TRANSPORTATION RESEARCH RECORD 1081

Urban Traffic Management

TRB
TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1986

Transportation Research Record 1081
Price $12.00
Editor: Naomi Kassabian
Compositor: Lucinda Reeder
Layout: Theresa Johnson

mode
1 highway transportation

subject area
54 operations and traffic control

Transportation Research Board publications are available by ordering directly from TRB. They may also be obtained on a regular basis through organizational or individual affiliation with TRB; affiliates or library subscribers are eligible for substantial discounts. For further information, write to the Transportation Research Board, National Research Council, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

Printed in the United States of America

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

Urban traffic management.

(Transportation research record, ISSN 0361-1981 ; 1081)
1. Traffic engineering—United States—Congresses.
I. National Research Council (U.S.). Transportation Research Board. II. Series.
TE7.H5 no. 1081 380.5 s 86-31208
[HE355] [338.4'1312'0973]
ISBN 0-309-04101-5

Contents

Cost-Effectiveness of Park-and-Ride Lots in the Seattle Metropolitan Area

G. SCOTT RUTHERFORD and CHRIS A. WELLANDER

ABSTRACT

A cost-effectiveness evaluation and a cost-benefit analysis were performed on a park-and-ride system consisting of 26 lots in the Seattle metropolitan area. Costs and benefits of the system were examined with respect to the user, the community at large, and the public agencies responsible for providing for the community's transportation needs. A user survey was conducted at the 26 lots. With the survey data and other data as input, a model was developed to calculate the total incurred trip costs with and without the park-and-ride lot. These trip costs were compared in a before-and-after analysis. In addition, the park-and-ride system was analyzed for its effect on the following transportation system measures of effectiveness: travel time, person miles traveled (PMT), vehicle miles traveled (VMT), traffic volumes, vehicle emissions, accidents, and energy consumption. General results indicated that the park-and-ride system in the Seattle area is cost-effective. The average park-and-ride trip was estimated to be 11.6 percent less expensive than the corresponding average previous trip by another mode. Results also indicated that the lots have had a slightly negative impact on travel time and PMT (i.e., these measures have increased), but VMT, traffic volumes, accidents, vehicle emissions, and energy consumption have all been reduced.

Park-and-ride lots are parking facilities, typically located some distance from the central business district (CBD), where the commuter changes from an automobile to some form of public transportation or ridesharing. In major urban areas throughout the United States such lots have been established to provide more efficient transportation and to assist in the conservation of energy. As such, they have become an integral part of the nation's urban transportation system framework. Nowhere is this more true than in the Seattle metropolitan area.

The agency responsible for providing transit service in the Seattle/King County area is the Municipality of Metropolitan Seattle (METRO). The first park-and-ride lot in the Seattle area was established in 1970 by METRO's predecessor, Seattle Transit, in the Northgate vicinity. Encouraged by the high utilization of this lot, the Washington State Department of Transportation (WSDOT) coordinated planning efforts with METRO to provide additional park-and-ride lots in the Seattle metropolitan area. Under a memorandum of understanding between the two agencies, WSDOT was to construct the lots using appropriate funds (Interstate, UMTA, state motor vehicle funds, and some METRO matching dollars), and METRO was to maintain them.

As of March 1984 the Seattle/King County area had 26 permanent, 8 semipermanent, and 16 interim park-and-ride lots. Lots are classified on the basis of their funding and long-range planning considerations. These 50 lots in total represented 12,520 automobile parking spaces. To date, WSDOT has spent approximately $47 million for construction of the 26 permanent lots.

G.S. Rutherford, Washington State Transportation Center, 135 More Hall, University of Washington, Seattle, Wash. 98195. C.A. Wellander, Parsons Brinckerhoff Quade and Douglas, Inc., 710 2nd Avenue, Suite 960, Seattle, Wash. 98104.

Planned additions to the existing park-and-ride system are extensive. Both METRO and the Puget Sound Council of Governments (PSCOG), the regional planning agency, recommend plans that would double the number of park-and-ride lots in the Seattle/King County region (1,2).

Despite the substantial sums of money that have been invested and are planned for investment in park-and-ride lots, little has been done to evaluate their total effectiveness. The initial goal of park-and-ride lots was to entice automobile commuters into express buses to alleviate freeway traffic congestion. Energy conservation became an additional objective with the advent of the Arab oil embargo in the early 1970s. To lure commuters from their cars to transit, the benefit to them had to be clearly outlined. Consequently, previous analyses of this topic have focused on benefits to the users through economic savings and energy conservation. However, a need exists to take a more comprehensive and detailed look at the costs and benefits of park-and-ride lots, not only with respect to the user, but with respect to the community at large and to the public agencies responsible for providing for the community's transportation needs. In short, do the benefits provided by park-and-ride lots sufficiently justify their expense? This study was undertaken to answer that question for the Seattle area.

The basic goal of this study was to determine the cost-effectiveness of existing park-and-ride lots with respect to the total transportation system in the Seattle metropolitan area. Results from this study may also be of use in the development of guidelines and tools for assessing the effectiveness of proposed park-and-ride facilities.

In meeting this goal, the basic objective was to provide a total cost-effectiveness evaluation of the existing park-and-ride lot system, which included looking at costs, benefits, and other measures of effectiveness as they related to each of the following groups:

- The community at large,
- The public agencies involved, and
- The park-and-ride lot user.

In the development of this study, the question arose whether highway capital costs, being "sunk" costs (i.e., the investment in them has already been made), should be included in the cost analysis. Depending on the purpose of the study and the application of its results, arguments can be made both for and against including these costs in the analysis. Because all the capital costs considered in this analysis--including those for both freeways and park-and-ride lots--have been sunk costs, it is legitimate to include them, including those for freeways, in the cost analysis.

Another strong argument for the inclusion of highway capital costs is that, with respect to the park-and-ride system, WSDOT's "participation with gas tax money is based on the premise that the construction of the park-and-ride lot system will relieve the need for the construction of additional highway lanes" (3). Still another argument is that the transportation system of the given area is in its infancy. In other words, the construction of either freeway lanes or a park-and-ride system is a valid alternative (neither are sunk costs in this case). In this instance, the trading off of the cost of freeway capacity with that of the park-and-ride system is an appropriate strategy.

However, there are also scenarios in which including highway capital costs is not necessarily appropriate. One such case involves analyzing the cost-effectiveness of a single proposed park-and-ride lot. For this case, highway capital costs are sunk but the cost of the lot is not. Given a situation in which it is highly unlikely that many additional freeway lanes will be built (which is the case for most major urban areas in the United States, including Seattle), the trade-off would not be between the cost of the park-and-ride lot and the cost of additional freeway construction, but rather the cost associated with the increased freeway congestion that would result if the lot were not built, the cost of implementing an alternative transportation system management (TSM) tactic of equivalent effectiveness, or the cost of implementing some other form of mass transportation.

Because a sidelight of this study is to provide a base that may be used in developing general guidelines for evaluating the effectiveness of park-and-ride lots, the foregoing scenario was considered. For this, general estimates of congestion costs were developed for inclusion in the cost analysis. Because of limited resources, costs of alternative TSM tactics or mass transit options were not developed.

