designed to yield approximately the same level of service in 1977 as the existing regional bus system provided at the beginning of 1974. The bus-fare zone structure was approximated by describing the fare in the reference case at 25 cents/trip plus 2 cents/mile (1.25 cents/kilometer) traveled on the bus. This resulted in an average fare of 46 cents in the reference case, which is the equivalent of the original SCRTD base fare (30 cents) plus 2 additional transit zones (16 cents). The average peak-period headway of the reference-case system was estimated to be 17 min; the off-peak headway was estimated to be 40 min. The service area was assumed to be the same as the service area of the existing regional bus system (includes the SCRTD, Orange County Transit District, and municipal bus lines in Santa Monica and Long Beach plus 11 other smaller systems).

Evaluating the effect of different fare reductions is now straightforward. The transportation model is given different fare structures; the model then estimates the resulting changes to the regional transportation system. The data given in Table 1 (3) compare 6 bus systems with varying fare reductions with the reference-case bus system. The 25-cent flat fare case is highlighted. Certain information pertains to all cases in Table 1:

1. Peak-period headways are 17 min;
2. Off-peak headways are 40 min;
3. Service area is 1,380 miles^2 (3588 km^2);
4. Sixty-eight percent of population in service area are eligible; and
5. All counties are affected.

Note that the model predicts an increase in daily bus passengers of about 15 percent. The model also predicts that decreasing the fare to a flat 25 cents would require increasing the annual bus subsidy from about $32 million to $69 million. The 15 percent increase in ridership predicted by the model correlates extremely well with the increase observed by the SCRTD. The effect of increased gasoline prices also can be shown by using the transportation model. In the reference case, the pump price of gasoline is assumed to average 40 cents/gallon (10.6 cents/liter) in 1977. Remember that the reference case is based on an extrapolation of trends observed from 1970 to 1972. Thus gasoline price increases that occurred in 1973 and 1974 are not included in the forecast. By May 1974, when the reduced fare had been in effect for several weeks, the average price of gasoline had risen to almost 60 cents/gallon (15.9 cents/liter). The increase in gasoline price caused a corresponding increase in bus ridership that is not taken into account in Table 1. Later in this paper, we will consider in detail the effects of increased prices of gasoline brought about either by the market or by additional gasoline taxes. With the 60-cent/gallon (15.9-cent/liter) price of gasoline included, the increase in ridership predicted by the model as a result of a flat 25-cent fare is about 30 percent. Thus we are nearly in exact agreement with the range of observed data for this transportation management tactic. Other works (3, 6, 7, 8) offer a complete description of the formulation of the transportation model.

BUS-SYSTEM IMPROVEMENTS

We have considered 3 types of bus-system improvement tactics that result in reductions in VMT (vehicle kilometers of travel): reductions in fares, increased frequency of service (that is, shorter headways between buses), and expanded service areas (that is, increasing the population served by the bus system).

First, different levels of intensiveness of each of the individual tactics were considered. The effect of different bus-fare structures has been described earlier. These individual tactics then were combined with the goal of providing the largest reduction in VMT (vehicle kilometers of travel) with the smallest increase in the required bus subsidy (3). By using this technique, we developed 12 composite bus systems for further analysis. The data given in Table 2 (3) show how the 12 composite bus systems were constructed in stages.

Second, each of the composite systems was evaluated by using the urban transportation model. Figure 1 shows the reduction in VMT (vehicle kilometers of travel) resulting from each composite bus system in terms of the required additional annual bus subsidy. [An LDMV is a light-duty motor vehicle. LDMVs weigh less than 6,000 lb (2700 kg) gross weight. These vehicles account for more than 90 percent of total motor VMT (vehicle kilometers of travel) (3).] We have chosen to present these results in terms of the additional subsidy required because we feel that this represents the "cost" of bus-system improvements as perceived by local decision makers. The composite systems are represented by the circular symbols. For example, the stage-1 system reduces VMT (vehicle kilometers of travel) by about 0.8 percent for an additional annual subsidy of $9 million. At the other extreme, the state 12-bus system requires an additional subsidy of more than $650 million/year and reduces VMT (vehicle kilometers of travel) by about 9.5 percent.

Third, our development of the composite bus systems was intended to approximate the most cost-effective set of bus-system improvements possible; cost was measured in terms of additional bus subsidy required, and effectiveness was measured in terms of the reduction in VMT (vehicle kilometers of travel) obtained. Our success in this respect also is shown in Figure 1. The triangular symbol represents the cost and effectiveness of reducing the bus fare to 0 while making no other improvements; the square symbol is a result of using 0 fare with peak-period headways reduced to 10 min but with no increase in service area. In both instances, substantially larger reductions in VMT (vehicle kilometers of travel) can be obtained for the same subsidy expenditure as can be seen by the composite bus-system curve.

Of course, we realize that many factors other than the required subsidy must be considered when describing the feasibility of different bus-system improvements. For example, the number of buses required by a new system may be affected by the number manufactured annually. In this instance we note that the reference-case bus system requires 2,082 buses (including spares), stage 5 requires 3,294 buses, stage 10 requires 5,489 buses, and stage 12 requires more than 9,000 buses. The stage-5 and possibly stage-10 systems are probably realistic for consideration in 1977. Stage 12, however, does not appear to be a practical alternative in the near term.

CAR-POOLING INCENTIVES

Three different car-pooling incentives were considered as tactics to provide regional reductions in VMT (vehicle kilometers of travel): (a) preferential freeway treatment for car pools (and buses), (b) computer matching for car poolers, and (c) exemptions of car poolers from parking surcharges. Again, each of these tactics was first evaluated individually (3). We will discuss one of the most promising combinations.

The evaluation of each tactic indicated that the preferential freeway treatment and computer matching showed the most promise for achieving substantial reductions in VMT (vehicle kilometers of travel). Figure 2 shows the effect on regional VMT (vehicle kilometers of travel) of providing preferential freeway treatment for car pools and buses if 40 percent of the employed people in the region participate in a car-pool matching program and are matched successfully. The results are presented in terms of the number of occupants required to quality for preferential treatment. Figure 2 shows that reductions in VMT (vehicle kilometers of travel) approaching 20 percent can be achieved if the required occupancy is 3, 4, or 5.

Two additional pieces of information are shown in Figure 2. First, the effect on modal split for each occupancy is described. In each case, the bus modal split decreases, implying that some persons currently making trips by bus will switch to the car-pooling mode. The loss in bus revenue will cause the required bus subsidy to increase. Second, resulting average automobile occupancy for essential trips also is shown. (All essential trips are work-related trips.) We assume that the demand for such trips is constant (that is, that alternative transportation policies will not affect the number of work trips occurring in the region in the short term even though the number of vehicle trips may change substantially). For the reference case, the essential-trip automobile occupancy is 1.13. Note that reduction in VMT (vehicle kilometers of travel), which was obtained from providing preferential freeway treatment for buses only, includes the effect of the computer matching. Preferential treatment for buses only, without computer matching, would yield only about a 1 percent reduction in VMT (vehicle kilometers of travel) (3).

The effectiveness of the car-pooling incentives shown in Figure 2 in reducting VMT (vehicle kilometers of travel) should be considered upper-bound estimates. We say this because of 2 important assumptions made in our analysis. The first assumption is that, in the case of preferential freeway treatment, all qualified car poolers travel the freeway portion of their trip at the average uncongested freeway speed (this also implies that all freeways are modified to provide preferential treatment). We also have assumed that vehicles not qualifying for preferential treatment encounter the same time delay as they currently do because of freeway congestion. This approach to preferential freeway treatment for car poolers reflects the policy orientation of the transportation model. There are at least 2 ways preferential treatment could be implemented: exclusive freeway lanes for car poolers or preferential ramp metering for car poolers. In the first instance, the time delay for those who are not car poolers can be guaranteed by limiting the number of non-car-pool lanes on each freeway to deliberately ensure congestion. In the second instance, the required time delay could be built into the freeway ramp meter. Note, however, that the manner in which the preferential treatment is provided is an implementation problem. The policy question concerns whether the preferential treatment will be effective. The second assumption is that 40 percent of the work force participate in computer matching and are matched successfully. We believe that 40 percent is an absolute upper limit on the number of employed people who could be incorporated into a matching program. Even considering these assumptions, however, preferential treatment and computer matching appear to be very attractive tactics.

We note that the effectiveness of the combined tactics in reducing VMT (vehicle kilometers of travel) is greater than the sum of the reductions in VMT (vehicle kilometers of travel) realized by the 2 tactics when evaluated separately (3). This synergistic effect can be explained. If preferential treatment only is considered, the potential car pooler must weigh the time advantages of no freeway congestion against the pickup-time penalty associated with collecting the other car poolers. When computer matching is included, the pickup-time penalties will decrease because each participant will become aware of additional neighbors closer to the potential car pooler's home who are eligible for his or her car pool. Without the preferential freeway treatment, computer matching lessens only the pickup-time penalty; congestion on the freeway portion of the trip still will be encountered.

ECONOMIC DISINCENTIVES

Two types of economic disincentives were considered in the SCAG study. The first is a surcharge based on VMT (vehicle kilometers of travel); this could be implemented by an additional gasoline tax (although many other possibilities exist). The second is a surcharge on vehicle trips, which most logically would be implemented by imposing a parking surcharge.

To show the effects of using a distance surcharge as a disincentive, we have chosen to present our results in terms of the equivalent pump price of gasoline. This technique allows us to consider simultaneously increases in the base price of gasoline attributable to the market mechanism and increases reflecting a higher gasoline tax.

Distance Surcharge (Increased Gasoline Price)

The effectiveness of the distance surcharge tactic has been evaluated for a range of bus-system improvements and a range of car-pooling incentives. The specific bus-improvement and car-pooling tactics used in this context were selected in consultation with the SCAG staff and were based on the results presented earlier in this paper.

Before describing the results of this part of the analysis, we must first discuss some of the implications of using the increased pump price of gasoline as a substitute for distance surcharge. The purpose of a distance surcharge is to increase the total cost per mile (kilometer) of driving an automobile. We can best explain by considering a hypothetical example. Suppose that the average cost (excluding fuel) of operating an automobile is 6 cents/mile (3.65 cents/km). (This cost includes amortized investment, insurance, license, and the like.) Suppose also that the average vehicle travels 10 miles/gallon (4.25 km/liter) of gasoline and that the pump price of gasoline is 40 cents/gallon (10.6 cents/liter) including taxes. Thus the total cost would be 10 cents/mile (6.25 cents/km).

Now assume that an additional 20-cent/gallon (5.3-cent/liter) gasoline tax is imposed. The immediate effect would be to make the fuel cost 6 cents/mile (3.75 cents/km); the total cost then would be 12 cents/mile (7.5 cents/km). However, if the additional gasoline tax remains in effect for some time, motorists will likely begin to adjust their behavior in an important way—they will buy new cars with better fuel economy. Suppose that after several years the fuel economy of the average vehicle increases to 15 miles/gallon (6.37 km/liter). The 60-cent/gallon (15.9-cent/liter) gasoline price would result in a fuel cost of only 4 cents/mile (2.5 cents/km) and the total cost would return to 10 cents/mile (6.25 cents/km). Although fuel consumption would still be decreased, there would be no cost-per-mile (cost-per-kilometer) penalty, and, hence, regional VMT (vehicle kilometers of travel) would no longer be affected. To achieve the earlier effect on VMT (vehicle kilometers of travel), one would have to increase the total pump price of gasoline to 90 cents/gallon (23.9 cents/liter).

When we evaluated increased gasoline prices by using the transportation model, we assumed that the fuel economy of the average vehicle does not change from that prescribed in the reference case [about 13.2 miles/gallon (5.6 km/liter)] (3). Thus the effects we present in this section should be regarded as completely valid only in the short term. Stated another way, when we show a result for an 80-cent/gallon (21.2-cent/liter) gasoline price, we assume that the price has just changed from the reference-case value of 40 cents/gallon (10.6 cents/liter). If several years pass between the change in gasoline price and the analysis year, then the reduction in VMT (vehicle kilometers of travel) should be less than we show because motorists will have had time to increase the average fuel economy of the fleet through their choice of new cars that have better fuel economy. Alternatively, if the policy decision is to maintain the same reduction in VMT (vehicle kilometers of travel) obtained initially with a gasoline tax, then the amount of the tax will need to be adjusted upward each year to account for the change in average vehicle fuel economy. Of course, we also are assuming that the local gasoline supply is perfectly elastic at the prevailing local market price. With this in mind, we will now discuss the effect on VMT (vehicle kilometers of travel) of increases in gasoline price.

Range of Bus-System Improvements

The impacts of gasoline price increases will depend on the level of bus-system improvement being considered. Therefore, we have analyzed the economic disincentives for 3 different systems: reference-case, stage-5, and stage-10 bus systems. The stage-5 system was chosen because it represents, at this time, the minimum likely improvement to the regional bus system by 1977. On the other hand, the stage-10 system with nearly 5,500 buses required can be considered the maximum feasible improvement for 1977.

The reduction in regional VMT (vehicle kilometers of travel) caused by increased gasoline prices for each of these bus systems is shown in Figure 3. The most evident feature of Figure 3 is that very large VMT (vehicle-kilometers-of-travel) reductions can be obtained if gasoline becomes expensive. However, some more subtle observations can be made. For example, with the reference-case bus system, a 20 percent reduction in VMT (vehicle kilometers of travel) would occur if gasoline were 85 cents/gallon (22.5 cents/liter). The stage-10 bus system would yield the same reduction in VMT (vehicle kilometers of travel) for a pump price of only about 65 cents/gallon (17.2

cents/liter). Figure 3 also is useful for considering alternative ways of alleviating gasoline shortages. If the shortfall in supplies were 10 percent [VMT (vehicle kilometers of travel) would need to be reduced by 10 percent to eliminate the shortfall], then the required free-market price of gasoline would rise to about 60 cents/gallon (15.9 cents/liter) with the reference-case bus system. Alternatively, the gasoline supply shortfall would be eliminated with the stage-10 bus system if the price rose to only 45 cents/gallon (11.9 cents/liter).

The reductions in VMT (vehicle kilometers of travel) shown in Figure 3 came about because of 3 basic changes in trip-making behavior. First, some trips made by automobile in the reference case will switch to the transit mode. Second, some trips made in low-occupancy automobiles will be made in car pools. [Although no specific car-pooling incentives are included in this part of the analysis, the increased cost per mile (kilometer) of driving will induce some people to form car pools and this effect has been included.] Third, some trips made in the reference case will no longer be made; we call these the trips forgone.

The number of trips forgone is one of the important impacts that needs to be included in evaluating economic disincentives. Trips forgone can be used to represent the loss of personal mobility brought about by the implementation of such tactics. The number of trips forgone is equivalent to the number of person trips that are no longer made because of the policy in effect. We have assumed that only inessential trips (all non-work-related trips) can be forgone as the result of a particular policy. Note, however, that essential vehicle trips can decrease, and, indeed, will decrease, as individuals either participate more heavily in car pools or switch from automobile to bus mode. Figure 4 shows the effect of gasoline prices on trips forgone for all households and for households in the Los Angeles region with less than $5,000 annual income (1972 dollars).

Consider first the effect of a 20 percent reduction in VMT (vehicle kilometers of travel) on the average household. From Figure 3, we saw that an 85-cent/gallon (22.5-cent/liter) price was required with the reference-case bus system; the resulting trips forgone would be about 6 percent (expressed as a percentage of the number of person trips taken in the reference case). The stage-10 bus system needs only a 65-cent/gallon (17.2-cent/liter) gasoline price; the corresponding number of trips forgone is less than 2 percent.

The effect of gasoline price is even more dramatic on the lower income groups. For example, consider that the average price of gasoline in Los Angeles in May 1974 was about 60 cents/gallon (15.9 cents/liter). This price causes the lower income group households to forgo about 4 percent of their trips with the reference-case bus system. However, if the stage-10 bus system was available, these households would not forgo trips but would actually make more trips than in the reference case (trips forgone are about -2 percent).

These examples show the importance of improving the regional transit system to reduce losses in personal mobility caused by increasing gasoline prices particularly for low-income households. Remember, the gasoline price can increase either through additional taxes as part of a strategy to reduce VMT (vehicle kilometers of travel) or through the market mechanism.

Range of Car-Pooling Incentives

We also have considered 3 different car-pooling-incentive policies for analysis in conjunction with the increased gasoline prices:

1. No additional car-pooling incentives [except the disincentive automatically included in the increased cost per mile (kilometer) of driving],
2. Preferential freeway treatment for buses and car pools with 3 or more occupants, and
3. Preferential freeway treatment plus computer matching with 40 percent of the work force presumed to be matched successfully.

Table 1. 1977 impacts of bus-fare reductions as predicted by the policy-oriented urban transportation model.

Bus System	Fares (cents) Per Trip	Fares (cents) Per Mile	VMT Reduction (percent)	Annualized System Cost (millions of dollars)	Annual Subsidy Required (millions of dollars)	Average Modal Split (percent)	Daily Bus Passengers	Average Trip Speed (mph)	Average Bus Occupancy	Buses Required	Bus-System Employees
Reference case	25	2	0	132	32	2.2	636,000	14	22	2,082	7,510
Case 1	25	1	0.8	132	43	2.4	705,000	14	27	2,082	7,510
Case 2	25	0	1.3	131	69	2.5	728,000	14	30	2,072	7,490
Case 3	20	0	1.5	131	79	2.6	762,000	14	31	2,072	7,490
Case 4	10	0	1.9	131	103	2.8	834,000	14	34	2,072	7,490
Case 5	5	0	2.1	131	116	2.9	872,000	14	35	2,072	7,490
Case 6	0	0	2.3	131	131	3.1	913,000	14	37	2,072	7,490

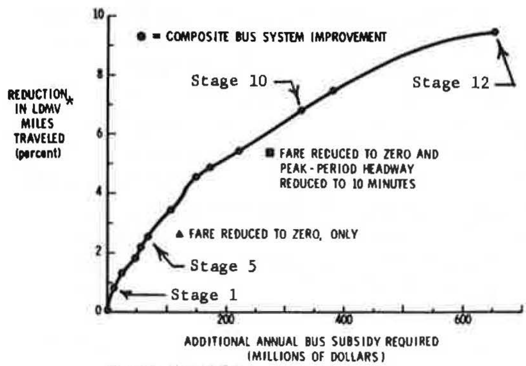
Note: 1 cent/mile = 0.625 cent/km. 1 mile = 1.6 km.