METHODOLOGY

A great deal of the data needed for this study was available through traditional sources. However, certain types of data regarding the park-and-ride lot user were not available and had to be obtained with a special survey. For this purpose, a windshield-placed mailback business-reply survey form was used. The study consisted of the 26 permanent park-and-ride lots in the Seattle metropolitan area sponsored by WSDOT. These lots were divided into four corridors, as shown in Figure 1. In the course of the survey, 6,138 forms were distributed among the 26 lots, and 2,402 were returned, for an overall return rate of 39.1 percent.

For the purposes of the cost-effectiveness evaluation, the primary information obtained from the survey dealt with what mode patrons used before using the park-and-ride lot. With this information, estimates of previous-mode trip costs could be made and compared with the costs of the corresponding trips involving park-and-ride lots in a before-and-after trip cost analysis. Trip costs as referred to here include much more than just out-of-pocket expenses. The full cost of a trip includes every identifiable cost incurred in the provision for that trip. Among those considered in this study are the user costs of time, vehicle operation, and parking; public agency costs of roadway provision and maintenance and transit service provision; roadway user costs due to traffic congestion; and other publicly incurred costs such as city planning, police services, and noise and air pollution. These cost components are outlined in Table 1.

In addition to the total public and private cost comparison, separate before-and-after analyses were made for user-incurred trip costs and for public-agency-incurred trip costs. Comparing costs from these three different perspectives enabled a clearer view as to how costs and benefits of park-and-ride lots were distributed among the respective groups concerned.

For the purposes of the before-and-after trip cost analysis, the study area was narrowed down to the north and southeast corridors, consisting of 11 lots in total, because they represented the relative extremes as far as park-and-ride lot utilization was concerned. The north corridor lots had the highest combined utilization rate and the southeast lots had the lowest. The north corridor is in a relatively mature stage, whereas the southeast corridor is still young and developing. Thus using these two corridors in the analysis covered both ends of the spectrum of park-and-ride lots in the Seattle area.

Park-and-ride lots in the Seattle area were designed primarily to serve the suburban commuter trip to downtown Seattle. This is reflected in the survey results showing that 95 percent of park-and-ride trips are work trips, and 70 percent of those from the north and southeast corridors go downtown. This study focuses on this primary park-and-ride trip--the work trip to downtown Seattle--in its before-and-after analysis.

For the north and southeast corridor cases analyzed, the percentage breakdown of previous-mode trip types was as follows:

Trip Type	Percent
Walk to transit	22.5
Drive to transit	32.1
Drive alone (automobile)	34.3
Carpool or vanpool	11.1

The corresponding park-and-ride trip breakdown was

Trip Type	Percent
Park-and-ride transit	96.8
Park-and-ride carpool/vanpool	3.2

TRIP COST MODEL

Given the basic analysis needs, a model was required that would reasonably estimate all identifiable costs of a commuter trip. The model needed to be theoretically consistent in estimating costs for each of the four previous-mode and the two park-and-ride trip types.

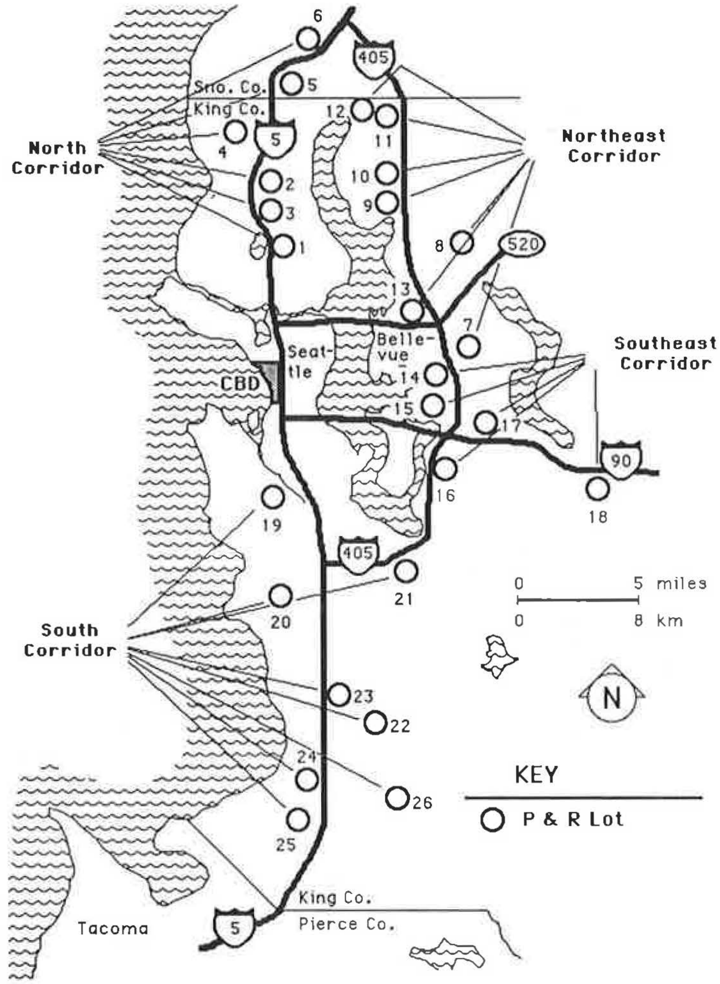

FIGURE 1 Park-and-ride lot study area.

Following a literature search and review, a study by Keeler, Small and Associates (4) was chosen as a base from which to develop the trip cost model. The Keeler-Small study was chosen primarily because (a) it encompassed all of the basic types of costs desired for this study and (b) it was a thorough and highly regarded study that remains today a principal work on the subject of urban transport costs.

The Keeler-Small study estimated trip costs for the major urban transportation modes--automobile, bus, and rail--in the San Francisco Bay area. With such inclusions as travel-time, public-service, pollution, and accident costs, it accounted for more costs than most previous studies.

To fulfill the needs of this study, some general modifications needed to be made to the Keeler-Small

TABLE 1 Total Public and Private Trip Cost Components

Component	Study Value	Reference
Time costs		
In vehicle	1/3 wage rate	(5-7)
Out of vehicle	2.5 x in-vehicle cost	(5-7)
Public costs		
Provision and maintenance of roadway	Peak period; bus 2.49 x automobile	(5,8)
Traffic congestion impact on road users	Time, fuel, maintenance	(5)
Other government-provided services (planning, police, etc.)	Keeler-Small	(4)
Environmental (noise and air pollution)	Keeler-Small	(4)
Automobile costs		
Ownership and operating (less fuel and accident)	FHWA, American Automobile Association, Hertz	(9-11)
Fuel	FHWA, American Automobile Association, Hertz	(9-11)
Accident	FHWA, American Automobile Association, Hertz	(9-11)
Parking costs		
Provision of park-and-ride lot parking	Actual construction and operating and maintenance costs	(12)
Parking at destination	Reported on survey	(5)
Transit costs		
All costs involved in providing transit service (less user fare)	METRO model	(13)
User fare	Actual fare	(5)

study. These modifications are described in detail elsewhere (5).

A review of studies on the value of travel time indicated a range of values (6,7). For the purposes of this study, a middle-range estimate of one-third of the commuter's hourly wage rate was used for the value of in-vehicle time. That value multiplied by 2.5 was used for the value of out-of-vehicle time. Although these values are generally accepted as representative, a sensitivity analysis was done to determine the impact of altering these assumptions.

RESULTS

Total Costs

The total cost comparison for the average previous-mode trip versus the average park-and-ride trip based on a total of 467 cases analyzed is presented in Figure 2, which also lists the component costs for each trip. It should be kept in mind that these costs are averages of individual observations for all trip types in each category; that is, the average previous-mode trip represents a combination of walk to transit, drive to transit, carpool or vanpool, and automobile trips, whereas the average park-and-ride trip incorporates both park-and-ride transit and park-and-ride carpool and vanpool trips.

The results show that on the average, the park-and-ride trip is 7 to 12 percent less expensive than the previous-mode trip, depending on how sunk costs are handled. The park-and-ride trip is more expensive with respect to time, transit, and parking costs. This may appear a little surprising until it is realized that there are no parking costs for the 55

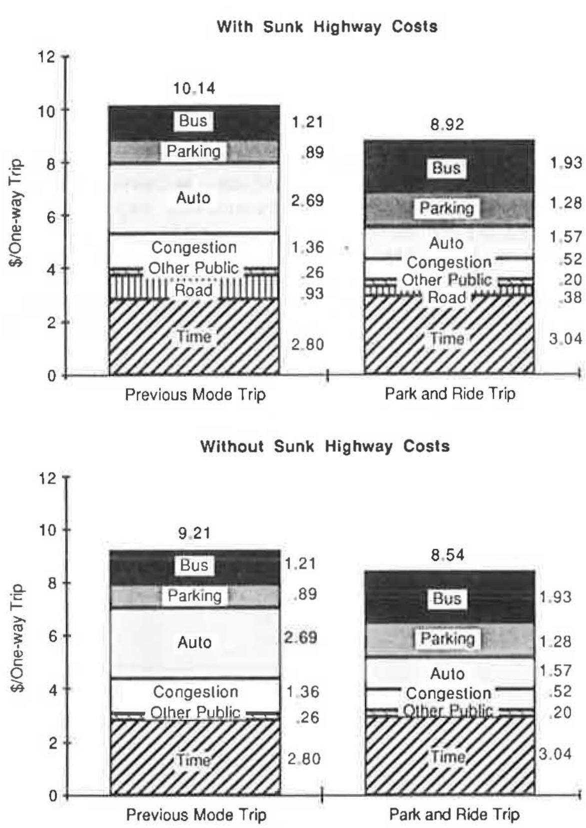

FIGURE 2 Total incurred cost comparison: combined average previous-mode trip versus combined average park-and-ride trip (highway costs included).

percent of previous-mode trips involving transit. The only previous-mode trip with significant parking costs is the one in which the automobile is driven alone. Conversely, every park-and-ride trip incurs the cost of parking at the park-and-ride lot (this is an agency cost, not a user cost).

Figure 3 presents the trip cost for each type of previous-mode trip as compared with the average park-and-ride trip. The only previous-mode trip more expensive than the park-and-ride trip is the one in which the automobile is driven alone. The drive-alone trip represents a large enough portion of previous-mode trips and its cost is high enough for it to cause the combined average previous-mode trip cost to be greater than that of the park-and-ride trip.

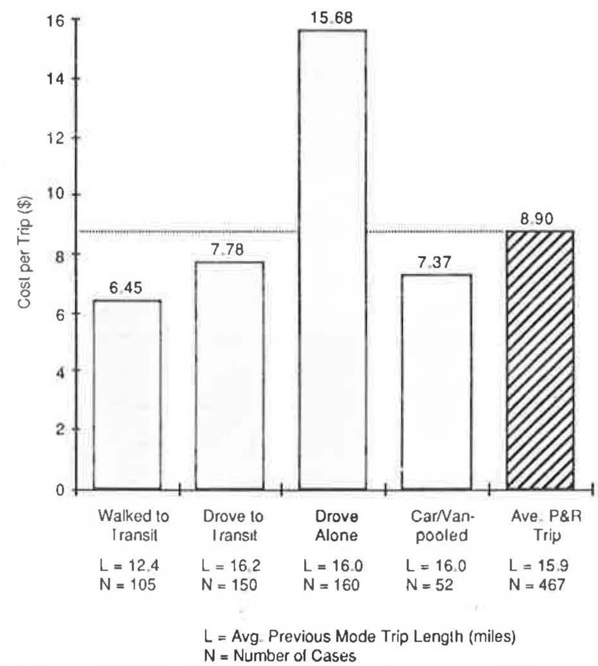

FIGURE 3 Previous-mode total trip cost by mode type versus average park-and-ride total trip cost (highway costs included).

Agency and User Costs

When total costs (i.e., those as they affect users, agencies, and the general community combined) are considered, results indicate park-and-ride lots to be cost-effective. But how do agencies and users fare when considered separately? Figure 4 shows before-and-after (previous mode versus park-and-ride mode) costs per person trip (including highway costs) as incurred by WSDOT, METRO, and the individual user. The agency "after" costs are shown for both existing lot use and 100 percent lot use levels. With respect to WSDOT, park-and-ride trips reduce roadway costs, but the added expense of providing the lot overrides these savings. The net result is that WSDOT spends $0.61 per park-and-ride person trip. However, because WSDOT's primary function is to serve the transportation needs of the public, which in this case includes both the park-and-ride lot user and the general roadway user, net costs to WSDOT must be weighed against benefits both to the park-and-ride and general roadway user. The savings to the park-and-ride lot user as shown in Figure 4 is $1.48, or 22.9 percent, per trip. This in itself more than makes up for WSDOT's expenses.