Table 2. Staged development of the 12 composite bus systems.

Stage	Description	Stage	Description
0	Reference bus system (fare = 25 cents plus 2 cents/mile, peak-period headway = 17 min, and existing service area = 1,380 miles²)	6	Lower peak-period headway to 10 min
		7	Lower fare to 25 cents/trip and have no zone charges
		8	Lower fare to 20 cents/trip
1	Lower fare to 25 cents plus 1 cent/mile	9	Lower fare to 10 cents/trip
2	Lower peak-period headway to 15 min	10	Lower peak-period headway to 7.5 min
3	Lower peak-period headway to 12.5 min	11	Increase service area in Los Angeles County
4	Increase service area[a] to 1,488 miles²		
5	Increase service area[a] to 1,613 miles²	12	Lower peak-period headway to 5 min

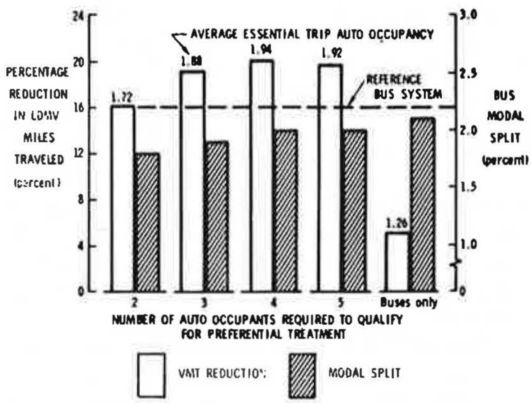
Note: 1 cent/mile = 0.625 cent/km. 1 mile² = 2.6 km².
[a]Service area expansions are in Orange County.

Figure 1. Effectiveness of the composite bus systems in reducing vehicle miles (kilometers) of travel in terms of additional bus subsidy required.



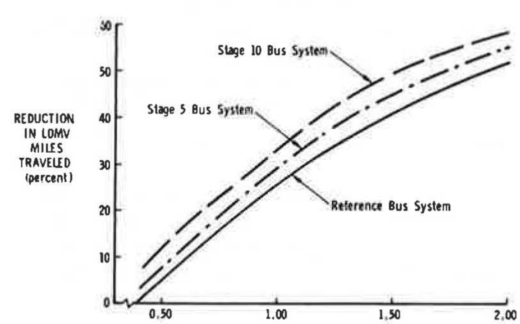
Note: 1 mile = 1.6 km.

Figure 2. Effect on vehicle miles (kilometers) of travel of providing preferential treatment for buses and car pools with 40 percent of the work force participating in computer matching.



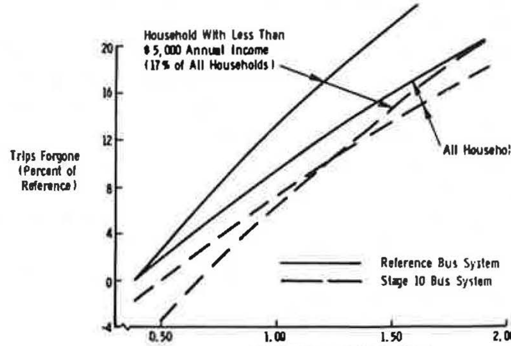
Note: 1 mile = 1.6 km.

Figure 3. Effect of gasoline price on vehicle miles (kilometers) of travel for 3 bus systems.



Note: 1 mile = 1.6 km.
$1/gallon = $0.265/liter.

Figure 4. Effect of gasoline price on trip-making behavior for 2 bus systems.



Note: $1/gallon = $0.265/liter.

Each incentive has been analyzed with the reference-case bus system.

Figure 5 shows the effect on VMT (vehicle kilometers of travel) of gasoline prices for the 3 car-pooling-incentive policies. Again we see that major reductions in VMT (vehicle kilometers of travel) can be obtained with high gasoline prices. Note also in Figure 5 the saturation effect on a reduction in VMT (vehicle kilometers of travel) that occurs after the price of gasoline has passed $1/gallon (26.5 cents/liter). That is, the additional reduction in VMT (vehicle kilometers of travel) obtained from the car-pooling incentives begins to taper off at about that point.

Another aspect of the car-pooling incentives should be realized. We have assumed that car pools are formed for essential trips only, and we further assume that an inelastic demand exists for essential trips (all essential trips must be made by low-occupancy automobile, in car pools, or on transit). Thus the car-pooling incentives have no effect on the number of trips forgone as a consequence of increased gasoline price. Specifically, the number of trips forgone at some gasoline price for any of the car-pooling policies will be the same as that shown in Figure 4 for the reference-case bus system. Therefore, car pooling can be used to achieve substantial reductions in VMT (vehicle kilometers of travel), but reductions in personal mobility caused by increasing gasoline prices can be alleviated only by improving the regional bus system.

Parking Surcharges Versus Distance Surcharges

The parking surcharge aimed at reducing the number of vehicle trips is more straightforward than a gasoline tax used as a distance surcharge. For example, one of the tactics in the final implementation plan for Los Angeles promulgated by EPA was an additional parking tax of 25 cents/hour on essentially all nonresidential parking (4). An examination of the travel patterns in the Los Angeles region indicates that parking surcharges may not be the most effective economic disincentive for reducing VMT (vehicle kilometers of travel). Such an analysis reveals that trips less than 4 miles (6.4 km) in length represent only 12 percent of the regional VMT (vehicle kilometers of travel) yet account for 50 percent of all trips. On the other hand, trips of approximately 11 miles (17.6 km) or more represent almost 55 percent of the regional VMT (vehicle kilometers of travel) but account for only 20 percent of the total trips (2). Thus an economic disincentive applied on a per-trip basis, such as a parking surcharge, may be less effective in reducing VMT (vehicle kilometers of travel) than one applied on a per-vehicle-mile (per-vehicle-kilometer) basis (for example, an additional gasoline tax). Stated another way, the parking surcharge will be most visible for short trips that account for only a small percentage of the regional VMT (vehicle kilometers of travel).

To further clarify the differences between distance and parking surcharges, we have compared their effectiveness in reducing VMT (vehicle kilometers of travel) by using the transportation model. A uniform basis for the comparison was provided by expressing the reduction in VMT (vehicle kilometers of travel) in terms of the annual expenditures by motorists in the region for the distance or parking surcharges. The expenditure caused by the tactic represents the total out-of-pocket costs to motorists. This comparison is shown in Figure 6a. Note that, for the same level of expenditure, the distance surcharge always yields a greater VMT (vehicle-kilometers-of-travel) reduction than the parking surcharge yields. The disparity becomes larger for increasing levels of VMT (vehicle-kilometers-of-travel) reduction. As we explained earlier, however, the effect on personal mobility also should be taken into account when economic disincentives are considered. The relative effects of distance and parking surcharges on trips forgone are shown in Figure 6b. Again the parking surcharge looks somewhat less favorable than distance surcharge for the range of VMT (vehicle-kilometer-of-travel) reduction shown.

Thus far, we have considered the distance and parking surcharges to be in effect for all trips. (Of course, the parking surcharge is applicable only to the nonresidential end of the trip.) We distinguish between 2 types of trips: (a) essential trips are all home-work-related trips, and (b) inessential trips are all other trips. Demand for essential trips remains constant, and these trips will be made either by low-occupancy automobiles, in car pools, or on transit. Inessential trips (shopping, recreation), however, have an elastic demand, which means that all forgone trips come from this category.

The parking-surcharge tactic provides another flexibility. We believe that the surcharge could be implemented to affect essential trips only. The advantage to using the parking-surcharge tactic in this context would be that practically no trips would be forgone as a result of the surcharge. Therefore, we also show in Figure 6b the effectiveness of the parking surcharge on essential trips only in reducing VMT (vehicle kilometers of travel). With a VMT (vehicle-kilometers-of-travel) reduction of up to about 25 percent, the parking surcharge used in this way is approximately identical in effectiveness to the distance surcharge. Consequently, in our analysis of the parking surcharge, we have assumed that it is applied to the nonresidential ends of essential trips only.

Parking Surcharge on Essential Trips

The effectiveness of the parking-surcharge tactic was investigated, first, in conjunction with the 3 previously described bus systems. We have expressed the parking-surcharge policy in terms of the daily surcharge imposed at the nonresidential end of each essential trip. These results showed that the incremental VMT (vehicle-kilometer-of-travel) reductions obtained as a consequence of the surcharge were almost independent of the bus system under consideration.

Finally, Figure 7 shows the effect that a parking surcharge would have on VMT (vehicle kilometers of travel) for different car-pooling-incentive policies. In addition to the no-additional-car-pooling-incentives case (which includes the reference-case bus system), we have considered the following policies:

1. Parking surcharge exemptions for car pools with 3 or more occupants,
2. Policy 1 plus preferential freeway treatment for car pools with 3 or more occupants and buses, and
3. Policies 1 and 2 plus computer matching with 40 percent of the work force being successfully matched.

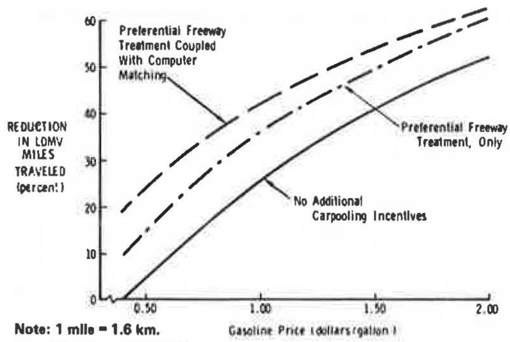
We can see in Figure 7 that parking-surcharge exemptions yield only modestly larger VMT (vehicle-kilometer-of-travel) reductions than the surcharge alone yields. The reader should remember, however, that parking-surcharge exemptions will lessen the motorist's out-of-pocket costs. We also can observe from Figure 7 that, if all the car-pooling-incentive policies are in effect, we begin to encounter a saturation effect after the surcharge is increased above about $1/day. That is, given all these incentives and disincentives on essential trips, the maximum total VMT (vehicle-kilometer-of-travel) reduction that apparently could be obtained is approximately 30 percent. Greater reductions in VMT (vehicle kilometers of travel) can be achieved only by concentrating on the inessential trips with additional economic disincentives and, to a lesser extent, with bus-system improvements.

SUMMARY

In this paper, we have provided a number of insights into the possible effectiveness of different tactics in reducing VMT (vehicle kilometers of travel) in the Los Angeles region and some of the consequences implied by use of these tactics. Six of the more important observations we have made can be summarized.

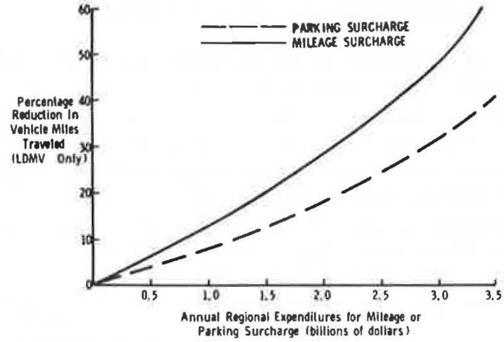
1. The maximum reduction in VMT (vehicle kilometers of travel) achievable by bus-system improvements alone is about 10 percent. The bus system required to accomplish such a reduction in the Los Angeles region probably should be considered impractical for implementation by 1977.

Figure 5. Effect of gasoline price on vehicle miles (kilometers) of travel for 3 car-pooling-incentive policies.

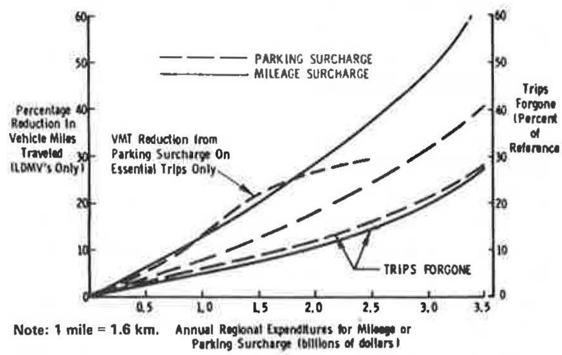


Note: 1 mile = 1.6 km.
$1/gallon = $0.265/liter.

Figure 6. Relative effectiveness of distance and parking surcharges in reducing vehicle miles (kilometers) of travel and changing trip-making behavior.



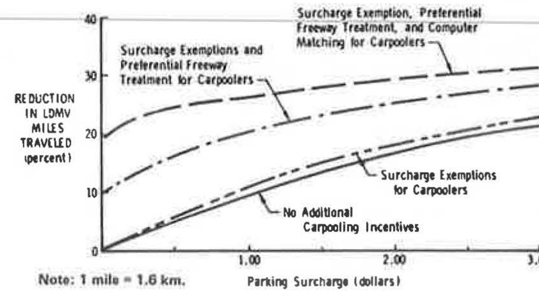
(a) VMT reduction only.



Note: 1 mile = 1.6 km.

(b) Added curves show trips foregone if there are surcharges on all trips; also the effect on VMT of parking surcharges solely on essential trips.

Figure 7. Effect on 1977 vehicle miles (kilometers) of travel of parking surcharges for essential trips only for 4 car-pooling-incentive policies.



Note: 1 mile = 1.6 km.

2. Reductions in VMT (vehicle kilometers of travel) as great as 20 percent can be obtained by combining preferential freeway treatment for car pools and buses with computer matching to encourage and simplify the formation of car pools.
3. Substantial reductions in VMT (vehicle kilometers of travel) can be achieved with increases in the pump price of gasoline. For example, with no bus-system improvements or additional car-pooling incentives, regional VMT (vehicle kilometers of travel) could be reduced by about 20 percent if gasoline were 85 cents/gallon (22.5 cents/liter).
4. An additional implication of increased gasoline prices is the resulting loss of personal mobility that is reflected in the number of trips forgone. Only improvements to the regional bus system can reduce the number of trips forgone because of increased gasoline prices.
5. The parking-surcharge tactic, if applied to essential trips only, is as effective as a distance surcharge in reducing VMT (vehicle kilometers of travel) [for VMT (vehicle-kilometer-of-travel) reductions that are less than 20 percent].
6. The maximum reduction in VMT (vehicle kilometers of travel) obtainable through transportation management tactics that concentrate on essential trips is about 30 percent. Larger VMT (vehicle-kilometer-of-travel) reductions can be obtained only by causing some of the inessential trips to switch to the transit mode or to be forgone.

We repeat that all of the effects of increased gasoline prices given in this paper are valid only in the short term, that is, only for several years after the increased prices occur. Some recent estimates of the long-term effects of increased gasoline prices are provided elsewhere (11), however.

We remind the reader that the results presented in this paper are specific to the Los Angeles region. The effectiveness of some of the tactics (particularly the car-pooling incentives) is undoubtedly related to the extensiveness of the Los Angeles freeway system. Thus, direct application of these results to other urban regions should not be attempted, although the policy-oriented urban transportation model with minor modifications could be used to generate corresponding results for other specific regions of interest. The principal requirement for transfer to another region is a rather complete forecast of the aggregate transportation system for the analysis year of interest (6, 8).

ACKNOWLEDGMENTS

We gratefully acknowledge the assistance of Frances Bolger Banarjee of the Southern California Association of Governments, who coordinated the SCAG Short-Range Program. We also are indebted to Rand Corporation colleagues James Bigelow, Robert Petruschell, and Thomas Kirkwood, who were instrumental in the development of the original transportation model, and Jean Gebman for his development of the companion air quality methodology. Gail Burkholz of the Rand Corporation provided her considerable skills in helping with the numerous computations required.

REFERENCES

1. B. F. Goeller et al. San Diego Clean Air Project. Rand Corp., R-1362-SD, Dec. 1973.
2. B. F. Goeller et al. Strategy Alternatives for Oxidant Control in the Los Angeles Air Quality Control Region. Rand Corp., R-1368-EPA, Dec. 1973.
3. W. T. Mikolowsky, J. R. Gebman, W. L. Stanley, and G. M. Burkholz. The Regional Impacts of Near-Term Transportation Alternatives: A Case Study of Los Angeles. Rand Corp., R-1524-SCAG, June 1974.
4. Environmental Protection Agency. Air Programs: Approval and Promulgation of Implementation Plans, California Transportation Control Plan. Federal Register, Vol. 38, No. 217, Nov. 12, 1973.

5. SCAG Short-Range Transportation Plan. Southern California Association of Governments, April 11, 1974.
6. J. H. Bigelow, B. F. Goeller, and R. L. Petruschell. A Policy-Oriented Urban Transportation Model: The San Diego Version. Rand Corp., R-1366-SD, Dec. 1973.
7. R. L. Petruschell and T. F. Kirkwood. A Generalized Bus System Cost Model. Rand Corp., R-1365-SD, Dec. 1973.
8. W. T. Mikolowsky et al. A Tradeoff Model for Selecting and Evaluating Regional Air Quality Control Strategies. Rand Corp., R-1367-SD, Dec. 1973.
9. Scenario Plan for 20 Percent VMT Reduction. Southern California Association of Governments, Dec. 1973.
10. SCAG Development Guide, Growth Forecast Selection. Southern California Association of Governments, Progress Rept. 74-1, Jan. 10, 1974.
11. S. Wildhorn, B. K. Burright, J. H. Enns, and T. F. Kirkwood. How to Save Gasoline: Public Policy Alternatives for the Automobile. Rand Corp., R-1560-NSF, Oct. 1974.

TRANSPORTATION PLANNING FOR SAIGON

Browne C. Goodwin, Daniel, Mann, Johnson, and Mendenhall

In the winter of 1973-74, the author provided advisory services to the South Vietnam Ministry of Public Works on transportation planning techniques. He installed the program packages of the Federal Highway Administration on urban transportation planning and the Urban Mass Transportation Administration on transportation planning system on computers in Saigon and instructed South Vietnamese personnel in the use of the packages for a long-range planning study they wished to conduct. Transportation in Saigon in 1973 and 1974 and major differences of Saigon and Western traffic composition are discussed. Some of the long-range planning alternatives considered in Saigon are presented. Some of the problems associated with applying the U.S. Department of Transportation planning packages in a remote location also are presented.

•IN mid 1973, Daniel, Mann, Johnson, and Mendenhall (DMJM) was requested by the Vietnam Ministry of Public Works and the U.S. Agency for International Development (AID) to provide advisory assistance to the South Vietnamese in urban transportation planning. DMJM sent me to Saigon to determine the objectives of a possible study, evaluate the personnel and data resources available, and prepare a scope of work for advisory services. This trip also served as an introduction to Saigon and to the characteristics of its transportation.

TRANSPORTATION IN SAIGON

Saigon in 1973 and 1974 was a city of nearly 3 million people living and moving in a community that was planned by the French for less than a half million. The primary street system consists of broad, straight avenues that originally were lined with trees but now have few trees remaining. These boulevards are interrupted frequently by traffic circles, and the traffic-bearing capacity of the roadway often is reduced by marketplaces and vendors overflowing the sidewalks into the curb lanes (Figures 1 and 2).

The vehicle mix in Saigon was heavily weighted toward motorcycles and other motorized 2- or 3-wheeled vehicles, and increases in gasoline prices resulted in an upsurge of bicycles and pedicabs as replacement for motorscooters and motorcycles. Approximately 80 percent of the private vehicles were small motorcycles and scooters, and many of the private automobiles were obsolete and poorly maintained French and Japanese imports (Figure 3).

Until late 1973, the principal form of public transportation was an extensive route system of 3-wheeled, 10-passenger Lambros powered by motorcycle engines. More than 4,000 of these vehicles operated over many fixed routes, stopped anwhere on demand, and charged low fares (Figure 4).

In late 1973 and early 1974, bus service was reintroduced to Saigon after an absence of more than 5 years; some of the buses were owned by unions of former Lambro drivers and operated over former Lambro routes, and others were privately owned. The bus routes were subject to government control, and the bus lines were heavily patronized; however, accurate counts of patronage for the system as a whole or for individual lines were not available (Figure 5).

Publication of this paper sponsored by Committee on Transportation Programming, Planning, and Evaluation.

Figure 1. Nguyen Hue Boulevard in downtown Saigon.

Figure 2. Curbside market.

Figure 3. Traffic on major arterial.

Other forms of public transportation included taxicabs (most of which were Renaults and Simcas of the 1950s), motorcycles, and pedicabs. Because of the energy shortage, the pedicabs made a tremendous resurgence in late 1973 and 1974. All of these vehicles operated by cruising for passengers or by waiting at busy locations such as markets, government offices, and schools. The passenger always had to bargain with the driver to establish a fare.

The vehicle occupancies observed in Saigon were substantially higher than those in the United States; even the motorcycles and scooters carried up to 5 persons regularly (Figure 6), and a family of 11 on a single Honda was sighted by one observer. The traffic mix and occupancy rates were so different from those experienced elsewhere that capacity and volume relationships had to be redefined. Observed speeds also were much lower than those elsewhere. Even driver expectations were different from those familiar to U.S. traffic engineers because intersection traffic control was frequently nonexistent or not operating and those signals that were present were too far from the intersection to be visible to drivers at the heads of queues. Entering the intersection thus became a game of chicken, with opposing drivers attempting to bluff each other and with the bigger vehicle usually winning. There was little driver lane discipline even though the traffic department had attempted to delineate frontage roads or right lanes for exclusive use of 2- and 3-wheeled vehicles (Figure 7). In spite of these problems, traffic in Saigon improved significantly in 1974, but the improvement mainly was due to the great decrease in American military traffic and to increased gasoline costs (more than 200 percent in the last year), which reduced the number of vehicles on the road.

SCOPE OF WORK

The South Vietnam Directorate General of Reconstruction and Urban Planning (DGRUP) with assistance from AID urban planning personnel had developed 5 alternative land use plans for metropolitan Saigon in the year 2000. For every square kilometer in the region, they had projected land use, population, employment, activity centers, communications, water and sewer lines, power distribution, and even the spacing of the local street system. They had prepared capital and operating cost estimates for all 5 alternatives, but the tables of costs that they showed included 1 blank row for the costs of a transportation network for interzone trips. The South Vietnamese objective for the project was to fill in the blank row. The AID objective was more limited, perhaps, but more realistic. AID wanted the South Vietnamese to develop some transportation planning capabilities of their own so that they could continue their efforts after American support was reduced. To this end, AID wanted the consultant advisor to concentrate efforts on teaching the South Vietnamese personnel-planning techniques and models by using the evaluation of the 5 alternative plans as a framework for instruction. The Vietnamese personnel assigned to the study by DGRUP consisted of a Saigon University engineering professor, an instructor in computer sciences, and a graduate assistant in engineering, all of whom acted as consultants to DGRUP. The Director General took an active interest in the project as did the Deputy Minister of Public Works; therefore, cooperation from the staff of the ministry was ensured. The facilities of the Office of the Prime Minister Computer Center, including an IBM 360/50 with 512-K memory capacity, were made available for the study even though the computer had been turned over only recently to the South Vietnamese and operating personnel were inexperienced in its use.

The South Vietnamese had done some preliminary work, including a travel survey. Because their experience with both employee and home-interview surveys was unfavorable, they decided to survey school children about the trip-making behavior in households. By making the survey a homework assignment, they were able to collect information from some 80,000 households; they coded and processed the information on a computer. Unfortunately, the sample selection and quality control of the survey were not well designed, and factoring the survey results to represent the entire metropolitan area was not possible. However, the DGRUP consultants were able to derive some trip-length distributions from the survey data, and the distributions were of use in calibrating

Figure 4. Saigon Lambro.

Figure 5. Saigon public bus.

Figure 6. Motor scooter with 5 passengers.

Figure 7. Typical intersection traffic.

traffic-assignment models. The DGRUP consultants also had developed a trip-distribution model that combined aspects of gravity models and opportunity models. Some of the South Vietnamese managers were somewhat skeptical about the DGRUP trip-distribution model. Therefore, they asked DMJM to evaluate the model and attempt to validate the results. This became one of its major tasks. Another major task was to demonstrate the development and coding of transportation networks. DMJM chose 3 kinds of networks as examples: simple spiderwebs, highways, and Lambro routes (as an example of a transit network).

DMJM planned to carry out a traffic assignment of the DGRUP trip tables to the various types of networks and carried out all of the necessary preliminary steps. However, when it came time to run the programs to load the networks, DMJM discovered several program problems that could not be corrected in Saigon; after returning to the United States, DMJM personnel prepared some data-conversion routines to overcome the problems and forwarded the programs and instructions for their use to South Vietnam.

DMJM prepared detailed capital cost estimates for various types of highway construction in South Vietnam and collected public transit system capital cost estimates. DMJM also instructed the South Vietnamese personnel in the analysis of traffic assignment outputs and in the design of transportation-corridor plans to serve demand projections. DMJM also showed the South Vietnamese how to prepare cost estimates from the network outputs. The final task of DMJM was to document all of its program packages, procedures, test results, and an instruction manual on the procedures required for the South Vietnamese to complete their study.

TRANSPORTATION PLANNING ANALYSIS

Validation of Trip-Distribution Model

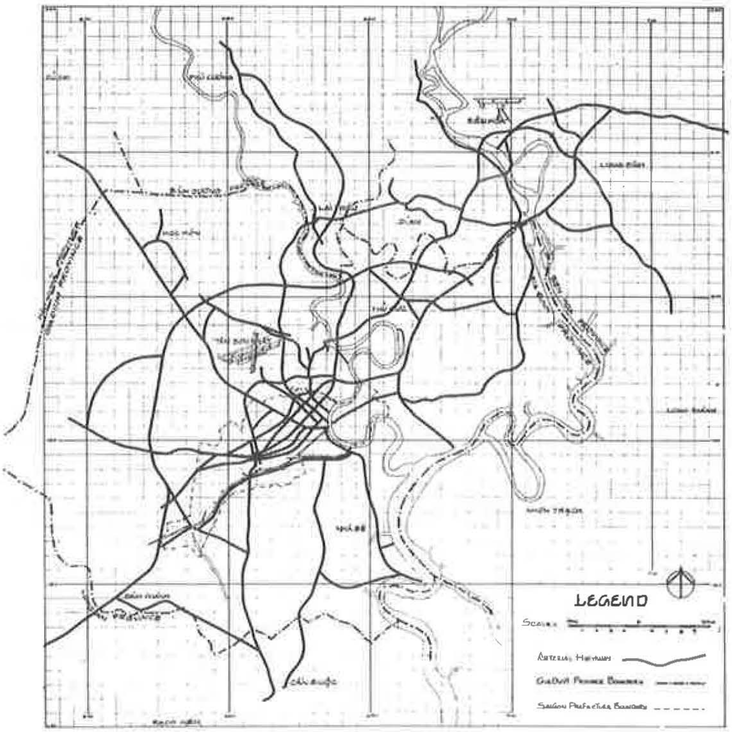
One of the tasks DMJM hoped to accomplish early in the study was a validation of the trip-distribution methodology that had been devised by DGRUP. DMJM eventually accomplished the task, but only after at least 1 false start and only near the end of its participation in the project. The approach of DMJM was to attempt to run a conventional gravity-distribution model on the production and attraction data developed by DGRUP, calibrate the gravity model to the trip-length distribution obtained from the travel survey, and compare the gravity-model outputs with the DGRUP model outputs. The DGRUP trip interchanges had been developed by using the airline distances between zone centroids as impedances; DMJM hoped to use the link distances of spiderweb networks as a better approximation. DMJM therefore prepared spiderweb networks for all 5 land use plans and spent several days coding and editing the spiderwebs. At the same time, DMJM proceeded with its attempts to reformat the DGRUP trip interchanges so that the trips could be loaded onto the spiderweb networks. However, both of these efforts were frustrated when it was discovered that the program that was supposed to be used to load spiderwebs still contained errors and that it was not possible to overcome the program problems.

The next DMJM task was to attempt to run the gravity model on the highway networks that it had coded. After overcoming some minor problems caused by the lack of observed trips of lengths between 0 and 1 km (because the only trips in the DMJM table were interzone trips and minimum zone separation was 1 km), DMJM finally was able to obtain a reasonable match with the observed trip-length distribution. DMJM also was unable to reformat the DGRUP trip tables for successful network loading, and eventually determined that an assembly-language program would have to be written to complete the reformatting.

Preparation of Networks

The highway network DMJM finally used in the model validation and as the basis for all further analysis was an extension of the existing network shown in Figure 8. DMJM

Figure 8. Saigon metropolitan area, existing arterial-highway system.



located centroids for all of the traffic zones and essentially extended existing streets to serve each zone. Networks were completed for plans 2 and 4, including all coding, editing, and computation of shortest zone-to-zone paths. All of the maps and printouts of these networks were turned over to DGRUP together with the instructions on how they were built; DGRUP had to complete the same process for the other 3 alternative plans or any additional combinations.

A second type of network that was prepared and tested to a limited extent was the Lambro network. Although this network could not be used for the analysis, DMJM felt that building it would be a useful exercise to demonstrate the application of the Urban Mass Transportation Administration Transportation Planning System (UTPS) programs to a transit network. Further analysis of transit networks would be desirable, and these programs also might be used to study short-term improvements in the existing bus system.

DMJM chose to use the Lambro system rather than the bus system because, when the project was started in late 1973, accurate information on bus routes was not available. DMJM plotted the Lambro routes on a large-scale map, assigned node numbers, and coded all of the street links as well as the line sequences. DMJM completed editing of the network, computed shortest paths, and even loaded the network with some artificial trip tables derived from gravity-model outputs. The UTPS Network Development Manual presents very complete instructions on preparing transit system networks, and DMJM recommended that such networks be prepared for the existing bus system. The Lambro system did serve to indicate some of the limitations of the planning models. In particular, Lambros in Saigon frequently operated at very close headways (10 to 15 seconds), and they traveled very slowly so that they could stop at the demand of a rider or a prospective passenger. DMJM, for its model, felt that arbitrarily assigning Lambro stops to street intersections was satisfactory, but program limitations would not allow DMJM to simulate the close headways actually experienced in the Lambro system.

Traffic Assignment and Network Analysis

The remaining steps in the planning process were to be carried out by DGRUP by using the procedures and program models provided to them. The procedures and programs were detailed in manuals.

The next step to be completed was traffic assignment. The DGRUP trip interchanges first had to be reformatted by using the conversion program that DMJM forwarded. Then the interchanges could be loaded on the highway network by using a Federal Highway Administration program that automatically accumulated the link usage over shortest interzone paths for all trips in the tables. Other programs could be used to print summaries of the link loads; the planners then should record the loads on the network map.

To analyze the results of traffic assignment, the DGRUP planners would have to work with traffic engineers from the Directorate General of Highways. Information about the design capacities of the links of the highway network, in terms of the vehicle mix and occupancy factors that were experienced in Saigon, would be required. The link volumes from the traffic assignment have to be compared with the capacities, and those links with insufficient capacity have to be identified and flagged. The planners and highway engineers then must determine how to increase capacities to meet excess demands. In some cases, alternate routes might be available, or widening the existing roads to add lanes might be possible. Another means of increasing capacity would be to provide frequent bus service, thereby increasing the vehicle-occupancy factors. When these measures are insufficient, new highways or expressways must be designed, or, when the demand is high enough, a fixed-guideway rapid-transit route must be designed. These new links must be added to the test network, the network must be rebuilt and edited, and the trips must be reassigned. The process continues until a balance is obtained between demand and capacity throughout a network.

The primary objective of the study was to determine the comparative capital costs of transportation system alternatives. The program packages provided a means of doing this. The network building and formatting routines allowed the planner to output the total length of the street and transit systems. The lengths of any additions to the basic system could be computed, and unit construction costs could be applied to develop comparative capital cost estmates. Development of operating cost estimates, however, would have required more data, more detailed analysis, and more resources.

SUGGESTED RESEARCH

Throughout its involvement in this study, DMJM identified areas where additional research was required. The research was needed both for the preliminary analysis and for the comprehensive transportation planning study that would have to be conducted before a new transportation system could be implemented.

Before this study can be completed, information on traffic volumes, capacities, and vehicle occupancies must be compiled. The best way to collect such data is to assign observers to make counts at key points throughout the city including counts of number of vehicles (by type) passing a point during time intervals and counts of the number of passengers in each vehicle. These counts should be taken during peak hours at high-volume locations to obtain a reasonable estimate of street cpacities. A comprehensive travel survey is needed, conducted through home interviews, work interviews, or the schools. The survey should attempt to collect information on both travel behavior of a large sample of Saigon residents and attitudes toward time valuation, mode preferences, and transportation costs. Preferably, the survey and traffic-count operations should be conducted during the same time period so that the traffic observations can be used to calibrate the travel behavior data when they have been processed through trip-generation, trip-distribution, and trip-assignment models.

The new bus system should be carefully studied by observing passenger volumes and boarding and alighting points, determining operating and stop times and speeds, and surveying passengers about their travel patterns. The bus system should be simulated by using some of the programs supplied, and the effects of changes in the operations should be analyzed.

Further socioeconomic analysis on population, employment, income, household size, and travel behavior should be conducted to support more extensive trip-generation analysis. Supporting transportation studies of parking, pedestrian movements, freight traffic, and railroad activity also are needed. South Vietnamese personnel need more training in transportation planning and design; the advisory service provided by foreign consultants and the formal courses of study have some use, but it would be even more useful if selected South Vietnamese personnel could spend time working with public and private transportation agencies in advanced countries.

INTERACTIVE PROGRAMMING SYSTEM FOR TRANSPORTATION PLANNING

Robert B. Cody and Mark S. Goldman, Peat, Marwick, Mitchell and Company; and
Andres G. Zellweger,* Office of Systems Engineering Management,
Federal Aviation Administration

A major need of the transportation planner is for a system for efficiently managing, analyzing, and updating the volumes of detailed data used in multimodal transportation planning. Without fast, inexpensive methods of analyzing data, the planner simply cannot respond quickly enough to local community needs for an adequate range of transportation design alternatives. The Interactive Planning System (IPS), developed as an extension to the Urban Mass Transportation Administration Transportation Planning System (UTPS), has been designed to meet these needs by providing a time-sharing operating system that eventually will make all of the UTPS software tools available to the planner in a convenient, interactive framework. To accomplish this IPS incorporates 3 major capabilities: (a) an ALGOL-like command language for interactive computation, display, editing, data management, and initiation of batch-mode processing; (b) an integrated data base that automatically relates planning data to alternative designs; and (c) a graphics software capability for generating maps, charts, graphs, and perspective drawings. The system will be accessible through a low-cost interactive graphics terminal remotely connected to a time-sharing computer.