In considering costs incurred by METRO, previous-

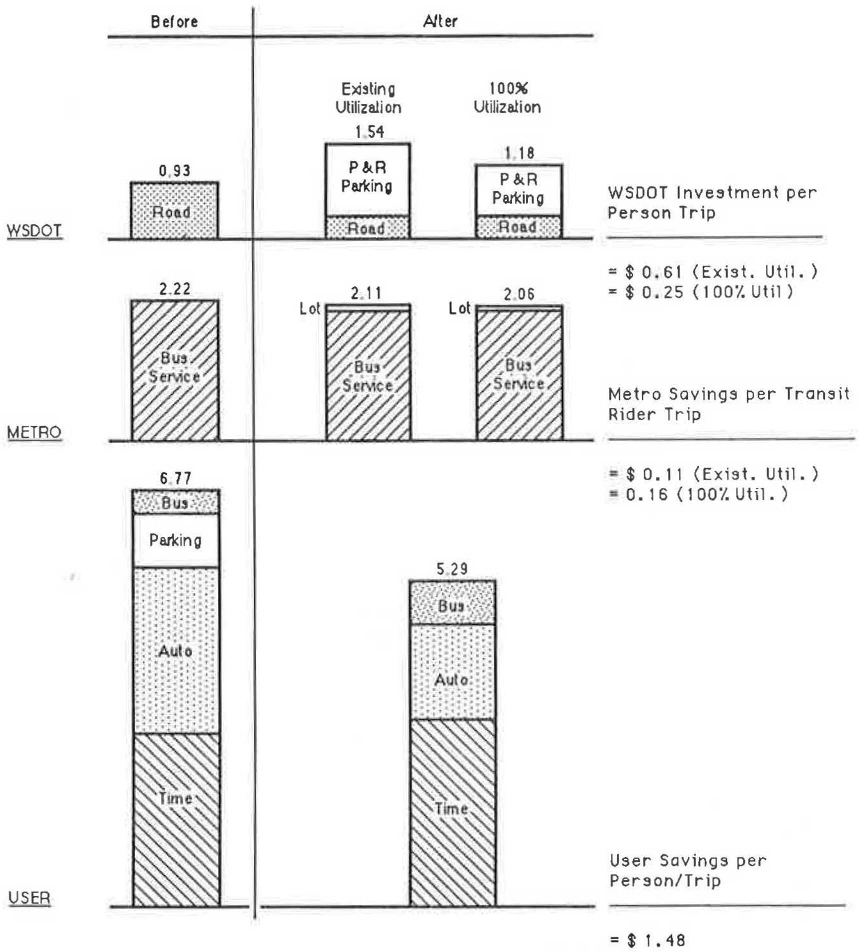

FIGURE 4 Agency and user incurred trip cost comparison (highway capital costs included, congestion costs excluded).

mode trips involving transit (55 percent of all previous mode trips) are compared with park-and-ride transit trips (96.8 percent of all park-and-ride trips). METRO's costs are reduced by $0.11, or 5.0 percent, per transit rider trip when park-and-ride lots are involved (if the lots were 100 percent utilized this would rise to $0.16, or 7.2 percent). In addition, among the data population analyzed, the introduction of park-and-ride lots contributed to a 77 percent increase in transit ridership.

Corridor Comparison

Figure 5 shows the percentage of savings due to park-and-ride lots along with utilization rates for each of the north and southeast corridors as well as for two individual lots, Northgate and Eastgate (3 and 17, Figure 1). These costs include highway capital costs. With respect to trip cost savings, park-and-ride lots are more effective in the southeast corridor than in the north. This is somewhat surprising in light of the fact that the southeast corridor has a much lower utilization rate (44.9 percent) than the north (79.2 percent). In fact, since its current utilization is so much lower, the southeast corridor has a higher potential for improvement. If the lots were fully utilized, the savings per park-and-ride trip would increase to 21.9 percent for the southeast corridor as opposed to 13.4 percent for the north. This contrast in cost-effectiveness is even more evident if the two se-

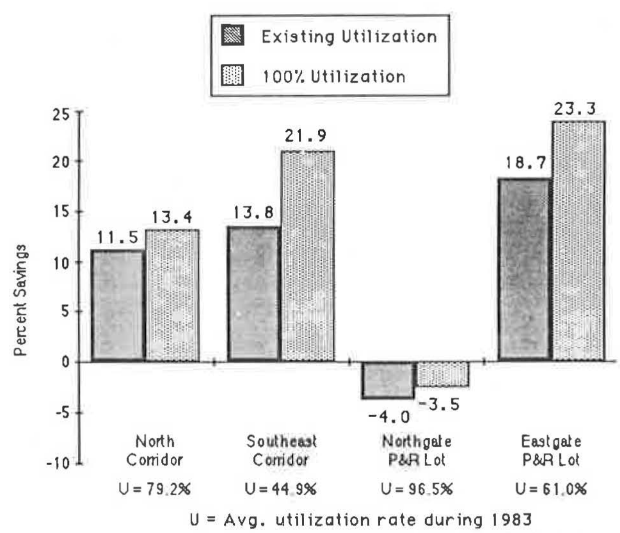

FIGURE 5 Total trip cost savings due to park-and-ride lots by corridor and by selected lots (highway capital costs included).

lected lots from each of the corridors are compared. The Northgate lot, even when fully utilized, experiences an average loss of 3.5 percent per trip, whereas Eastgate shows an impressive savings of 23.3 percent when fully utilized.

Several factors are involved in producing this difference between the two corridors. One is that southeast corridor trips must follow I-90, which was a much more costly road to build than was I-5 in the north corridor. Hence, replacing automobile trips with transit trips results in greater savings in the southeast corridor than in the north.

Perhaps a more significant reason, however, is found by comparing the percentage breakdown of previous-mode trips between the two corridors (see Figure 6). Both corridors are fairly similar in their percentages of drive-to-transit and carpool and vanpool trips. However, a significant difference exists between their walk-to-transit and automobile-drive-alone trips. Park-and-ride lots in the southeast corridor drew a significantly greater proportion of automobile-drive-alone trips from the roadway than did those in the north. At the same time, fewer southeast park-and-riders had previously walked to transit. When compared with the park-and-ride trip, the automobile-drive-alone trip is much more costly and the walk-to-transit trip is less expensive (see Figure 3). Thus, the southeast corridor experiences a greater savings in overall trip costs than does the north corridor.

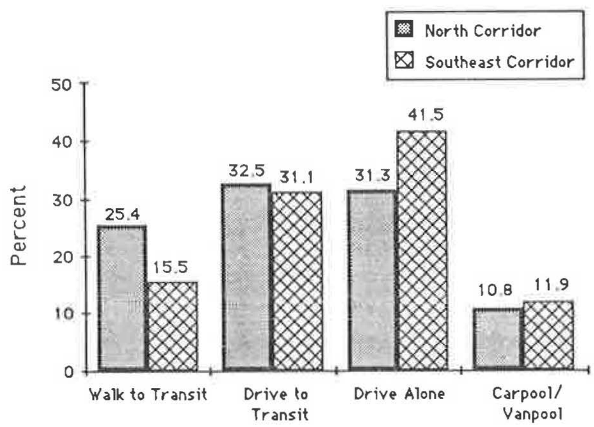

FIGURE 6 Previous-mode percentage breakdowns by corridor.

Figure 7 shows the general cost comparison results by corridor for the case in which highway capital costs are excluded from the cost analysis. In this case, the north corridor appears to fare better than the southeast (8.7 percent versus 4.3 percent savings). This is because estimated congestion costs are higher in the north corridor than in the southeast, whereas highway costs are much greater in the southeast than in the north corridor. Thus, excluding highway costs from the analysis causes a greater reduction in park-and-ride trip savings in the southeast than it does in the north corridor.

An interesting note here is that for both situations discussed (with and without the inclusion of highway capital costs) the southeast corridor fares better than the north corridor when the lots are 100 percent utilized.

Sensitivity Analysis for Various Input Parameter Values

In determining the values for various input parameters, the researchers considered several values based on varying assumptions and sources. Most significant among these were those used for the value of time, highway costs, congestion costs, and automobile owning and operating costs. Several values could be used for each of these parameters. Those used in the cost analysis just presented were those determined most reasonable for use in this study. However, for comparison purposes it was desirable to see how the cost analysis might change if different values were used for these parameters. In the course of the study, the general results of the model were found to be relatively insensitive to changes in estimates used for the value of time; however, they were sensitive to changes in highway, congestion, and automobile costs.