•THE URBAN Mass Transportation Administration (UMTA) since early 1972 has been working actively on a program to improve the effectiveness of urban multimodal transportation planning tools. The primary product of the program is a set of improved analytical techniques and computer-based planning tools designed to assist state and local governments in determining needs and evaluating proposals for transit and highway improvements in urban areas of the United States. This set of tools, called the UMTA Transportation Planning System (UTPS), currently consists of a series of batch-oriented programs for use on the IBM 360/370 series of computers. More recently, UMTA has been involved in upgrading the UTPS package to include an interactive data-browsing, data-manipulation, and graphics-display subsystem called the Interactive Planning System (IPS). Its purpose is to make the computer more accesible to transportation planners and analysts. These workers have desperate needs for systems that will help them

1. Manage large masses of planning data;
2. Efficiently examine, analyze, and update data; and
3. Quickly generate graphs, charts, and maps to display the results of planning analyses.

---

*Mr. Zellweger was with the Transportation Systems Center, U.S. Department of Transportation, and on temporary duty with the Office of Transit Planning, Urban Mass Transportation Administration, when this research was performed.

Publication of this paper sponsored by Committee on Transportation Programming, Planning, and Evaluation.

A major need of the transportation planner is for a system for managing the volumes of detailed data used in multimodal transportation planning. Current batch-processing methods place on the planner all the burden of manually organizing the assembly, analysis, processing, and display of these data. For all but the simplest of planning projects, these processes are complex, highly interrelated, and composed of a multitude of discrete steps, many of which must be repeated to correct errors and adjust results. A second major need, which also is not met with batch-processing techniques, is for a system for efficiently examining, analyzing, and updating the data and displaying results. Without fast, inexpensive methods for analyzing data, the planner simply cannot respond quickly enough to local community needs for an adequate range of transportation design alternatives. The planner also needs a versatile technique for creating pictorial representations of data during the planning process. Graphic outputs are necessary to expedite the analysis of data and to aid in the comprehension of results. Cut-and-try techniques frequently are required to develop plots or charts that are suitable for presentation. With batch-processing techniques, this is time consuming and difficult. An interactive technique that can be used to both generate charts and maps and modify them in cut-and-try fashion until they are satisfactory is needed.

The purpose of IPS is to meet these needs. A more detailed description of objectives including data-browsing capability and data-base design, has been given by Dial et al. (1 The development of requirements and design concepts to meet these objectives is based partially on earlier work by Ruiter and Sussman (2) and Gur (3, 4, 5), who developed the INTRANS-BROWSE system for analysis and display of zone land use data. IPS has been designed for use by the trained transportation planner and is intended to be easy to understand and apply by new users without loss of power for more experienced users. IPS should be operable from a variety of terminals [teletypes; direct-view storage-tube (DVST) terminals, such as the Tektronix 4012; and intelligent graphics terminals such as IMLAC] with the same basic protocol. It should be possible to transfer IPS from one computer to another with minimal programming effort and, above all, without effects on the command structure and operational characteristics of the system.

Initially, IPS will be used for interactive manipulation and analysis of input data for UTPS batch runs and for further analysis and graphic display of UTPS program outputs. This method of operation is dictated by the high computer requirements of the current UTPS models and programs. New models, particularly those that apply to sketch planning, that will be more suitable for interactive execution are under development by UMTA. These models will be incorporated directly into the IPS subsystem of UTPS when they are completed.

DESCRIPTION

The capabilities of IPS are shown in its 3 major components:

1. A command language for interactive computation, display, editing, data management, and initiation of batch-mode processing;
2. An integrated data base that automatically relates planning data to alternative designs; and
3. A graphics software capability for generating maps, charts, graphs, and perspective drawings.

With its ability to perform both interactive and batch-mode functions, IPS assumes the role of an operating system or host, making all of the UTPS software tools available to the planner in a convenient, interactive framework. The relationship of the IPS host to the data base, current UTPS models, and future interactive models is shown in Figure 1. The host is supported by a direct-access data base containing land use, trip-matrix, network, picture, command-language procedure, report, and card-image files. Regional land use, matrix, and network data are organized as vectors, are indexed by planning zone or node, and have 1 vector for each attribute. These vectors, in fact, usually are called attributes. Some examples are zone population, node coordinates, and trips from one zone to all other zones. Attributes, pictures, procedures, and reports are called file members; each is directly accessible and subject to well-defined operations. This file organization harmonizes with both interactive and batch-processing requirements. Moreover, it is functionally adapted to the kinds of operations that interest the planner.

The planner is able to access planning data and use IPS through an interactive-graphics terminal remotely connected to a central time-sharing computer by means of a 300 or 1200 Baud full duplex dial-up telephone line. The typical terminal has an American National Standard Code for Information Interchange (ASCII) keyboard and a DVST that saves the display until it receives an erase command. Alternatively, the more versatile refresh-type cathode ray tube (CRT) equippped with a small minicomputer can be used to store the display. In addition, the terminal is equipped with a hard-copy unit and an optional graphics tablet for input of graphics data. The hard-copy equipment permits the user to make immediate photographic copies of the DVST-CRT display.

EXAMPLE

The capabilities of IPS to aid in the transportation systems analysis process is illustrated in the following cases. Of particular interest is the method used by the planner to organize the data. Let us suppose that a transportation planning study is being conducted for an imaginary city called Hometown, U.S.A. The base year is 1973, and dual-mode and express-bus alternatives are being considered for years 1980 and 1985. The planner has assembled base-year data and has made initial estimates of future-year land use and total trip data and is ready to update base-year networks to reflect the desired alternatives. By using the data management capabilities of IPS, the planner already has organized his or her files and labeled them with plan labels as shown in Figure 2. The files associated with plan label hometown contain land use and trip data; those associated with alternative plans hometown·express bus and hometown·dual mode contain mainly network data.

At this point, the planner wishes to study the forecast data further and construct the future-year network alternatives. By using a low-cost interactive-graphics terminal remotely connected to a time-sharing computer, the planner begins an IPS session by typing the command

```
use (hometown.express bus)
```

This tells IPS to use data files accessible under plan label hometown·express bus or, if not available there, under its ancestor plan hometown. For example, attributes in a land use file labeled land use : hometown now will be automatically accessible to the user by merely stating attribute name.

The planner is now ready to begin analysis. First, he or she projects zone-per-person automobile ownership and labels it autos owned by typing the ALGOL-like command

```
autos owned := autos.1980/population.1980
```

The terms autos.1980 and population.1980 are zone attributes (in the data base) that forecast 1980 zone automobile registrations and population respectively. IPS performs this calculation by dividing each element of the autos.1980 attribute by the corresponding element of the population.1980 attribute. The result is saved temporarily in a work space.

Next, the planner plots per-person automobile ownership versus projected income on the CRT screen with the command

plot (income.1980, autos owned)

IPS automatically draws axes to a scale determined by the data, enters the names of the attributes plotted, and draws the plot. In a typical case this takes 10 to 15 sec (most of this time is required to transmit the picture from the computer to the terminal).

The planner finds that the plot fails to compare satisfactorily with a corresponding base-year plot apparently because of 1 or 2 unexpectedly low zone-income figures. To investigate this problem, the planner enters the command

if income.1980 < 1000 then income.1980 else skip

IPS responds by displaying a list, by zone, of average zone incomes less than $1,000/year. The calculation is performed by automatic iteration over each zone of the attribute; elements failing the test are skipped. On examining the display, the planner sees that zones 25 and 26 are incorrect and enters the following corrections by indexing the income attribute:

income.1980[25] := 5250

income.1980[26] := 7300

After repeating the plot and making some further checks, the planner is ready to construct the 1980 express-bus network by using the UTPS batch-mode program UNET. Because the planner wants the new network file to be identified with the 1980 express-bus alternative, he or she names a new plan with the command

create (hometown.express bus.1980)

This supersedes the initial use command but continues to permit access to data labeled hometown·express bus (or hometown). If the planner now updates such data, he or she can reference the updates under the new plan, but the original data still can be referenced by invoking the parent plan. The new plan structure is shown in Figure 3. The planner now issues the command

submit (unet)

Parameters and options required by program UNET will be requested by the use of interactive dialogue by IPS, and then the program will be executed independently at some later time depending on the priority requested by the planner. The output network file will be identified with the label hometown·express bus·1980. This is shown in dotted lines on Figure 3. At this point, the planner may wish to sign off and return later to examine UNET output. However, the results of calculations early in the session are still in the work space. The planner can store all results or only those needed to be used again. For example, the planner can store a land use attribute in the land use file associated with the current plan by typing the command save (autos owned, land use)

and then release the work space by signing off, or the planner can save the work space by the command

save work space

and retrieve it when he or she returns to the terminal. These examples are simple, even prosaic, but they illustrate the potential savings in time, effort, and cost that interactive planning techniques can provide.

BASIC INTERACTIVE PLANNING SYSTEM COMMANDS

Computation and Output

The IPS user performs operations on the data and generates maps and graphs based on the data by typing commands at the terminal. Normally, statements entered at the terminal are executed immediately by the computer. For example, when the user enters

autos owned := autos/population

the computer examines the statement, and, if any errors exist, reports them or, if no errors exist, computes the expression on the right side of the symbol := and assigns the computed value to the variable named on the left side of the symbol but does not display the result. In this example, autos/population is evaluated, and the result is assigned to the variable autos owned. The response time of the computer is sufficient to allow the user to type in statements almost as quickly as he or she desires. The set of operations available to the IPS user for constructing expressions are the basic arithmetic operations of addition, subtraction, multiplication, division, and exponentiation; comparison operations; and a set of functions to compute dot products, square roots, logarithms, and trigonometric functions; and Boolean operations such as AND, OR, and NOT. Table 1 gives a list of these operations (and others to be described). The IPS command in the previous example has the form of an assignment statement:

variable := expression

However, the user may enter a statement consisting of only an expression [such as 5*sqrt (27)or autos*2.7]. The computer will evaluate the expression and display the result, which may be a scalar or a vector (attribute) depending on the terms in the expression. This feature permits the user to exercise IPS as a powerful desk-top calculator.

The ability to implicity perform operations on all elements of an attribute is of significant help to the planner using IPS. Of course, operating on selected elements of an attribute by providing a list of indexes also is possible. Thus the statement

a [5, 10-20, 30-last] := 100

would assign the value 100 to the fifth, tenth through twentieth, and thirtieth through

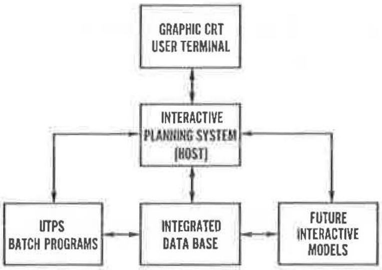


Figure 1. Relationship of Interactive Planning System to data base and models.

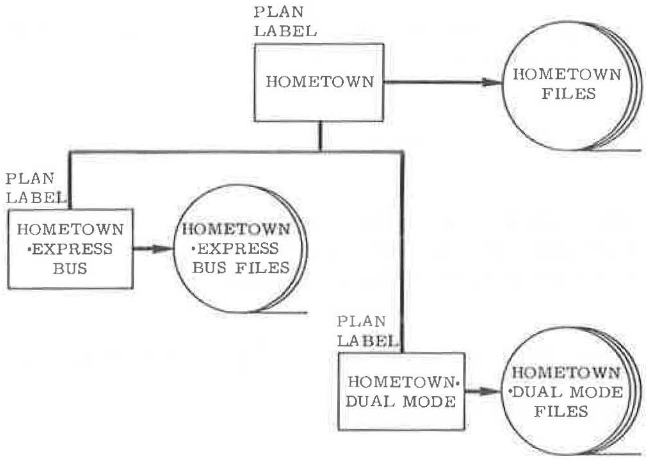


Figure 2. Plan structure for base-year network.

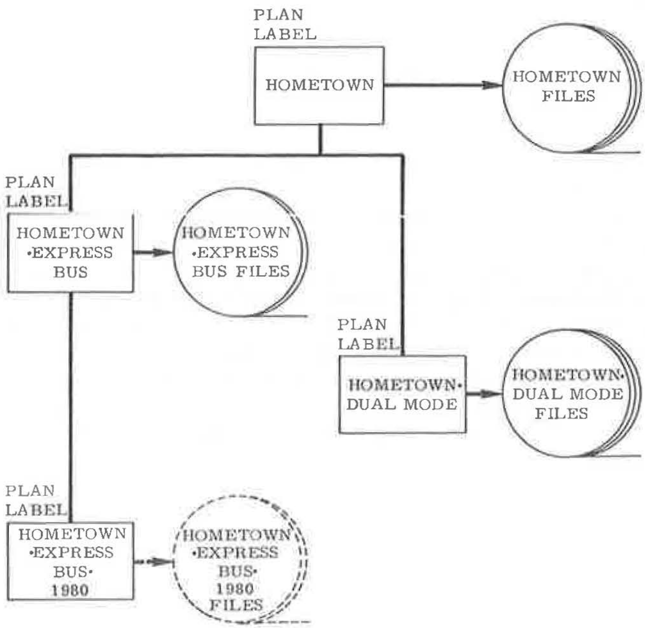


Figure 3. Addition of 1980 express-bus plan.

Table 1. Type-specific operations on file members.

File Member	Operation	Operator
Attribute	Arithmetic	+, -, *, /, **
	Comparison	<, >, =, <=, >=, NOT<, NOT>, NOT=
	Vector	Dot Product
	Logical	AND, OR, NOT, NAND, NOR, XOR, IMP, EQU
Picture	Transformations	TRANSLATE, SCALE
	Display	DISPLAY
Procedure	Editing	Insert, delete, replace, and the like
Reports and card-image sets	None	None (initially, standard editors will be used)

last element of the attribute a.

An assignment statement or expression may be executed conditionally by enclosing it in an IF ... THEN ... ELSE construct. For example, in the command

```
if a < b then x := y else x := z
```

if the comparison a < b is true, then the assignment x := y is executed; otherwise, the assignment x := z is executed. If these variables are attributes, then the statement is executed iteratively and the result x may contain elements from both y and z.

Names and Variables

A name in IPS can stand for integer, real, string, or logical variables, or it can stand for a procedure, picture, or report. Variables are single elements, such as scalars, or 1-dimensional arrays, such as attributes. All elements of an attribute must be of the same type. Integer, real, and logical variables are the familiar types used in FORTRAN or ALGOL. A string variable contains a string of up to 256 characters. These may be any combination of letters, digits, or special characters.

Matrices (such as trip and fare matrices) exist in the data base, but, in IPS, they are dealt with a row or column at a time. Thus the command

```
trips from zone.5 := matrix (trip table, 5)
```

would define the attribute trips from zone.5 as the fifth row of a matrix called trip table. (Note that variable names can consist of more than 1 word.)

In keeping with a user-oriented philosophy, no restrictions exist on the use of names for variables and procedures as they do in FORTRAN. More significantly, the IPS user is not required to declare the type or length of the variable. These are attributes of the data rather than of the name of the variable. Thus in the statement

```
a := b+5
```

the type and length of the evaluated expression b+5 will be associated with a after execution of the statement. If b was a real vector of 10 elements, then the command would make a a vector of 10 real elements, each of which is 5 greater than the corresponding element in b.

Procedures

As the planner becomes familiar with IPS, he or she undoubtedly will develop his or her own repertoire of operations for data manipulation and display. To save the planner the tedious task of entering the same set of statements each time he or she looks at a new set of data, IPS permits the planner to construct procedures with a simple editor. A procedure is a named set of statements that can be executed simply by entering the name of the procedure. It can change specified variables in the manner of a FORTRAN subroutine, or it can return a value in the manner of a FORTRAN function. Consider the following example:

```
procedure compare incomes (factor)
    erase
    plot (zones, income)
    new income := factor * income
    plot dashed line (zones, new income)
```

Executing this procedure [by entering compare incomes (factor)] will cause erasure of the CRT, drawing of an appropriate set of axes, drawing of a solid-line curve of incomes for a set of zones, computation of a new set of incomes based on a predictive factor f (this factor could be a single variable or a vector with a different value for each zone), and addition to the display of a dashed line showing the new incomes for each zone. In this example, plot and plot dashed line are part of the repertoire of built-in procedures included with IPS. A user procedure can reference other user procedures as well as IPS procedures. Recursive procedures also are permitted. The example shows another important characteristic of procedures, namely, that they can be made data independent. This means that the previously mentioned procedure operates on the currently defined attribute income by using whatever argument is passed to the procedure as the multiplicative factor.

IPS procedures can contain conditional statements and commands for explicit iteration. These take 3 forms.

1. IF (Boolean expression) THEN (set of satements);
2. IF (Boolean expression) THEN (set of statements) ELSE (set of statements); and
3. WHILE (Boolean expression) DO (set of statements).

Observe that, in a procedure, a THEN or ELSE clause can be followed by a set of dependent statements and is not limited to a single statement as described previously for directly executable commands. In the WHILE ... DO construct, the DO clause is executed repeatedly while the Boolean expression is true. The DO clause, of course, must change the value of 1 or more of the variables in the WHILE clause or execution of the procedure will continue indefinitely. The dependent statements of a conditional or iterative statement themselves can be conditional or iterative statements; that is, the statements can be nested.

IPS syntax depends on differences in indentation to identify the beginning and end of each set of statements in the previous 3 constructs. Thus IPS procedures have an ALGOL-like block structure without requiring the use of ALGOL begin and end brackets. This makes for readable text.

A simple yet powerful editor is provided for entering, testing, and correcting procedures. Its operation is analogous to that provided in advanced time-sharing operating systems.

GRAPHICS

The primary aims of the IPS graphics capability are to provide graphs, charts, and maps that will aid the planner in quickly comprehending data and making the trade-off analyses and judgments required in developing alternative multimodal transportation plans. The long-range aim is to build up a repertoire of graphics tools that will lead to substantially improved transportation planning methods. In addition to generating standard plots and maps on CRT screens, pen plotters, and computer-output microfilm (COM) devices, it is intended to provide a general-purpose language for constructing graphic objects that can be displayed in perspective and to include software tools for development of interactive-graphics techniques. These techniques can be used not only to expedite and improve the generation of graphic outputs but also to open the door to a whole new class of person-machine problem-solving methods that has potential for substantial time and cost savings, greater flexibility, and improvements in quality over existing methods. Work already has been started in applying such techniques (6, 7, 8) and in measuring their effectiveness (9) in transportation systems analysis. As has been shown, no shortage of potential transportation planning applications for interactive-graphics techniques exists (10).