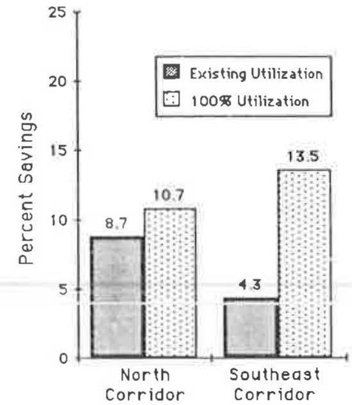

FIGURE 7 Trip cost savings due to park-and-ride lots by corridor (highway costs excluded).

General results of trip cost model runs for cases representing several different combinations of three primary input parameters (highway costs, congestion costs, and automobile costs) are presented in Figure 8. In this sensitivity analysis, peak-period highway costs were either included or not included and congestion costs were varied among low, medium, and high estimates. Automobile costs were varied among those estimated by FHWA (the most conservative), AAA (middle range), and Hertz (the highest). When these varying input combinations were considered, park-and-ride lots proved to be cost-effective for all but the most conservative situations (i.e., when highway capital costs were excluded, either congestion costs were excluded or the lowest estimate for them was used, and the lower-range automobile cost estimates were used).

In a further sensitivity analysis, the trip cost comparison was conducted based on the most extreme sets of parameter-value combinations. Of all the parameter values identified, those that would be most favorable to the previous-mode trip (i.e., would lower the cost of the previous-mode trip more than that of the park-and-ride trip) were outlined as follows as extreme case 1:

- Highway capital costs excluded,
- Congestion costs excluded,
- Automobile costs based on FHWA and park-and-ride second-car values [the park-and-ride second-car concept and the Keeler-Small highway cost method are explained in detail elsewhere (5)],
- In-vehicle time one-half the hourly wage rate, and
- Out-of-vehicle time 3.33 times in-vehicle time.

Extreme case 2, that which was most favorable to the park-and-ride trip, was identified by the following parameter values:

- Highway costs based on the Keeler-Small method,

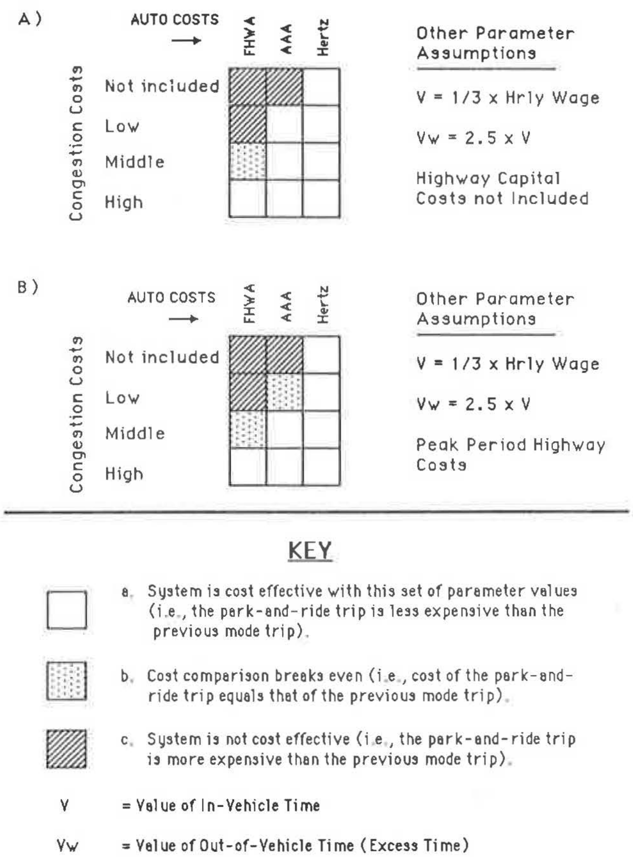

FIGURE 8 Trip cost comparison sensitivity analysis for various input parameter values.

- Congestion costs based on the high estimates,
- Automobile costs based on Hertz estimates,
- In-vehicle time equal to one-fourth the hourly wage rate, and
- Out-of-vehicle time 1.5 times in-vehicle time.

The results of the first extreme case show the previous-mode trip to be 7.2 percent less expensive than the park-and-ride trip ($8.50 versus $9.16). The results of the other extreme case, however, indicated the previous-mode trip to be 35.4 percent less expensive than the park-and-ride trip ($12.33 versus $9.17). These extremes encompass a broad range of possibilities as far as the trip cost analysis is concerned and indicate that park-and-ride lots are highly likely to be cost-effective for the situation analyzed in the preceding cost analysis.

Measures of Effectiveness

In order to provide a more comprehensive analysis, it was desirable to evaluate several measures of effectiveness independently and as much as possible in terms of their own units rather than in dollars. This was done for the following measures: travel time, person miles traveled, vehicle miles traveled (VMT), traffic volumes, vehicle emissions, accidents, and energy consumption. Table 2 presents a general summary of the evaluation of these individual measures of effectiveness.

For the most part, park-and-ride lots have had a small yet positive impact with regard to individual measures of effectiveness. Although travel time and person miles traveled have increased slightly, the other measures--VMT, traffic volumes, accidents, vehicle emissions, and energy consumption--have experienced reductions. In other words, the negative impact of slightly longer trip lengths and travel times for the commuter is offset by the positive effects of a more efficient transportation system (fewer VMT), fewer vehicle accidents, better air quality, and more efficient use of energy.

CONCLUSIONS

The basic conclusion of this study is that park-and-ride lots in the Seattle metropolitan area, as a system, are cost-effective. The benefits they provide to the general community justify their expense. Park-and-ride lots provide considerable savings to the user with respect to automobile and parking expenses and they also prove beneficial to both WSDOT and METRO, the agencies directly involved. The user savings from the park-and-ride system have significantly outweighed WSDOT's investment. With respect to METRO, park-and-ride trips have proven less costly to provide then other transit trips, and, in addition, the lots have contributed to an increase in transit ridership.

REFERENCES

1. Regional Transportation Plan. Puget Sound Council of Governments, Seattle, Wash., 1982.

TABLE 2 Measure-of-Effectiveness Evaluation Summary

		Estimated Percent Change	
Measure of Effectiveness	Unit	Park-and-Ride Trip Versus Previous-Mode Trip	Park-and-Ride Lots Versus Total Regional Values
Travel time	Minutes/person trip	+13.3	–
Person miles traveled	Miles/person trip	+3.9	–
Accidents	Dollar equivalent/person trip	−35.5	–
Energy consumption	Gallon of gas/person trip	−21.3	–
VMT	Miles/day	–	−0.5[a]
Traffic volumes	Vehicle trips/day	–	−1.3[b]
Vehicle emissions	Grams/day		
Carbon monoxide		–	−0.09[c]
Hydrocarbons		–	−0.12[c]
Nitrogen oxide		–	−0.16[c]
Total suspended particles		–	+0.08[c]

[a]Represents percent change with respect to total VMT on Interstate and principal arterials in King County.
[b]Indicates percent change due to park-and-ride lots on the I-5 segment immediately north of downtown Seattle.
[c]Represents percent change with respect to total air pollutants in King County.

2. Mobility for the Eighties: Metro Transition Phase IV, Technical Report. Draft Final Report. Municipality of Metropolitan Seattle, Seattle Wash., 1980.
3. W.C. Bogart and D.K. Glaze. Metro Park-and-Ride System: Lane Equivalency Analysis. Washington State Department of Transportation, Olympia, 1976.
4. The Full Costs of Urban Transport, Part 3: Automobile Costs and Final Intermodal Cost Comparisons. Institute of Urban and Regional Development, University of California at Berkeley, 1975.
5. G.S. Rutherford and C.A. Wellander. Cost Effectiveness of Park-and-Ride Lots in the Puget Sound Region. Washington State Department of Transportation, Olympia, 1985.
6. P.R. Stopher. Derivation of Values of Time from Travel Demand Models. In Transportation Research Record 587, TRB, National Research Council, Washington, D.C., 1976, pp. 12-18.
7. F. Southworth. Calibration of Multinomial Logit Models of Mode and Destination Choice. Transportation Research A, Vol. 4, 1976.
8. Final Report on the Federal Highway Cost Allocation Study. U.S. Department of Transportation, May 1982.
9. Costs of Owning and Operating Automobiles and Vans 1984. FHWA, U.S. Department of Transportation, May 1984.
10. Your Driving Costs. American Automobile Association, Falls Church, Va., 1982.
11. Press information release. Hertz Corporation, New York, May 31, 1982, and March 21, 1983.
12. Parking Cost Inventory, August-September 1982. Puget Sound Council of Governments, Seattle, Wash., 1982.
13. B. Burnett. Route Cost Model Development and Fare Study Results. METRO Transit, Seattle, Wash., 1983.

Publication of this paper sponsored by Committee on Transportation System Management.

Proposed Warrants for High-Occupancy-Vehicle Treatments in New York State

DANIEL K. BOYLE

ABSTRACT

At present the New York State Department of Transportation has informal guidelines for evaluating proposals for high-occupancy-vehicle (HOV) lanes. As attention to this particular treatment increases, it is important that many worthy projects be evaluated similarly. This report examines before-and-after conditions for approximately 25 HOV treatments nationwide and proposes warrants for the preliminary analysis of HOV projects. Particular attention is given to existing traffic volumes, person movement, and potential travel-time savings. These proposed warrants can help determine whether to advance a proposed HOV project beyond the general first-stage analysis to a detailed consideration of alternatives.

The New York State Department of Transportation (NYSDOT) is beginning to see proposals from upstate areas for high-occupancy-vehicle (HOV) lanes, and the emphasis on "rebuilding New York" will create opportunities for temporary HOV treatments, which may be advanced to permanent status once reconstruction has been completed. Because of the unique nature of HOV treatments, guidelines or warrants are needed to help in making sound judgments concerning the relative merits of HOV proposals.

The literature generally advises against use of warrants for HOV projects (1,2). Reasons for this position include the unique nature of each project, difficulties caused by the involvement of several agencies with conflicting philosophies, the essentially political nature of any decision on HOV treatments, and the emphasis on creating new demand for high-occupancy vehicles as opposed to accommodating existing bus riders and carpoolers. FHWA recommends against uniform engineering-type warrants and suggests instead the identification of charac-

Transportation Statistics and Analysis Section, Planning Division, New York State Department of Transportation, Albany, N.Y. 12232.

teristics and criteria common to successful projects. In a sense, this a matter of semantics. The purpose here is to establish planning warrants that can serve as an indication early in the project development process as to whether HOV alternatives merit more detailed attention. This is consistent in spirit with the FHWA suggestions. A similar effort was undertaken by the North Central Texas Council of Governments (NCTCOG) in 1978 (3), and their findings are incorporated here.

In establishing HOV warrants, the following factors are considered:

- Existing traffic volumes (including level of transit service) and congestion,
- Person movement,
- Travel-time savings,
- Downtown conditions (e.g., intensity of development and employment levels), and
- Other factors affecting the success of HOV treatments.

These are discussed individually, along with problems encountered in implementing HOV lanes. Following this, various measures of the success of HOV treatments are presented. Ancillary actions contributing to successful projects are examined. Physical and design considerations are highlighted, although this study by no means treats these points in detail. Finally, a recommended set of first-cut warrants is presented.

Reflecting the HOV literature, this study focuses on freeway treatments, with some attention given to arterial projects. Because ramp treatments are not likely to be implemented in New York State in the near future, these are not considered.

ESTABLISHMENT OF HOV WARRANTS

Existing Traffic Volumes and Congestion

Severe, periodic, and predictable congestion is often the major motivating factor in initiating HOV lanes (4). Although exact calculations are difficult because of changes in the number of lanes over a given section of freeway or in hours of operation, traffic volumes on freeways before HOV treatment generally exceed 1,500 vehicles per lane per hour during the peak period and 1,600 vehicles per lane in the peak hour (Table 1). Limited data for arterials indicated traffic volumes before HOV treatment in the neighborhood of 650 vehicles per lane per hour in the peak period (Table 1). If a roadway is operating at level-of-service (LOS) D or worse, investigation of HOV alternatives is recommended (2,3). At LOS E or F, a physically separated lane (Shirley Highway, San Bernardino Freeway) may be warranted (17). Although the same number of people is moved, benefits of up to a 5 percent reduction in the number of vehicles may be realized with an HOV lane that is not physically separated and up to a 10 percent reduction with a physically separated HOV lane (1). Care must be taken to ensure that there is no significant degradation of existing traffic flow in nonpriority lanes, although minor adverse initial impacts are to be expected. It should be noted that in 8 out of 12 cases where average automobile speed was reported, average peak hour/peak period speed of nonpriority traffic increased or remained constant after implementation of the HOV lane (Table 2). Speed before HOV treatment averaged less than 25 mph for the peak hour and less than 30 mph for the peak period. At these speeds HOV lanes can increase the total number of people moved over the highway.

TABLE 1 Vehicles per Lane per Hour Before HOV Treatment *(1, 4-15, 16)*

Project	Type	Peak Period	Peak Hour
Freeway Treatments			
Boston, Southeast Expressway			
1971	Contraflow	1,518	2,072
1977	Take a lane	1,800	1,719
San Francisco, Oakland Bay Bridge	Bridge toll	1,572	1,689
Marin County, US-101	Contraflow/add a lane	1,651	1,750
Seattle, I-5	Reversed median		1,273
Virginia-D.C., Shirley Highway	Separated	1,394	1,756
Boston, I-93	Separated	828	
Santa Monica, Diamond Lane	Take a lane	2,020	
Miami, I-95	Add a lane	1,900	1,581
Houston North Freeway			
Add a lane	Add a lane	1,651	
Contraflow	Contraflow		1,743
Portland, Banfield Expressway	Add a lane		1,955
San Bernardino	Separated	1,741	1,828
Honolulu, Moanalua	Add a lane	1,750	
I-495, Lincoln Tunnel	Contraflow		940
Arterial Treatments			
Miami, South Dixie Highway	Contraflow/add a lane	1,630	
Dallas			
Harry Hines Boulevard	Curb lane	458	
Fort Worth Avenue	Curb lane	603	
Honolulu, Kalanianaole	Contraflow/add a lane	971	

Existing bus volumes are also of interest in determining the usefulness of an HOV proposal. This must be approached with caution, for although a region with a historically strong tradition of transit use is more likely to be able to support an HOV lane, it is also true that a major purpose of HOV projects may be to create new demand. The literature gets around this problem by suggesting design-year criteria or potential bus volumes (2,3,5,6,19,20). A minimum of 40 buses in the peak hour is the consensus figure, slightly higher for concurrent flow on freeways and median lanes on arterials and slightly lower for other arterial treatments. This works out to 1,600 bus passengers in the peak hour.