Currently, 3 basic capabilities are included in the initial IPS graphics package, including ability to

1. Generate standard plots and maps,
2. Construct "wire-frame" graphic objects in 3 dimensions and display them in perspective, and
3. Save CRT screen displays in the IPS data base.

The standard plots will include x-y plots, regression line plots, frequency distributions (histograms), pie charts, land use maps, and network plots. These will be implemented so that a simple command such as plot regression (income, auto ownership) will generate a graph with standardized axes the scaling of which is computed automatically from the data. Thus each graph or chart will have a standardized form based on the use of default parameters to permit generation with the simplest possible command. The standard forms can be changed by the use of specification commands that tailor graphs or charts to individual requirements. Commands will be provided to plot zone land use maps by using zone-centroid coordinate and boundary information stored in the data base. The user is planned to be permitted to input boundary information by tracing zone outlines with a graphics tablet and stylus. Techniques for displaying attributes of each zone include display of numerical values, symbols whose sizes are proportional to the numerical values, and zone shading to depict density. This includes symbol-shading techniques (3) and CALFORM line-shading techniques (11).

A general-purpose graphics capability (12, 13, 14) will be provided to permit the planner to create arbitrary 2- or 3-dimensional displays, subject to translation, scaling, rotation, and projective and perspective transformations. The basic tools for constructing these displays will be a set of graphic primitives for drawing lines and points and providing annotations. Defining command language procedures that build up graphic objects from primitives and other previously prepared procedures will be possible. This, of course, will permit the planner to increase the sophistication of standard displays and will also allow him or her to develop displays of actual structures.

To increase user flexibility, building up a display in increments will be possible. Drawing commands transmitted to the display device are recorded in a temporary file called a transformed display file. The user can define a segment of this file by issuing a PICTURE command. This segment, or picture, will include all pieces of the display drawn since the last PICTURE command or since the display was started if no PICTURE command has been given previously. These pictures are most useful in a refresh-type display because the display can be varied readily by turning on or turning off the individual pictures that make up the display. When the user is satisfied, he or she can take a "snapshot" of the display by giving a SAVEPIC command. This collects and combines all the turned-on segments of the display file into a single picture and saves it in the data base. Then the user can issue a CLEAR command to erase the screen and the display file and begin constructing another display or issue a DISPLAY command to retrieve the saved picture and redisplay it on the CRT screen or another device such as a plotter. An additional feature is that any defined picture can be translated and scaled for inclusion as part of another display.

FILE SYSTEM (INTEGRATED DATA BASE)

The IPS file system includes separate files for each of the 6 basic types of file data: land use attributes, matrices, network attributes, pictures, command-language procedures, and text matter including reports and card-image data. To file members of each of these types, the planner may assign descriptive names, such as population, link volumes, or corridor zone map. The range of operations to which file members are subject has been given in Table 1. File members also are subject to LIST and DELETE utility operations. Retrieval of a file member occurs automatically on reference to its name. Retrieval is facilitated by a master directory file that contains the name of each file, a list of its members, and pointers to each member. The directory file also keeps track of backup copies of file members that are saved when a file member is corrected or deleted.

A novel feature of the directory file is its ability to let the planner organize data under labeled planning alternatives. The asumption is that the process of creating and evaluating alternative transportation plans can be represented effectively as a tree-structured modeling process in which plans and subplans are developed at ever-increasing levels of detail and specificity. Although the plan structure illustrated in the example described previously was quite simple, the planner is free to develop more elaborate structures in accordance with the complexity of his or her transportation planning problem.

The planner generates a plan structure by using the CREATE command. When this command is invoked, it generates and activates a new plan that becomes a successor of the plan that was active before the CREATE command. A previously created plan can be reactivated by means of a USE command.

Data files developed or modified when a plan is active are said to belong to that plan and can be accessed whenever the plan is active without specifying the plan label. If an old file generated under a predecessor plan has 1 or more of its file members modified, then new members are created to reflect the modifications. The new members are identified under the new plan, but the corresponding old members are still identified and accessible under the old plan. Unchanged members are accessible under either plan. This is so because the system automatically creates a new logical file that physically contains the modified members but has only pointers to the unchanged members. The old file could itself be a similar logical file or could, in fact, be the original file. The planner can always reference it by using an appropriate USE command identifying its plan label. Utility commands are provided to list the structure of plans and logical files created by the planner.

We have described the internal world of the integrated data base, but we must still provide for communication with the outside world. That is, to readily add outside files to the IDB or to copy internal files onto external media, such as a magnetic tape, must be possible. This is accomplished with INPUT and OUTPUT commands that transfer either complete files or specific file members from one world to the other. However, binary external files that do not conform to UTPS formats cannot meaningfully be transferred into the integrated data base (IDB). These must first be processed either through standard UTPS conversion routines or by means of user-coded routines.

STATUS OF INTERACTIVE PLANNING SYSTEM

The overall functional specification of IPS has been completed (15). Currently, 2 parallel efforts are under way in preparation for IPS implementation. First, a skeletal subsystem of IPS is being identified for initial implementation. The objective is to give planners a system that can be used to perform basic mathematical operations, can support simple user defined procedures, can interface with a direct-access data base, and allows the generation of basic plots and simple 2-dimensional wire-frame drawings. The more esoteric features described in the functional specification are anticipated to be added to the skeletal system incrementally. The second effort is implementation of the graphics package to be used for IPS on a PDP-10 computer. The package selected for IPS is the graphics compatibility system (GCS), a terminal- and computer-independent system developed at the U.S. Military Academy (16). GCS initially will support several of the more common alphanumerical terminals, the Tektronix 4010 series of direct-view storage-tube terminals, and the IMLAC PDS-1 intelligent graphics terminal.

The interactive portion, particularly the command language of IPS as currently defined, is intended primarily for use with a direct-view storage-tube terminal. As a continuation of the functional specification, a trade-off study is being performed to determine how user interaction might be improved through some of the more dynamic techniques of a low-cost, intelligent, refresh-type terminal (such as IMLAC). The possibility of having the intelligent terminal share some of the computational workload with the central processor for both improved response and reduced cost of operation also is being investigated.

The initial version of IPS is expected to be available for field testing early in 1976. The results and experience will aid in determining priorities for further development and improvement of IPS and for development of instruction courses. The field-testing program also will provide information for determining benefits and costs of using IPS in transportation planning studies of varying size and scope.

SUMMARY

IPS is a new transportation planning tool that combines powerful computational and graphic capabilities. It will provide a framework within which the planner can efficiently examine and analyze land use and other transportation-related data, execute batch-processing models, and study results.

Although IPS command language syntax is similar to ALGOL, the interactive features are more comparable to those of APL. IPS has been designed with ease of use by the transportation planner (rather than the experienced computer programmer) foremost in mind. The command structure, the user-defined procedures, the data-retrieval mechanisms, and the graphics operations were tailored to free the user from unnecessary and cumbersome details through carefully designed default options and considerable built-in intelligence on the part of IPS. IPS provides the novice user with a minimal set of simple and easily learned commands that allow data browsing and analysis to generate meaningful results. At the same time, IPS has the power and flexibility needed by the experienced user to tailor the system and its outputs to his or her particular requirements.

IPS will interface with a structured, plan-oriented data base. This data base in turn will provide input to and receive output from the currently existing UTPS battery of transportation planning and analysis programs.

The IPS system obviously is not ideal because it does not provide for interactive execution of planning models. Unfortunately, existing models for transportation planning require large amounts of processing time and thus do not lend themselves to an interactive mode of operation. There has been recent interest in developing new planning models, particularly in the long-range (sketch-planning) area, that use smaller sets of input data and require less computation. As these models become available, interactive versions will be incorporated into IPS. This will lead to a fuller realization of the potential benefits of an interactive planning system. Decision makers will be able to ask a planner questions, and the planner, through use of IPS, will be able to respond quickly enough in a format understandable by the decision maker to favorably affect the decision-making process.

ACKNOWLEDGMENT

We wish to express our appreciation to Robert B. Dial, Director, Planning Methodology and Technical Support Division, Office of Transit Planning, Urban Mass Transportation Administration, for his consultation and support in preparing this paper.

REFERENCES

1. R. B. Dial, P. S. Loubal, E. L. Luther, and G. J. H. Brown. A Procedure for Long Range Transportation (Sketch) Planning. International Conference on Transportation Research, Bruges, Belgium, June 18-21, 1973.

2. E. R. Ruiter and J. M. Sussman. Interactive Computer Graphics for Transportation Analysis: Cost Effectiveness and Initial System Design. Massachusetts Institute of Technology, Rept. 71-46, Dec. 1971, 82 pp.
3. Y. Gur. A Computer System for Interactive Analysis and Planning of Urban and Transportation Systems. College of Engineering, Univ. of Illinois at Chicago Circle, Technical Rept. 1, May 1972, 46 pp.
4. Y. Gur. INTRANS-BROWZE Version 1-2, Interactive User Manual. College of Engineering, Univ. of Illinois at Chicago Circle, Technical Rept. 2, Jan. 1973.
5. Y. Gur. INTRANS and BROWSE, An Interactive Graphics System for Planning and Related Data Analysis. Highway Research Record 455, 1973, pp. 23-35.
6. M. H. Rapp. Planing Demand-Adaptive Urban Public Transportation Systems: The Man Computer Interactive Graphic Approach. Urban Transportation Program, Univ. of Washington, Research Rept. 71-4, 1972, 203 pp.
7. M. H. Rapp. Interactive Editing of Transportation Networks. Urban Transportation Program, Univ. of Washington, Research Rept. 4, 1970, 35 pp.
8. Interactive Graphic Transit Design System User's Manual. In UMTA New Systems Requirements Analysis Program, Peat, Marwick, Mitchell and Co., Rept. URD. PMM. 73. 1. 1, March 26, 1973.
9. J. B. Schneider and D. L. Porter. Assessing the Utility of a Interactive Graphic Computing System: A Case Study of a Transportation Systems Design Problem. Urban Transportation Program, Univ. of Washington, Research Rept. 73-2 (UMTA-URT-3-73-2), 1973, 17 pp.
10. J. B. Schneider. Interactive Graphics in Transportation Systems Planning and Design. Proc. of seminar at Battelle Seattle Research Center, Oct. 31-Nov. 1, 1973, Departments of Urban Planning and Civil Engineering, Univ. of Washington, 95 pp.
11. Laboratory for Computer Graphics and Spatial Analysis. Graduate School of Design, Harvard Univ., program description and availability memorandum for CALFORM, July 1972, 6 pp.
12. W. M. Newman and R. F. Sproull. Principles of Interactive Computer Graphics. McGraw-Hill Book Co., 1973, 607 pp.
13. W. M. Newman and R. F. Sproull. An Approach to Graphics System Design. Proc., Institute of Electrical and Electronics Engineers, New York, Vol. 62, No. 4, April 1974, pp. 471-483.
14. W. M. Newman. Display Procedures. Communications of ACM, Vol. 14, No. 10, Oct. 1971, pp. 651-660.
15. Functional Specifications for an Interactive Planning System. Peat, Marwick, Mitchell and Co.
16. Graphic Compatibility System (GCS) Programmer's Reference Manual. Instruction Support Division, U.S. Military Academy, Rept. 74-2, April 1974.

GOAL-PROGRAMMING APPROACH TO ASSESSING URBAN TRANSIT SYSTEMS

Jason C. Yu, Transportation Research Center, University of Utah; and
Richard C. Hawthorne, Northern Virginia Transportation Commission, Arlington

Transportation systems often are evaluated to see whether they satisfy a variety of community goals. Of primary concern in this study is the development of a procedure for using the goal-programming technique, a modification and extension of linear programming, to evaluate urban transit systems for meeting the transportation-related goals of a community. These goals are intended to be general enough to permit adaptation of the goal-programming technique for the solution of a wide variety of urban problems. First, constraints are formulated from the inputs from a community; then the output variables are chosen to correlate with basic characteristics of urban transit systems to select a system or group of systems to fulfill the community transportation requirements. A computer program is employed to ease application of the goal programming and allow flexibility for a complex set of equations. A set of sample community goals are assumed to illustrate how the technique is practical in actual applications.

•DURING this century, the population of the nation's urban areas has grown enormously, and all indications are that these trends will continue. Because of the extreme orientation to the use of automobiles for transportation, a series of problems have become increasingly prevalent. Congestion of urban streets and freeways, especially at times of peak travel, increases travel times, and accident rates soar. Air and noise pollution has reached hazardous levels. Attempts to build new highways to deal with increasing traffic have met with resistance because of their disruptive effects on the community and because new highways are "self-defeating" in that they cause more trips to be generated. Because of these and many other problems, the basic goals of the American people are changing and environmental and social considerations are being valued more highly than rapid automobile travel within the urban area. Therefore, many communities are considering the feasibility of public transit systems to meet current and projected transportation needs.

Determining which system is best for a given area is a difficult problem. A wide variety of technologies are available, from moving walkways to large rail rapid transit systems, each of which meets the needs of certain situations. Work previously done in this field centered on discussing the many criteria that should be considered when transportation systems are evaluated. The cost-effectiveness technique, in particular, has been the subject of many previous studies; this technique generally incorporates the social, environmental, economic, and performance objectives of a transportation system. Recent studies by Ellis (7) and Ward (30) are good examples of analyses of these aspects. The latter is perhaps one of the most important developments because of its in-depth look at the wide range of these factors. The shortcoming of many of these studies is that they consider the total view of things that should be evaluated but often give no measurable criteria to determine how the desirable objectives could be used to decide among technologies.

Publication of this paper sponsored by Committee on Transportation Programming, Planning, and Evaluation.

Other studies have developed techniques for evaluating alternative systems. However, many of these studies have offered solutions in very general terms (such as circulation and line-haul) and described the type of urban setting in which a system might be useful, but they have given little systematic basis for selection. Meyer, Kain, and Wohl (18) attempted to evaluate automobile, bus, and rail travel by reducing all 3 methods to common performance factors and by using a dollar-based evaluation. On a theoretical basis, the concept certainly provides interesting considerations of the effects of various urban actions on transportation and vice versa. However, this procedure is quite complicated and contains a wide variety of assumptions about interest rates, costs, and the like that hinder its practicality. Hoel (13) evaluated city-center distribution systems by using a model that determines total travel time and gives different weights to walking, waiting, and movement times. He noted that determining the values to place on these different aspects was difficult and subjective at best. Perhaps the values would even be dynamic and change with types of trips.

These previously mentioned studies are indicative of the types of solutions offered concerning the problem of system selection. However, there are currently no effective methods for assessing system candidates and initially choosing a system. Therefore, there is an urgent need to develop an evaluation technique for initially determining the group of urban public transit systems that would be most capable of providing the basic transportation needs of a community. Such a technique can be adapted to public transit assessment without having to resort to reducing all values to a common denominator such as dollars. It also can serve as a device to choose a small number from among many alternatives for more detailed examination.

STUDY OBJECTIVES

The basic objective of this study was to develop an evaluation technique by which an urban area can input the values and priorities of its transportation goals into an analytical process and, with the output, can identify a group of transit systems that will satisfy these goals to a reasonable extent. Because the transportation system must satisfy a variety of community goals, the candidate systems must be assessed to decide which best fits the range of these goals.

The goal-programming technique, a modification and extension of linear programming, allows a simultaneous solution of a series of complex objectives rather than a single objective. This study was intended to show that such a technique is usable for evaluating transportation systems by means of a series of ranked subgoals. This study also attempted to develop criteria so that the characteristics of various urban transportation systems can be correlated with the output of the goal-programming application. For illustrative purposes, the solution technique then was tested through application to an example urban transportation problem.

METHOD OF APPROACH

In deciding on an approach to urban transit assessment, one must develop a technique that has a variety of characteristics. First, analysis rather than description is desirable to give a quantitative basis for comparing the actual values of a particular urban area with available systems. Second, the procedure should be flexible to permit the inclusion of a variety of goals. Finally, it should be computer adaptable to allow use of a complex set of equations if the need arises in a particular situation or procedure development warrants their use. The goal-programming technique, which was developed primarily as a management tool, has obvious advantages for application to the urban transportation assessment problem. The most important advantage is its great flexibility in accepting a wide variety of constraints. Government groups, decision makers, or planners in the urban area may have difficulty in quantifying their exact transportation needs and may have only approximate values and priorities. These problems can be resolved by goal programming even though the multiple goals in some ways may be conflicting. The technique can be applied to satisfy the goals to the extent possible based on the priority assigned them. Moreover, it will give exact solutions with values to the identifiable variables that can be correlated with candidate-system characteristics. Because the nature of this solution technique seems to fit the requirements of transportation planning so well, the possibility of adapting it to technological system evaluation was explored in this study.

The theory and application of this technique are well documented in a recent book by Lee (16). Basically, the goal-programming method is a form of linear programming that allows the simultaneous solution of a system of subgoals rather than a single objective function. Goal programming, instead of directly maximizing or minimizing the objective function, minimizes deviation between goals and what can be achieved within the given set of constraints. The deviation of the variables of the subgoals from the constraints is represented in the objective function usually with a positive or negative deviation or both positive and negative deviations from each constraint. Then the objective function becomes the minimization of these deviations based on the relative importance or priority assigned to them.

In keeping with the objective of the study, we first formulated the constraint equations in order to accept inputs about the community that could be reasonably expected to be available or decided on by the transportation decision-making groups. The variables, whose values would be the output of the program, were chosen to correlate with available information on public transit systems and to be extensive enough to describe a system or group of systems sufficiently to identify them from among others.

The original intention of the study was to include variables dealing with social and environmental as well as performance and economic factors. Close study revealed that the social and environmental effects of a system are primarily a function of right-of-way (ROW) routing and type of propulsion respectively. The propulsion system, which affects the level of noise and air pollution produced, often can be changed or chosen to meet the needs of the community if the normal one is unacceptable. In other words, many systems can use a variety of propulsion methods, such as electrical pickups, diesel engines, or electric storage batteries, and give approximately the same performance. Systems based on electrical motors are particularly pollution free if emissions at the power-generating plant are kept to acceptable levels; almost all technologies use or can be adapted to use this type of propulsion. Therefore, in most cases, the propulsion systems will be acceptable, or systems can be adapted to meet community environmental standards.

In a similar way, the guideway routing of the system is a major factor in determining the type and extent of community disruption. If the system uses an existing ROW (public buses on existing streets), problems are minimal. If the system requires a separate ROW, or performs better with one, then problems multiply. However, the solution revolves around careful choice of the route of the ROW and expeditious use of elevated, grade-level, and underground sections that best fit each situation. Consequently, this problem can best be solved through proper routing after a system is chosen rather than during the choosing process. Because judgments and variations made after the system is chosen have a large influence on social and environmental factors, we decided to concentrate on the requirements of transportation-performance-related subgoals and tried to choose a group of systems on this basis. The impact of the system on socioeconomic development and environmental compatibility then could be investigated on the basis of available types of propulsion and alternative ROW routing. This procedure appears to integrate well with the environmental impact statement (EIS) for an area if any large-scale transportation improvement is to be considered. The EIS requires an evaluation of all other alternatives to the proposal, which is a rather broad requirement. It would be a reasonable argument that the systems eliminated from evaluation by the goal-programming procedure do not satisfy the transportation needs of the area and therefore are not usable alternatives regardless of their environmental compatibility.

SYSTEM PERFORMANCE REQUIREMENTS

Extensive studies of the characteristics of current and planned urban transportation systems have been made. These studies, by their nature, have several weaknesses. For example, the Chilton study (5) and the Handman et al. study (9) suffered from a lack of available information on proposed systems and from the difficulty of deciding what information about the systems to include, both of which are typical problems. Furthermore, because developmental work is in progress on many of the proposed (and even operational) systems and because of accompanying concept and performance changes, the data often have been outdated. However, these studies do serve as a good source for determining the range of performance of groups of systems and, no doubt, have been very helpful to urban planners in view of the lack of a procedure for other means of initial assessment.

In this study, the transportation systems available for urban applications were subdivided into 5 basic groups, and performance characteristics were listed as representative of each group. Because many of the systems are still in prototype stages (especially moving walkways, personal vehicles, and jitneys), the characteristics often were based on sketchy data. However, as the systems are refined and more data become available, the figures can be updated easily and the number of groups can be increased to give greater selectivity.

Input Constraints

As noted before, only the system performance characteristics are included in this analysis. Input by the community, in the form of equation constraints for a goal program, was chosen to represent the important characteristics of a system to the traveler and the overall transportation needs of the area.

System Speed, Waiting Time, and Total Perceived Travel Time

Many studies have shown that total travel time, which consists of waiting time, line-haul time, and terminal access time, is perhaps the most important determinant of modal choice. Waiting time usually is seen as more critical than other time elements. We felt that, from the size and layout of the community and previous studies of acceptable performance levels, transportation planners could specify desired values of system speed for the normal or average trip (converted to time by using average trip length), average acceptable waiting times for a vehicle, and total perceived travel time for the average user.

System Extensiveness

To provide an input concerning the access time to and from stations, an extensiveness variable, defined here as the average desirable walking time to a terminal, should be included. This access time will be a function of terminal density, in terms of the area served by each station. One method of determining this average desirable time would be to identify the generators where stations are desirable and, by using half the average distance between them, calculate the average time after assuming a given walking speed. This extensiveness concept is equivalent to system accessibility because it determines how fully the urban area will be covered by the system and, therefore, how accessible it will be to individual origins and destinations.

System Capacity

The input most important to the planners on a community basis is probably system capacity, or the number of passengers the system can transport in a given period. This is especially important in commuter-oriented situations where peak-hour flows are high. An overcrowded system results in long passenger waiting times, which are undesirable to users. Therefore, the system must be sufficient to meet demands with acceptable delay times, and an input dealing with peak-hour capacity is included.

Acceptable Fare Level

Another input important to both individuals and the community is acceptable fare level, or the charge above which the system probably would not be attractive to a sufficient number of customers. It is also critical to the community because costs above the acceptable level must be made up by the community to maintain service. The input level may even include some subsidy amount if it will be available.

Output Variables

After the community-constraint inputs have been determined, linear equations linking them with system characteristics as variables must be formulated. These variables should be as precise as possible to specify a given group of systems but should be general enough so that data on the variables can be obtained from reliable sources. The availability of information proved to be a problem because many of the beltway, jitney, and personal vehicle systems are prototypes or merely advanced concepts, and performance information concerning aspects such as cost is quite difficult to find.

System Costs

The system-cost constraint correlates directly with the variable. It is made up of capital and operating costs exclusive of ROW costs. The acceptable fare level is a direct function of the anticipated system cost and differs only by deviation variables.

Average Headway, Travel Time, and Terminal-Access Time

Travel time is a function of average system speeds, and the average trip length must be converted to travel speed for system comparisons. Waiting time can be seen as a function of the headway between vehicles. Obviously, if it is a demand-responsive, delays will be minimal, and, for a continually available system, delays might be only a few seconds. Similarly, system extensiveness can be correlated with a terminal-access time that is calculated by using the average station spacing and an assumed walking speed. These 3 variables also are used in the equation for the total perceived travel time, which is a function of walking, waiting, and line-haul, or riding, time. Studies have shown that users value or judge these times differently, and they should be weighted differently when a total perceived time is calculated.

Vehicle Size

System capacity is a function of both vehicle size and service frequency in a time period. Because knowing system vehicle size is desirable, vehicle spacing is taken as the average maximum waiting time, or the maximum time the user would have to wait with average vehicle spacing. By means of this time between vehicles, minimum system capacity would be found by using a vehicle of specified size. The function is formulated by using the vehicle size as the variable multiplied by 3,600 divided by average maximum waiting time in seconds to convert it to passengers per hour.

The subgoal equations for the goal-programming techniques therefore will be made up of the following constraints (inputs) and variables (outputs):

Constraint	Variable
Acceptable fare level	System costs
Average maximum waiting time for a vehicle	Average headways
System speeds	Average travel time
System extensiveness	Terminal access time
System capacity	Vehicle size
Total perceived travel time	Headway, travel speed, and terminal access time

These characteristics would serve to define quite clearly a group of systems with comparable performance. They also fit the previously specified requirements concerning reasonable availability of data.

MODEL FORMULATION

By using the constraints and variables determined previously, one can formulate the goal-programming model. More specifically, the model is developed by determining the allowable deviations and writing the "objective" equation.

Constraint Equations

A more extensive discussion of the use of goal programming and formulation of the equations can be found in the book by Lee (16). Basically, the constraints are set up in an equality format, with the d_x indicating positive (d^+) and negative (d^-) deviation from the constraint value. For the constraints where only 1 direction of deviation is allowable, only that deviation variable is included. The constraint or subgoal equations, then, are as follows:

$$A_2X_2 + A_3X_3 + A_4X_4 + d_1^- - d_1^+ = PTT \qquad (1)$$

$$X_1 \leq AF \qquad X_1 + d_2^- - d_2^+ = AF \qquad (2)$$

$$X_2 \leq WT \qquad X_2 - d_3^+ + d_3^- = WT \qquad (3)$$

$$X_3 \leq AT/SS \qquad X_3 + d_4^- - d_4^+ = AT/SS \qquad (4)$$

$$X_4 \leq EXT \qquad X_4 + d_5^- - d_5^+ = EXT \qquad (5)$$

$$A_1X_5 \geq CAP \qquad A_1X_5 - d_6^+ = CAP \qquad (6)$$

where

A_2, A_3, A_4 = weighting constants,

X_2 = headway,
X_3 = travel time,
X_4 = terminal access time,
PTT = perceived travel time,
X_1 = system costs,
AF = acceptable fare,
WT = average maximum waiting time,
AT = average trip length,
SS = system speed,
EXT = extensiveness,
A_1 = 3,600/average maximum waiting time,
X_5 = vehicle size, and
CAP = peak-hour capacity.

The constants in equation 1 are not specified, but are left for the transportation planners in the urban area to determine. The constants will reflect the weight placed by a particular area on each component of the total time. Studies have shown that waiting time generally is valued about 2.5 times more than riding time and that walking time generally is valued about 2.0 times more than riding time (11). However, these values do differ among studies, and other values can be chosen. It also should be noted that consideration of the constraint equations will show that capacity allows deviation in 1 direction only. In other words, the system capacity must be equal to or greater than the demand. The other 5 variables can vary up or down around the input value, although there is a desirable deviation direction in each case. An exception might be extensiveness if the acceptable absolute maximum walking time were used. If so, the equation could be adjusted accordingly by deleting the d^+ deviation from the constraint equation.

Objective Function

After the constraint equations are derived, the objective equation then is formulated to minimize the deviation variables. Priorities are assigned to each variable in the objective equation, and the program attempts to obtain the minimization of the subgoals with the highest priorities first. The priorities are assigned by the community in the manner desired. Here, the priorities are assumed to be in the order given below. The objective function is written to emphasize the direction of the desirable deviation in each case, and the basic equation becomes

$$\text{Min } Z = P_1d_1^- + P_2d_2^- + P_3d_3^- + P_4d_4^- + P_5d_5^- + P_6d_6^+ \quad (7)$$

$$A_2X_2 + A_3X_3 + A_4X_4 + d_1^- - d_1^+ = PTT \quad (8)$$

$$X_1 + d_2^- - d_2^+ = AF \quad (9)$$

$$X_2 - d_3^+ + d_3^- = WT \quad (10)$$

$$X_3 + d_4^- - d_4^+ = AT/SS \quad (11)$$

$$X_4 + d_5^- - d_5^+ = EXT \quad (12)$$

$$A_1X_6 - d_6^+ = CAP \quad (13)$$

All values of X and d are equal to or greater than 0.

Solution Program

With this format, the goal program can be solved through a variety of methods, including graphic and simplex techniques. A computer program also was developed by Lee (16) for a wide variety of goal-programming applications, and this is used in the example application.

The priorities shown in the objective function deserve more discussion. By using the priorities, one considers the low-order goals only after higher order goals are achieved as desired. Therefore, the transportation planners must discuss the goals, decide which are most important for the community concerned, and order them accordingly. If the same priority is assigned to 2 subgoals, these subgoals must be commensurable, and a coefficient of regret must be used.

SYSTEM CHARACTERISTICS

After the goal-programming equations have been formulated and outputs have been obtained, alternative transit systems must be characterized to correlate them with the variable outputs. Also some boundaries must be set on the types of systems included. These boundaries were drawn basically to include current and proposed types of public transportation applicable for use in an urban situation for movement of larger numbers of people within the area.

System Groups

Dividing the various systems into general categories was more difficult than setting boundaries. It was felt that the 2 categories often used (line-haul, circulation) were not enough, but the 9 offered by Rea and Miller (22) were too detailed. Five major classes were chosen, and their characteristics are given in Table 1. The rail rapid transit class contains predominantly the traditional subway-type systems with variations in types of wheels, propulsion, and the like. Monorails also are included in this category. The rubber-tired bus operating on local streets is included in the bus group. These buses can use a variety of propulsion systems if at least separate bus lanes exist. A variety of systems, such as the one at Morgantown, fall in the jitney category. Jitneys generally operate on separate ROW and use small, automated vehicles. The electric car and other personal vehicles are in the personal-vehicle class. Some of these

Table 1. Transit system characteristics.

System Group	Costs (dollars/ passenger-mile)	Average Headway (sec)	Average Travel Speed (mph)	Terminal Access Time (sec)	Vehicle Size (passengers/ vehicle)	Necessity of Separate Right-of-Way
Rail rapid transit	0.241	120	25 to 40	300	60[a]	Yes
Bus	0.081	180 to 300	5 to 15	180	35 to 50	Optional
Jitney	0.060	10 to 60	10 to 20	180	6 to 30[a]	Yes
Personal vehicle	0.075	30	20	120	2	Optional
Moving walkway	0.045	5	2 to 8	72	0 to 2	Yes

Note: $1/passenger-mile = $0.625/passenger-km. 1 mph = 1.6 km/h.
[a]10 cars/train.

vehicles are dual mode and all are assumed to be publicly owned. Mechanical pedestrian aids are found in the moving walkway category. These aids usually are some type of continuously moving belt system that permits frequent access. Most existing transportation systems fall within one of these categories. The categorization is quite general, but the system operating and performance characteristics in each group are similar. Values for each of the 5 variables as given in Table 1 were estimated in part on the basis of state-of-the-art projections.

It should be noted that Table 1 was derived from a wide variety of sources, and its compilation is a good example of the difficulty of evaluating systems without a systematic process. Vehicle size data came primarily from the study of systems by Handman et al. (9) and are based on seating capacity alone (standees were not considered). Average travel speeds came from Chilton (5), and this source also was used to supplement vehicle size data. Headway figures, particularly for the rail rapid transit, jitney, and moving walkway groups, were drawn from a study by the Transportation Research Institute (27); this study also contained considerable additional information on these systems.

Cost and terminal-access-time figures were difficult to obtain. Access time was found by multiplying half the average distance between stations by the walking speed of the normal pedestrian [3 mph (4.8 km/h)]. In no case was the distance used greater than 0.25 mile (0.4 km); to expect users to walk farther than this is unrealistic (31). Although these calculations have shortcomings, they provide a good basis for comparing the systems.

Cost information on the use of buses and rail rapid transit came from a study by Reed (23). This study is a detailed analysis of the cost of different trip lengths that uses transit methods versus the automobile. A paper by Levinson (17), which deals with smaller capacity systems (jitney and moving walkways), derived the cost figures for these groups. All figures included average construction costs and anticipated operating costs but were adjusted to exclude any ROW costs. The values given are for the time before the energy crisis, and, with inflation, the cost figures may in some cases be somewhat below current estimates. More accurate figures are difficult to determine because of economic conditions, but the ones given serve as a good basis for comparison.

Obtaining information on personal vehicles proved to be most difficult because of the limited number of proposed systems. As a result, much of the data came from the University of Pennsylvania (28) and was integrated with information on dual-mode systems such as StaRRcar.

The figures in Table 1 represent a summary of the data on the appropriate groups from a wide variety of sources. To be useful, the estimated values of system characteristics must be updated periodically as system technology advances and better data become available. The cost data are particularily fast changing and should be adjusted as demonstrations, actual applications, and economic conditions allow better estimates to be made.

A great deal more information could have been given concerning each system. For example, systems with separate ROW differ in social disruption and safety levels from systems without separate ROW. However, greater research of all the indicated systems is necessary before a detailed evaluation can be made. The option of a separate ROW is given because this is such a key factor and because performance with and without it can be markedly different.

Correlation of Variables

One must correlate the tabulated characteristics and the variable values to see which group of systems best fits the transportation needs. Simply making a manual match and noting which system contains the values of each variable are possible. Many times it will be obvious which group best fits the values. There may be situations, though, in which the values are scattered throughout different groups. In these cases, several alternatives must be considered. The first is a weighting evaluation system that consists of assigning weights to the variables according to their importance and totaling the weights in each group to see which scores highest. This is probably the least desirable; however, there are cases when it might be usable especially if the number of variables was significantly increased. Another alternative is to look at the group containing the greatest number of variables or the most important variable and correlate the other output variables with the performance values of this system group. An acceptable correlation may well be found for the others even if the variables do not fall directly within the range. A third alternative, if there are 2 groups of systems that contain the variables, is to attempt to blend the 2 systems to design a system that incorporates the desirable aspects of both. This would be most difficult, but it should at least be considered. A technology within 1 of the 2 groups may be closer to the other group than most, and slight modification would allow it to fit all the goals. The last alternative is a situation in which no single group is better than the others. In this situation, the transportation planners should look at their input values with a view toward modifying them. If their goals are so diverse that no system can fulfill them, then perhaps the values are not realistic. A careful reevaluation to make them more commensurate with each other would seem to be indicated in this case.

EXAMPLE APPLICATION

The example case was chosen to represent a typical, hypothetical set of community values to demonstrate the use of the goal-programming technique. The community is assumed to be of medium size with a population of around 500,000 in a central area of reasonably homogeneous travel demand. Peak-hour trips are projected to average 5,000 passengers/hour for the 1995 planning date because the area is not highly commuter oriented. The system chosen must have sufficient capacity to meet this demand, and a high level of service is expected.

A bus system previously operated in the area failed financially, and currently there is no public transit. In preparation for a new system, which was made necessary because of the crowded road conditions, a transportation planning group studied the transportation requirements and financial standing of the community. In conjunction with information found in the appropriate technical literature, a set of constraints for the new system was determined. For example, an average maximum waiting time of 40 sec was deemed desirable together with travel speeds averaging 20 mph (32 km/h) for the typical 3-mile (4.8-km) trip. Because accessibility to the system is important, a maximum walking time of 5 min to the terminals is specified. A study of current and potential transit users shows that a total perceived door-to-door trip of 20 min is acceptable to the majority of them. Operating expenses of communities of similar size with transit systems and modal-split cost data show that 8 cents/passenger-mile (5 cents/passenger-km) is a reasonable limit for fares. Results of a local survey show that the following weights are placed on the various aspects of travel time:

1. Riding time = 1.0,
2. Terminal waiting time = 2.5, and
3. Terminal access time = 2.0.

These values are inserted into the goal-programming equations and then processed by the computer program.