Within 1 to 3 years, service levels should reach 50 to 75 percent of design-year warrants (2). Peak-hour carpool volumes are less frequently addressed. Suggested design-year volumes are set up so as to ensure that a carpool lane carries the same number of persons as a regular lane (5,19). Pre-HOV-lane peak-hour volumes as low as 10 buses per hour have been reported on the San Bernardino, Banfield, and Miami I-95 projects, whereas minimum peak-period volumes before HOV implementation fall in the range of 15 to 35 buses, with the exception of the South Dixie Highway project in Miami (Table 3). Pre-HOV-lane carpools per peak hour generally numbered between 100 and 200, and the corresponding figure for the peak period is roughly 650, with considerable variation (6-8,12-15,18). The disparity between existing and design-year bus volumes indicates the expectation that HOV demand will be generated. A minimal level of express bus service is acceptable at the outset, but carpools must also be allowed in the HOV lane if bus volumes are low.

Graphs and nomographs have been developed to judge the appropriateness of HOV proposals (3,6). These are generally based on existing traffic volumes and automobile occupancy rates and can easily be used in conjunction with the warrants developed here.

A final note with regard to traffic volumes concerns the peak/off-peak directional split. Contraflow

TABLE 2 Average Before-and-After Speeds on HOV Projects *(5,7,10,13,16,18)*

		Peak-Period Speed (mph)				Peak-Hour Speed (mph)			
		General Lane		HOV Lane		General Lane		HOV Lane	
Project	Type	Before	After	Before	After	Before	After	Before	After
Boston Southeast Expressway									
1971	Contraflow					23.0	29.0	23.0	50.4
1977	Take a lane					21.0	15.5	21.0	37.2
Marin County, US-101	Contraflow/add a lane	34.1	47.6	34.1	53.4	30.0	40.0	30.0	47.1
Virginia-D.C., Shirley Highway	Separated					19.0	17.7	55.5	51.5
San Francisco, bus lanes	Central business district			14.8	16.4				
Miami, I-95	Add a lane	32.0	41.4	37.2	53.5				
Houston North Freeway									
Add a lane	Add a lane	26.0	26.0	26.0	48.0				
Contraflow	Contraflow	17.0		17.0		21.0	25.0		
Portland, Banfield Expressway	Add a lane					38.2	37.9	38.2	51.5
Dallas									
Harry Hines Boulevard	Curb Lane	31.8	33.9						
Fort Worth Avenue	Curb lane	33.3	36.6						
San Bernardino	Separated					25.4	23.6	25.4	55.0
I-495, Lincoln Tunnel	Contraflow					10.0	11.5	10.0	30.0

TABLE 3 Pre-HOV-Lane Bus Volumes *(5-7, 9, 10, 12-15, 18, 21)*

		Buses per Lane per Hour	
Project	Type	Peak Period	Peak Hour
Boston, Southeast Expressway			
1971	Contraflow		57
1977	Take a lane		50
Dallas, North Central Corridor	—		115
San Francisco, Oakland Bay Bridge	Bridge toll	476	327
Marin County, US-101	Contraflow/add a lane	214	86
Virginia-D.C., Shirley Highway	Separated		176
Santa Monica, Diamond Lane	Take a lane	35	
Miami			
I-95	Add a lane	24	10
South Dixie Highway	Contraflow/add a lane	5	
Portland, Banfield Expressway	Add a lane		10
San Bernardino	Separated		10
Honolulu			
Moanalua	Add a lane	17	
Kalanianaole	Contraflow/add a lane	33	
I-495, Lincoln Tunnel	Contraflow		497

lanes are appropriate only if the traffic flow is imbalanced. FHWA suggests a minimum 60/40 peak/off-peak directional split on a given freeway before contraflow is considered, whereas others recommend 65/35 and even higher (2,4,12,17,22). Service in the off-peak direction should be maintained at LOS C if at all possible and in the worst case at LOS D (2). Contraflow as a solution to peak-direction congestion can lead to problems in the opposite direction if off-peak travel is increasing, as is happening in Houston.

Person Movement

Congestion alone is not a justification for all types of HOV actions, as experience with "take-a-lane" projects has shown. Increasing person throughput is a key goal of most HOV treatments. This is usually measured on a persons-per-lane basis, with a comparison of HOV-lane and average nonpriority-lane person throughput for either the peak hour or the peak period (1-3,5, 17,19). A project increases the person-carrying efficiency of the roadway if the ratio of person throughput in the HOV lane to average person throughput in the general lanes exceeds 1.0. Another calculation sometimes made is the percentage of persons in the priority lane in the peak hour or period (2,6); this is compared with the percentage of peak-direction roadway taken up by the priority lane (i.e., if there are three general-purpose lanes and one priority lane in the peak direction, the HOV lane occupies 25 percent of the roadway). A slight variation of the foregoing measures is to compare the person throughput of the HOV lane with the average person throughput of all lanes, including the HOV lane. In making comparisons, at least one analyst has suggested that an HOV lane be judged against existing rather than "what-if" conditions, because public acceptance is based on previous experience (6).

Table 4 shows data on lane throughput for HOV projects. Surprisingly, 4 of 11 projects show HOV person throughput exceeding or approaching person throughput in the general lane. Several projects generally considered to be successes do not meet this criterion, as shown in Table 4. It should be noted that in many cases, this ratio increases over time as the HOV lane attracts new users (see paper by Southworth and Westbrook in this Record).

Travel-Time Savings

The ability of an HOV treatment to generate travel-time savings has been called the single most important predictor of its success. Travel-time savings for high-occupancy vehicles can be calculated in two ways: a before-and-after comparison or a comparison of HOV travel time with non-priority-lane travel time. The latter method, which yields a result that can be called the travel-time advantage, is most often used in the literature. Consideration must also be given to non-priority-lane travel-time changes; these are calculated on a before-and-after basis. Usually, travel time is only considered on the HOV treatment itself and not for the entire trip, because other conditions are presumed to remain constant and therefore do not contribute to travel-time savings.