ANALYSIS OF RESULTS

For the stated example problem the results are:

Variable	Computed Value	Priority
PTT = $2.5X_2 + 1.0X_3 + 2.0X_4$, seconds	1,200	1
X_1, cents	8	2
X_2, seconds	40.0	3
X_3, seconds	540	4
X_4, seconds	280	5
X_5, passengers per vehicle	56	6

The analysis attempts to achieve each goal by meeting the constraints as closely as possible. PTT is achieved exactly; therefore it is given the highest priority. The results may be interpreted as showing the minimum values of system performance needed to satisfy all constraint equations. Because X_4 is rated lowest of the time-related factors, it is adjusted so that the first priority constraint of PTT = 1,200 sec would be met.

Because the program will adjust first the priorities of lowest value, care should be taken when assigning them so that the variables, when adjusted, will reflect the maximum attractiveness to the user. In other words, the variables that are deviated to meet the higher priorities of constraints (in this case, X_4) should be those that are important to the user. To have a system with a PTT of 1,200 sec and a 280-sec walk is probably better than to have one with a PTT of 1,200 sec, a 400-sec walk, and shorter ride because the user considers walking and waiting to be more distasteful than riding. Some initial rough calculations also might be helpful to ensure that the variables that will be adjusted have enough flexibility to absorb the deviation. In some cases, a variable might be reduced to 0, which would have little real meaning. If the equations are so complex that it is not readily apparent which variables will receive the deviation, a trial run could be made. If unrealistic values occur, then the priorities can be adjusted.

After the desired performance characteristics have been found, one has to correlate them with the data in Table 1. For the example, it is apparent that all the systems meet the cost constraint [8 cents/passenger-mile (5 cents/passenger-km)]; that jitney, personal vehicles, and moving walkway meet the headway requirements (less than 40 sec); and that rail, jitney, and personal vehicles meet the travel speed [20 mph (32 km/h)]. The terminal density constraint (280 sec) is met by all system groups except rail. Jitney, bus, and rail fulfill the capacity requirement (56 passengers/vehicle assuming multiple jitney cars). Therefore, jitney systems satisfy all the needed characteristics and should be evaluated further to determine which actual technology meets the full range of social, environmental, and transportation goals of the community.

It can be seen from this example that correlating results with the system characteristics gives a good indication of the needed systems. If additional constraints are needed or developed, the computer program can easily solve more complex problems. The fact that the variables are deviated in the order of lowest priority should be taken into account when deciding on the ordering of the variables. Those characteristics judged as most attractive should be lowered in priority in order to be adjusted in the direction of this attractiveness.

CONCLUSIONS

This study suggests the application of the goal-programming technique to urban transportation evaluation. The choice of variables, equations, and assumptions was made to keep the procedure simple and reasonably clear and to allow concentration on determining the usability of the goal-programming procedures for initial public transit assessment application. The main point is that the goal-programming technique is available for use in the assessment of highly complex transportation systems. This technique is of course only a part of the overall picture of transportation system planning, but techniques of this type can effectively indicate to the planner those systems that merit close evaluation for service performance.

For this technique to be usable in an actual application, each community would have to carefully evaluate its own goals and the assumptions made by this study and determine which conflicts occur. Making a model applicable without alterations to any urban situation would never be possible. Revision and tailoring of the procedures to each individual application are expected to be necessary. For example, suppose the community, after having determined which group of systems fits its transportation needs, evaluated these systems and decided that they were not satisfactorily compatible with its social and environmental goals or developing concerns such as energy consumption. If these social goals and energy consumption were considered more important than transportation goals, the community could determine constraint equations for the socioenvironmental goals that would fit into the goal-programming format along with the transportation performance goals and thereby integrate these aspects into the system evaluation.

REFERENCES

1. S. J. Bellemo and S. C. Provost. Toward an Evaluation of Subarea Transportation Systems. Highway Research Record 293, 1969, pp. 14-32.
2. D. S. Berry et al. The Technology of Urban Transportation. Northwestern Univ. Press, Evanston, Ill., 1963.
3. R. A. Burco and C. D. Henderson. Systems Innovations for Urban Transportation. Transportation Engineering Journal, ASCE, Vol. 97, No. TE 2, May 1971.
4. E. T. Canty et al. Planning and Evaluation Methods. In New Systems Implementation Study, NTIS, Springfield, Va., Vol. 2, Feb. 1968.
5. E. N. Chilton, ed. Future Urban Transportation Systems: Technological Assessment MR-2. NTIS, Springfield, Va., May 1967.
6. D. A. Eisele. State of the Art—Urban Transportation Systems. Transportation Engineering Journal, ASCE, Vol. 95, No. TE 3, Aug. 1969.
7. R. H. Ellis. Reexamination of Transportation Planning. Transportation Engineering Journal, ASCE, Vol. 99, No. TE 3, May 1973.
8. M. G. Ferreri. Mass Transportation: The Hardware. Highway Research Record 318, 1970, pp. 20-26.
9. A. L. Handman et al. Transportation System Candidates for Urban Applications. NTIS, Springfield, Va., May 1970.
10. D. G. Haney. Future Urban Transportation Systems: Desired Characteristics. NTIS, Springfield, Va., May 1967.
11. C. Henderson et al. Future Urban Transportation Systems: Description, Evaluations, and Program. Stanford Research Institute, Menlo Park, Calif., March 1968.
12. M. Hill. A Method for the Evaluation of Transportation Plans. Highway Research Record 180, 1967, pp. 21-34.
13. L. A. Hoel. Evaluating Alternative Strategies for Central-City Distribution. Highway Research Record 293, 1969, pp. 1-13.
14. W. S. Homburger, ed. Urban Mass Transit Planning. Univ. of California, Berkeley, 1967.
15. Capacities and Limitations of Urban Transportation Modes. Institute of Traffic Engineers, Washington, D.C., May 1965.
16. S. M. Lee. Goal Programming for Decision Analysis. Averbach Publishers, Inc., Philadelphia, 1972.
17. H. S. Levinson. People Movers: Planning and Potentials. Highway Research Record 397, 1972, pp. 1-11.
18. J. R. Meyer, J. F. Kain, and M. Wohl. The Urban Transportation Problem. Harvard Univ. Press, Cambridge, Mass., 1965.
19. D. A. Morin. Highways and Modal Choice Decisions. Transportation Engineering Journal, ASCE, Vol. 99, No. TE 1, Feb. 1973.
20. E. K. Morlok. The Comparison of Transport Technologies. Highway Research Record 238, 1968, pp. 1-22.
21. J. J. Murray, ed. Urban and Regional Ground Transportation. Planning-

Transport Associates, Inc., Durham, N.C., 1973.
22. J. C. Rea and J. H. Miller. A Comparative Study of Urban Transportation Technologies: The Service Specification Envelope Approach. Pennsylvania State Univ., Aug. 1972.
23. M. F. Reed. Comparison of Urban Travel Economic Costs. Highway Users Federation, Washington, D.C., Technical Study Memorandum 6, Feb. 1973.
24. B. Richards. New Movement in the Cities. Reinholt Publishing Corp., London, 1966.
25. C. C. Schimpeler and W. L. Grecco. Systems Evaluation: An Approach Based on Community Structure and Values. Highway Research Record 238, 1968, pp. 123-152.
26. W. L. Smith. Quantifying the Environmental Impact of Transportation Systems. ASCE National Transportation Engineering Meeting, Tulsa, July 9-12, 1973.
27. Advanced Urban Transportation Systems. Transportation Research Institute, Carnegie-Mellon Univ., Rept. 5, May 1970.
28. Minicar Transit System. Univ. of Pennsylvania, Final Rept., Phase 1, Books 1 and 2, Dec. 1968.
29. J. E. Vitt, H. J. Bauer, E. T. Canty, T. F. Golob, and K. W. Heathington. Determining the Importance of User-Related Attributes for a Demand-Responsive Transportation System. Highway Research Record 318, 1970, pp. 50-65.
30. E. J. Ward. Systems Approach to Choice in Transportation Technology. Transportation Engineering Journal, ASCE, Vol. 96, No. TE 4, Nov. 1970.
31. J. C. Yu and W. E. Wilhelm, Jr. A Location Principle of Urban Terminal Distribution. Highway Research Record 395, 1972, pp. 47-60.

PROGRAMMING TRANSPORT INVESTMENT: A PRIORITY-PLANNING PROCEDURE

John H. Shortreed, University of Waterloo; and
Richard F. Crowther, Planning Office,
Ontario Ministry of Transportation and Communications

A priority-programming procedure was developed and is being implemented by the Ontario Ministry of Transportation and Communications. The procedure initially will deal with rural highway investment but can be extended to transit and urban areas. An earlier paper has given a general background of the procedure. This paper shows how the linear-programming formulation is a valuable extension of current methods of cost-benefit analysis. The basis of the extension is the explicit consideration of trade-offs concerning the time of investment for improvements. The method also provides for different interest rates for discounting benefits and costs. The paper describes the linear-programming formulation including the treatment of alternatives, regional budgets, and commitments. The paper also discusses the treatment of interrelated or joint benefits of improvements. Finally, the paper presents the calculation procedure for the key benefits—user time and vehicle operating cost. This procedure accounts for variations in hourly volumes over the year and uses existing information as input.

•SELECTING transport projects for construction is a major problem for all transportation departments. Difficulties have been intensified by (a) the dramatic increase in the number of existing facilities that require ongoing maintenance expenditure; (b) the relative reduction in transport budgets because of demands for funds for education, health, and welfare; and (c) the incessant increase in the demand for transport facilities. When faced with this problem, the province of Ontario, in cooperation with Read Voorhees and Associates, Ltd., developed a methodology for priority programming for both road and transit facilities (1, 2). This methodology is being implemented. An interesting result of the development of the methodology for priorities was that the procedure also was valuable as a management tool for organizing the investment in transport facilities and providing continuity between planning studies and design and construction activities. This is described elsewhere (3). The purpose of this paper is to outline the technical aspects of the priority methodology and to indicate the flexibility of the method for handling policy variables, interdependent projects, and the like. This paper also discusses the advantages and limitations of the priority-planning technique.

PRIORITY-PLANNING PROBLEM

A transport agency generates a list of transportation improvements IMP_j's where j goes from 1 to n, the total improvements in the list. For each IMP_j certain data are calculated:

Publication of this paper sponsored by Committee on Transportation Programming, Planning, and Evaluation.

C_{jkt} = construction cost of the j th improvement incurred in year k if construction is started in the t th year. For an improvement that requires 3 years to construct, C_{jtt}, $C_{j\,t+1\,t}$, and $C_{j\,t+2\,t}$ would not be 0.

C_{jt} = present value of the construction costs of the j th improvement given construction starts in year t, all of which are discounted to year t at a specified interest rate R; that is,

$$C_{jt} = \sum_{k=t}^{k=t+p} \frac{C_{jkt}}{(1 + R)^{k-t}} \quad (1)$$

p = construction period.

t = index of year of start of construction with t = 1 usually being 2 to 4 years in the future to allow for the design of the facilities; t goes from 1 to m, and typical values of m are 20 years.

MC_{jt} = present value of the annual maintenance costs of the j th improvement for the years t through t + 25, all of which are discounted to year t at a specified interest rate R.

B_{jt} = present value of the annual benefits of the j th improvement for the years t through t + 25, all of which are discounted to year t at an interest rate R.

The data for an example improvement j are shown in Figure 1 and given in Table 1. The example takes 2 years to construct, costing $400,000 in the first year of construction and $201,000 in the second year of construction when it is started in the first year. The present value of the construction cost is calculated by using the convention that costs occurring during a year are considered to occur at the end of the year. Thus, in Table 1, the value of C_{j1}, the cost of constructing the j th project in the first year, is [$400,000 (1/1.08)] + [$201,000 (1/1.08^2)] or $541,800. In a similar way, C_{j2} = $543,600, and so on.

If the improvement was started in year 1, then benefits and annual maintenance costs would start to flow in year 3; benefits would be $73,000 and maintenance costs would be $20,400 in the first year of operation. These annual benefits and costs are summed over 25 years to give the values of B_{jt} and MC_{jt}. For example,

$$B_{j1} = \sum_{t=3}^{25} \frac{\text{annual benefit in year } t}{(1.08)^t} = \$752{,}800 \quad (2)$$

Similarly, if the construction was started in year t = 19, then B_{j19} would be $992,900 (Table 1). Table 1 also gives the net present value in year t of the construction of project j started in year t. This is $B_{jt} - C_{jt} - MC_{jt}$, which also is shown in Figure 1.

Each year of starting construction can be thought of as a different alternative project. To compare the alternatives of the construction of the j th project in years t = 1, . . . , x, y, z, . . . , m, one must compare the net present value for each alternative at one point in time. Normally, the common point in time is taken as the start of year 1. Thus for any 2 alternative starting dates t = x or t = y for project j we compare the present value in year 1 of $(B_{jx} - MC_{jx} - C_{jx})$ and $(B_{jy} - MC_{jy} - C_{jy})$, or we compare $[1/(1 + R)\ x - 1]\ (B_{jx} - MC_{jx} - C_{jx})$ and $[1/(1 + R)\ y - 1]\ (B_{jy} - MC - C_{jy})$ where R = discount rate. The net present value of the example project in the first years of construction t discounted to year 1 for comparison purposes is shown in Figure 1 and given in Table 1. The net present value reaches a maximum in year 12, and, with no budget constraints, this is the best time to start construction of the improvement. That is, in comparing the 20 alternatives, which are the 20 different starting dates for project j, the best alternative is that with the highest net present value in year 1. Heggie

Table 1. Values for example problem for improvement j.

Year	Input Data: 1st-Year Construction Costs	2nd-Year Construction Costs	Annual Benefits	Annual Maintenance Cost	Present Value in Year t: C_{jt}	MC_{jt}	B_{jt}	Net Present Value of Benefits in Construction Year t	Net Present Value of Benefits Less Costs in Year 1 for Construction in Year t
1	400,000				541,800	195,200	752,800	15,800	15,800
2	401,000	201,000			543,600	197,000	766,200	25,500	23,600
3	402,000	202,000	73,000	20,400	545,400	198,800	779,500	35,300	30,300
12									52,900
19	418,000	218,000	97,000	23,600	573,900	227,200	992,900	191,700	48,000
20	419,000	219,000	98,500	23,800	575,700	229,000	1,006,200	201,500	46,700
21	–	–	100,000	24,000				–	–
44	–	–	14,500	28,600				–	–
45	–	–	13,500	28,800				–	–

Note: All values are in dollars.

Figure 1. Example data for improvement j.

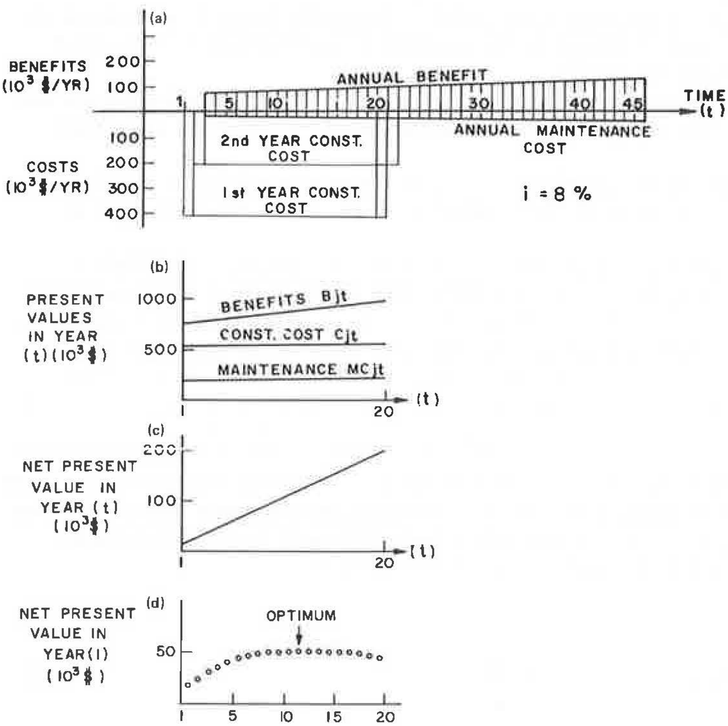
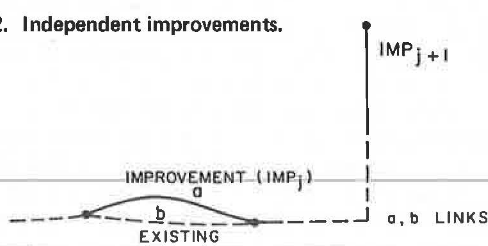


Figure 2. Independent improvements.



YEAR (t)	VOLUME ON EXISTING LINKS (b): WITH IMPj	WITHOUT IMPj	VOLUME ON IMPj (LINK a)
1	3000	1,200	1,800
2	3200	1,200	2,000
⋮			
⋮			
44	8,800	1,400	7,400
45	9,100	1,400	7,700

(4) shows that, for most conditions, the maximum net present value occurs in the year when the first-year rate of return of the annual net benefits relative to the cost first exceeds the discount rate. Normally, however, the net present value criterion is easier to use. With no budget constraints, the example project would be started in year 12.

PRIORITY PLANNING WITH BUDGET CONSTRAINTS

Given a list of n improvements and their optimum construction year t_{opt}, budget constraints generally prevent starting each improvement in the optimum year. The problem then is maximizing the net present value that is due to constructing the improvements over the planning horizon m without violating budget constraints, which must be known for all m years in the planning horizon. This type of maximizing problem subject to constraints can be solved readily by linear programming (4, 8).

The linear-programming problem is to maximize

$$\sum_{j=1}^{n} \sum_{t=1}^{m} X_{jt} V_{jt} \tag{3}$$

subject to

$$\sum_{t=1}^{n} X_{jt} \leq 1 \tag{4}$$

$$\sum_{j=1}^{n} \sum_{k=t}^{k=t+p} X_{jt} CST_{jkt} \leq b_y \tag{5}$$

$$X_{jt} \geq 0 \tag{6}$$

where

X_{jt} = fraction of improvement j started in year t,
V_{jt} = present value of benefits in year t = $[1/(1 + R)^{t-1}]$ $(B_{jt} - MC_{jt})$,
CST_{jkt} = actual construction cost incurred in year k, for a project started in year t, and
b_t = budget for year t.

Equation 3 is the maximization of benefits. We could maximize benefits less costs as was done in the example problem. However, the net benefits V_{jt} had to be maximized because the construction costs are dealt with specifically in the budget constraints. The choice of maximizing benefits means that the discount rate for comparing construction costs over time is effectively determined within the linear-programming solution and is, of course, related to the magnitude of the budget constraints. This is an advantage that becomes available with the linear-programming solution and is of course not possible with the example that had no budget constraints.

Equation 4 states that the project can be built only once and may not be built at all. If the project must be built, then this equation would be an equality. Because a non-integer linear program is used, up to m projects will not be completely started in 1 year, but, for the other n - m projects, X_{jt} will be 1.0 for some j and 0 for all other j. These so-called split projects generally are assigned to the year with the largest fraction X_{jt}, and experience has shown that this does not create difficulties.

Equation 5 is the budget constraint. The second-year construction costs for a project started in the t - 1 year will occur against the tth year budget.

Equation 6 states that construction costs cannot be recaptured by selling or "unbuilding" an improvement. Because of the linear-programming solution methods, a linear-programming problem must be expressed so that this condition holds. These constraints do not have to be explicitly stated in a linear-programming computer run because they are assumed to hold.

RESULTS OF PRIORITY PLANNING

The linear-program solution gives the following:

1. Year of start of construction for project j,
2. Present value of the net benefits of the entire priority program,
3. Discount rate for capital costs in each budget year, and
4. Measure of reduction in maximum benefits due to shifting a project from its programmed priority.

Input data are available, as a result, for further use of the method in programming improvements for design and construction. These aspects are covered elsewhere (1, 2, 3).

PLANNING HORIZON

The problem of the finite planning horizon can be managed several ways.

1. Assign a high terminal-year budget but no benefits to improvements started in year t = m the final year of the planning horizon. At the same time, change equation 4 to $\sum_{t=1}^{n} X_{jt} = 1$. The final year then becomes a dumping ground for all improvements that should not be built during the first m - 1 years of the planning horizon.
2. With the equations as given, adjust V_{jt} to reflect the fact that improvements started in the final few years of the planning horizon will not incur full construction costs. That is, if an improvement started in year t = m will incur $\frac{1}{3}$ of its construction costs in that year and $\frac{2}{3}$ subsequently, set $V_{jm} = \frac{1}{3}\,[1/(1 + R)^{m-1}]\,(B_{jm} - mC_{jm})$, which is the procedure being used in Ontario.
3. Extend the planning horizon budgets and improvement parameters far enough so that all worthwhile improvements can be scheduled.

INCLUSION OF POLICY VARIABLES

The problem of equations 3, 4, and 5 involves a simple list of improvements with only budget constraints on the construction costs. The flexibility of the linear-programming method allows many other circumstances, such as other cost constraints, regional development policies, and committed improvements, to be introduced into the priority planning.

1. Under other cost restraints, maintenance costs would be included as a cost subject to the budget. Then V_{jt} would include only B_{jt}, and CST_{jkt} would include construction and maintenance costs.
2. Under regional development policies, suppose encouraging development in northern areas of a province is desired. To do this, either (a) a special weighting

(say 1.5) can be applied to the benefits of projects in this area or (b) a separate budget constraint can be set aside for this area. For example, let X_{jta} be the fraction of an improvement j started in region a in year t, and then

$$\sum_{j=1}^{j=n} \sum_{k=t}^{k=t+p} X_{jta} \, CST_{jkta} \geq b_{ta} \tag{7}$$

This requires that at least b_{ta} be spent in the favored region in year t. This constraint also can be used to set minimum 5- or 10-year spending levels.

3. Under committed improvements, suppose an improvement j = 10 is committed for starting by year t = 7 so that it will connect with a road over a new dam being completed in year t = 9. Then we have for equation 4 for j = 10

$$\sum_{t=1}^{7} X_{10,t} = 1 \tag{8}$$

which ensures that the improvement will be started by the seventh year.

USER BENEFITS FOR INDEPENDENT IMPROVEMENTS

An improvement is independent when its benefits are independent of all other improvements considered in the planning period. Naturally, its benefits are a fraction of other road links but not of any road links subject to possible improvement. A typical independent improvement is shown in Figure 2. The benefits for improvement j do not depend on improvement j + 1 or any other improvement. This is the simplest case, and, fortunately, in intercity transport networks, most improvements are of this type. The user benefits due to improvement j in Figure 2 arise from volumes on the improvement (here assumed to be a new road) and from volumes left on the old road because of higher speeds and less congestion. An improvement is considered to be made up of a number of links that will vary in physical characteristics and volumes. In Figure 2, the improvement has only 1 link a, and the existing road is link b. The procedure developed for calculating user benefits for a particular road link involves the consideration of each hour in the year so that the speed and operating costs of the traffic can be determined more accurately. The flow chart of the user benefit calculation is shown in Figure 3. By using the permanent counting station associated with each link, one can find the distribution of hours in the year for each volume level for the annual average daily traffic for each year t. Then by using the Highway Capacity Manual (5), operating cost data (6, 7) and a value of travel time, one can calculate the total user cost on each link with and without the improvement for each hour in the year. The user benefit due to the improvement in year t then is merely the sum over the hours in the year and over the links associated with the improvement of the difference in total user costs. A computer program for Figure 3 is in operation at the Ontario Ministry of Transportation and Communications.

USER BENEFITS FOR DEPENDENT IMPROVEMENTS

Dependent improvements are defined as improvements with benefits that depend on the existence or nonexistence of another improvement. A typical situation is shown in Figure 4 in which a new intercity route is made up of 2 improvements IMP_j and IMP_{j+1}. The benefit of IMP_j and IMP_{j+1} together is greater than the sum of the benefits of each

Figure 3. Flow chart for calculating user benefits.

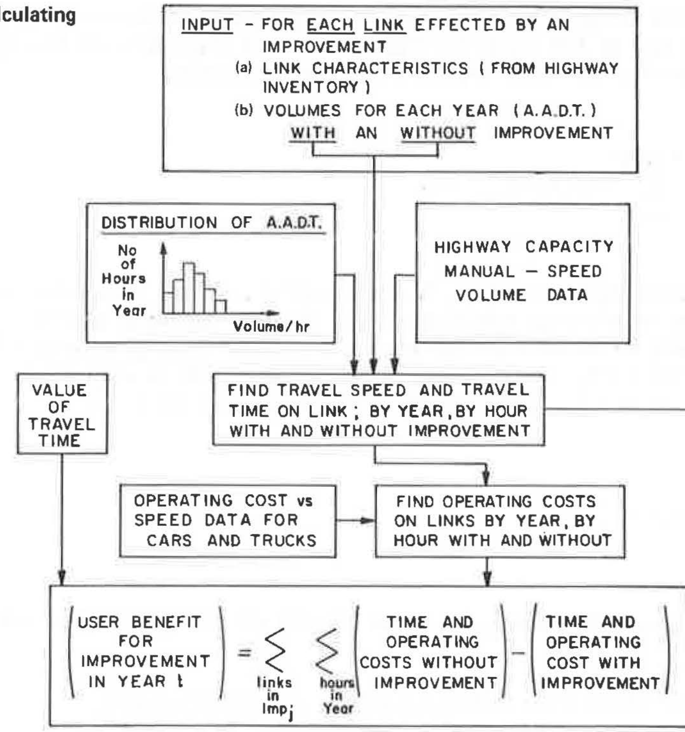
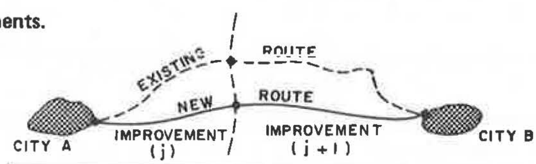


Figure 4. Dependent improvements.



YEAR (t)	PRESENT NET BENEFIT (V_{jt}) IMP$_j$ ONLY	IMP$_{j+1}$ ONLY	BOTH IMP$_j$ AND IMP$_{j+1}$	DUMMY IMPROVEMENT SAY IMP$_{j+2}$
1	.21	.60	1.40	.59
2	.22	.62	1.45	.61
19	.30	.75	1.96	.91
20	.29	.73	1.87	.85

(ENTRIES IN $ 10^6)

individual improvement. For example, in year 2, IMP$_j$ has a V_{jt} of \$210,000 and IMP$_{j+1}$ has a V_{jt} of \$600,000. If both were started in year 2, the total V_{jt} would be \$1,400,000, which is \$590,000 more than the combined individual V_{jt}'s of improvement j and j + 1. This extra benefit is assigned to a dummy improvement that has 0 cost and a benefit equal to the extra benefit and can only be considered where improvements j and j + 1 are started. The constraint equations that accomplish this in the linear program are as follows:

$$\sum_{t=1}^{m} X_{jt} \leq 1 \tag{9}$$

$$\sum_{t=1}^{m} X_{j+1,t} \leq 1 \tag{10}$$

$$\sum_{t=1}^{m} X_{j+2,t} \leq 1 \tag{11}$$

$$\sum_{t=1}^{m} + X_{jt} - X_{j+2,t} \geq 0 \tag{12}$$

$$\sum_{t=1}^{m} X_{j+1,t} - X_{j+2,t} \geq 0 \tag{13}$$

$$10^{20} X_{j,1} + 10^{18} X_{j,2} + \ldots - 10^{20} X_{j+2,1} - 10^{18} X_{j+2,t} \ldots \geq 0 \tag{14}$$

$$10^{20} X_{j+1,1} + 10^{18} X_{j+1,2} + \ldots - 10^{20} X_{j+2,1} - 10^{18} X_{j+2,t} \ldots \geq 0 \tag{15}$$

Equations 9, 10, and 11 are as usual. Equations 12 and 13 ensure that no more of the dummy improvements are made than the minimum of improvement j or j + 1. Equations 14 and 15 counteract a tendency of the linear-programming solution to split the improvement (build a fraction of each over several years) to gain the dummy benefits as soon as possible. The use of descending-order-of-magnitude weights on the start of construction variables X_{jt} effectively prevents this and ensures that all improvements are built in a single year.

SEQUENTIALLY DEPENDENT IMPROVEMENTS AND STAGING

A similar technique can be used when one improvement must be constructed after another one or when an improvement must be constructed in stages. For example, the acquisition of right-of-way can be separated from the remainder of facility construction. The first stage (acquisition of right-of-way) has costs but no benefits; the second stage (facility construction) has both costs and benefits. Also stage 1 must be completed before stage 2 starts. The constraints are similar to those previously given:

$$\sum_{t=1}^{m} X_{jt} \leq 1 \tag{16}$$

$$\sum_{t=1}^{m} X_{j+1,t} \leq 1 \tag{17}$$

$$\sum_{t=1}^{m} X_{jt} - X_{j+1,t} \geq 0 \tag{18}$$

$$10^{20}X_{j,1} + 10^{19}X_{j,2} + \ldots - 10^{20}X_{j+1,2} - 10^{19}X_{j+1,2} - \ldots \geq 0 \quad (19)$$

Equations 16, 17, and 18 state that only 1 facility can be built, only 1 right-of-way can be purchased, and the amount of facility built cannot exceed the amount of right-of-way purchased. Equation 19 effectively prevents construction before right-of-way acquisition.

MUTUALLY EXCLUSIVE IMPROVEMENTS

In some circumstances other than the setting of priorities, deciding the priorities between 2 improvement alternatives [j (a) or j (b)] may be desirable. Both improvements are included in the normal way and extra constraint is added:

$$\sum_{t=1}^{n} X_{j(a)t} + X_{j(b)t} \leq 1 \quad (20)$$

This constraint states that, if a is built in some year, then b may not be built, and vice versa. Also, because of the inequality, neither need be built. A program to build a fraction f of a and a fraction 1 - f of b also would satisfy these constraints. As a practical matter, choosing to build either in the indicated year would be satisfactory.

One way that mutually exclusive improvements can occur is in alternative alignments when the primary need can be met on either alignment and not enough demand exists for 2 facilities. Also the mutually exclusive formulation is useful when different forms of a facility in the same location are to be considered. Thus the linear program can be used to decide whether a 2-lane or a 4-lane bridge should be built and, simultaneously, to determine the best construction year for the selected alternative.

OTHER BENEFITS AND COSTS

Many benefits other than user benefits are incorporated into the Ontario procedure as are costs other than construction costs. These are discussed elsewhere (2). User benefits were presented here because (a) they compose a main part of all benefits and (b) some major technical refinements were carried out in estimating these benefits as shown in Figure 3.

Salvage values of the improvements at the end of the 25-year stream of benefits normally are included in the planning procedure as a 1-time benefit. For the sake of clarity, this was not included in the examples presented here.

DISCUSSION OF RESULTS

Priority-planning techniques represent an advance over traditional cost-benefit analysis. Priority-planning techniques explicitly recognize the trade-off over time between building an improvement now or later in addition to the normal comparison of different improvements. In the testing of the technique, this advantage realized a 5 percent increase in net benefits over traditional methods of setting priorities on a year-by-year rank ordering of net present value.

Unlike other programming methods (4, 8), this technique has eliminated capital costs from the linear-programming objective function. This has the advantage that the interest rate selected is used solely for discounting benefits over time and is not also used for the discounting of capital sums. The effective discount rates for the capital sums are determined by the linear program as dual variables of the budget rows. This clear separation of discounting of benefits (mainly time saving) and opportunity cost of capital is a considerable conceptual advantage when selecting the interest rate for economic analysis.

The linear-programming technique has the advantage that commitments and other policy decisions can be inserted directly into the equations and then the technique optimizes the remainder of the improvements to be scheduled.

The main disadvantage of the procedure is the extensive data requirements. In Ontario, about 2 years is necessary to change existing data files and generate the required data. It should be noted that most of these data would be required for any economic evaluation of priorities.

The method requires the availability of a linear-programming computer program. These are generally available and did not pose any problems in tests conducted so far. The linear program uses continuous variables rather than integer variables, and this causes some splitting of projects. In the test situations and elsewhere (4), this has proved to be only a minor annoyance and has not detracted from the procedure.

However accurate and sophisticated the analysis is, the results are no better than the input data are. For this reason, work should continue on improving the accuracy of the input data in a manner similar to the refinement of the calculation of user benefits.

If an agency wishes to carry out priority programming, there appear to be considerable other managerial advantages to using the linear-programming method (3).

CONCLUSIONS

The techniques described in this paper advance economic analysis for priority programming of improvements by considering the maximization of benefits over the entire planning period given budget constraints and by clearly distinguishing between discount rate for benefits and consideration of capital costs. In the test program and in continuing application to the provincial highway system in Ontario, these techniques have shown themselves to be also practicable and useful.

REFERENCES

1. Development of a Methodology for Planning Improvement Priorities, Phase 1. Ontario Ministry of Transportation and Communications and Read Voorhees and Associates, Ltd., Toronto, 1972.
2. Development of a Methodology for Planning Improvement Priorities, Phase 2. Ontario Ministry of Transportation and Communications and Read Voorhees and Associates, Ltd., Toronto, 1972.
3. W. Melinyshyn, R. Crowther, and J. D. O'Doherty. Transportation Planning Improvement Priorities: Development of a Methodology. Highway Research Record 458, 1973, pp. 1-12.
4. I. G. Heggie. Transport Engineering Economics. McGraw-Hill Book Co., London, 1972.
5. Highway Capacity Manual—1965. HRB Special Rept. 87, 1965.
6. P. J. Claffey. Running Costs of Motor Vehicles as Affected by Road Design and Traffic. NCHRP Rept. 111, 1971.
7. R. W. Winfrey. Economic Analysis for Highways. Intext Educational Publications, New York, 1969.
8. H. M. Weingartner. Mathematical Programming and the Analysis of Capital Budgeting Problems. Markham Publishing Co., Chicago, 1965.

SPONSORSHIP OF THIS RECORD

GROUP 1—TRANSPORTATION SYSTEMS PLANNING AND ADMINISTRATION
Charles V. Wootan, Texas A&M University, chairman

SOCIAL, ECONOMIC, AND ENVIRONMENTAL FACTORS SECTION
Floyd I. Thiel, Federal Highway Administration, chairman

Committee on Transportation Programming, Planning, and Evaluation
Robert E. Spicher, Comsis Corporation, chairman
James B. Chiles, Dan C. Dees, C. E. Forbes, Robert H. Friis, Frederick Gottemoeller, C. G. Grayson, Robert A. Keith, Vincent A. Mattson, William R. McCallum, William L. Mertz, Charles H. Moorefield, Henry L. Peyrebrune, Stanley P. E. Price, Ronald W. Pulling, Lloyd A. Rivard, Douglas C. Smith, John L. Staha, E. R. Terrell, L. Ellis Walton, Jr.

Committee on Taxation, Finance, and Pricing
Charles A. Hedges, U.S. Department of Transportation, chairman
Richard P. Brief, Henry W. Bruck, Lawrence D. Dahms, Irving Hoch, Norman Kennedy, Gerald Kraft, Julius Margolis, John R. Meyer, Leon N. Moses, Gordon M. Murray, James R. Nelson, J. E. Peddy, Joseph H. Stafford, William S. Vickrey, Richard M. Zettel

Kenneth E. Cook and Stephen E. Blake, Transportation Research Board staff

Sponsorship is indicated by a footnote on the first page of each report. The organizational units and the chairmen and members are as of December 31, 1974.