Person throughput and travel-time savings are combined in the measure person-minutes of travel. This measure is most useful when there is a travel-time increase in the nonpriority lanes. Person-minutes saved in the HOV lane can be compared with person-minutes lost in nonpriority lanes to judge the overall effectiveness of the HOV treatment (3). Five minutes is often mentioned as the minimum ac-

TABLE 4 Person Throughput per Lane on HOV Treatments *(1,6,8-15)*

			Person Throughput per Lane				Ratio of Person Throughput per Lane (HOV:General)	
			HOV Lane		General Lanes			
Project	Type	Roadway Class	Peak Period	Peak Hour	Peak Period	Peak Hour	Peak Period	Peak Hour
Boston, Southeast Expressway 1977	Take a lane	Freeway	8,496	4,015	6,552	2,738	1.30	1.47
Marin County, US-101	Contraflow/add a lane	Freeway	4,728		6,214		0.76	
Boston, I-93	Separated	Freeway	1,729		2,169		0.80	
Santa Monica, Diamond Lane	Take a lane	Freeway	19,099		39,107		0.49	
Miami								
I-95	Add a lane	Freeway	4,356		4,496		0.97	
South Dixie Highway	Contraflow/add a lane	Arterial	4,528		6,792		0.67	
Houston North Freeway	Add a lane	Freeway	4,200		3,087		1.36	
Portland, Banfield Expressway	Add a lane	Freeway		1,073		2,273		0.47
San Bernardino	Separated	Freeway	9,815		8,215		1.19	
Honolulu								
Moanalua	Add a lane	Freeway	2,621		3,077		0.85	
Kalanianaole	Contraflow/add a lane	Arterial	2,618		3,071		0.85	

ceptable travel-time savings (1,3,19), although figures as low as 3 min are found for certain types of bus-only treatments and minimum numbers of 7, 10, and 15 to 20 min are also in the literature (2,3,17, 23). It is generally accepted that travel-time savings of less than 5 min are barely perceptible, and FHWA recommends 10 min as a minimum (2). Because HOV projects vary in length, a ratio form (time per distance) is often suggested as an appropriate measure. There is widespread agreement that an HOV treatment should provide a travel-time savings of at least 1 min per mile length of HOV treatment (1-3). This is equivalent to raising the average speed of the vehicles in the HOV lane from 30 mph (before) to 60 mph, from 20 to 30 mph, or from 15 to 20 mph, assuming that the average speed of non-priority-lane vehicles remains roughly constant. Put this way, it is obvious that HOV projects have the best chance of success when average speeds are low, that is, in congested situations. Of existing projects with data available, 9 of 16 freeway projects and 4 of 8 arterial projects showed travel-time savings of at least 1 min per mile (Table 5). Along with reductions in travel time, HOV lanes can also reduce travel-time variance, which is particularly important for transit.

Long-distance HOV treatments on highly congested routes are likely to produce significant travel-time savings. A systems approach to HOV treatments--for example, a park-and-ride lot with an exclusive ramp to an HOV lane that exits in the central business district (CBD) via an exclusive ramp to a contraflow lane on a downtown street--can make a small savings

TABLE 5 Travel-Time Savings per Mile in HOV Lane *(1,6,7,16,21,24,34)*

					Travel-Time Savings per Mile (min/mi)	
Project	Type	Roadway Class	Computed Travel-Time Savings in HOV Lane (min/mi)	Project Length (mi)	Computed	Reported
Boston, Southeast Expressway						
1971	Contraflow	Freeway	7.5	8.4	0.89	1.25
1977	Take a lane	Freeway	12.2	8.0	1.53	0.60
San Francisco, Oakland Bay Bridge	Bridge toll	Freeway	3.3	0.5	6.50	10.00
Marin County, US-101	Contraflow/add a lane	Freeway	0.5	3.7	0.14	0.25
Seattle, I-5	Reversed median	Freeway	9.2			
Virginia-D.C., Shirley Highway	Separated	Freeway	23.0	12.0	1.92	1.85
Boston, I-93	Separated	Freeway	4.0	0.75	5.33	5.30
Garden State Parkway	Add a lane	Freeway		12.0		1.00
Santa Monica, Diamond Lane	Take a lane	Freeway	4.8	12.6	0.38	0.50
Miami						
I-95	Add a lane	Freeway	1.7	7.5	0.23	0.25
N.W. 7th Avenue	Reversed median	Arterial		9.9		0.65
South Dixie Highway	Contraflow/add a lane	Arterial	7.4	5.5	1.35	1.30
Houston North Freeway						
Add a lane	Add a lane	Freeway	3.2	3.3	0.97	
Contraflow	Contraflow	Freeway	12.7	9.6	1.32	
Portland, Banfield Expressway	Add a lane	Freeway	1.3	3.3	0.39	0.30
Dallas						
Harry Hines Boulevard	Curb lane	Arterial		2.0		0.40
Fort Worth Avenue	Curb lane	Arterial		2.0		0.02
Baltimore, York Road	Curb lane	Arterial		6.5		0.05
San Bernardino	Separated	Freeway	9.0	11.0	0.82	0.93
Honolulu						
Moanalua	Add a lane	Freeway	5.0	2.7	1.85	1.85
Kalanianaole	Contraflow/add a lane	Arterial	3.0	2.5	1.20	1.30
I-495, Lincoln Tunnel	Contraflow	Freeway	8.0	2.5	3.20	3.13
Long Island Expressway	Contraflow	Freeway	15.0	2.0	7.50	7.50
Arlington, Virginia						
Arlington Boulevard (Route 50)	Curb lane	Arterial		4.5		1.10
Wilson Boulevard	Curb lane	Arterial		3.5		1.40

in time on each component, which adds up to significant overall travel-time savings (23). It should be noted that motorists tend to perceive travel-time savings as up to twice as large as they actually are (1). A significant travel-time advantage on the HOV treatment is necessary to make up for access-time losses in mode switches from single-occupancy automobile to bus or carpool (6). Thus, careful attention to warrants involving travel-time savings for HOV projects is justified.

Downtown Conditions

The general consensus is that a strong, intensively developed downtown that is the focal point for regional employment is a necessary component for a successful HOV project (5,8,19). A strong CBD can provide a ready market for express bus service and facilitate carpool formation. High parking costs, which usually accompany a CBD of this type, can also motivate HOV use. Although quantification is relatively rare, a minimum CBD employment of 20,000 to 30,000 has been suggested. For an intensive right-of-way busway, more stringent standards are suggested: 50,000 employment in the CBD and 20 million ft^2 of office space or 1 mi^2 of intensive development characteristic of a vibrant downtown (19). There are recent indications, however, that the emphasis on downtown may not be as important as once thought. Recent proposals are under serious consideration in the Seattle and New York City metropolitan areas for HOV lanes on suburban expressways not radially oriented to downtown. It is possible that future commercial and industrial development in the suburbs will justify HOV treatments on circumferential highways.

Appropriateness of Carpools

It is said that most successful HOV lanes have been designed for buses, with carpools permitted as the capacity of the lane allows (6). Although this view understates the important role that carpools play in HOV success stories, it is true that carpools are defined and allowed in such a way as to ensure sufficient use of the lane without forfeiting the travel-time advantage an HOV lane provides (12). This is accomplished by varying the number of persons that define a carpool. Although three persons is the most widely used definition [11 of 15 projects identified in the literature began with or changed to a three-person definition (Table 6)], it is not uncommon for two persons to be used as the minimum, and in severely congested situations a four-person minimum has sometimes been the rule. Pre-HOV-lane carpool counts indicate that between 3 and 18 percent of existing vehicles are eligible to use the HOV lane (Table 7). Current FHWA policy (Wayne Berman, April 1985) is to reject funding for an HOV treatment unless the carpool definition is at least three persons (except in unusual circumstances, such as Seattle's circumferential project mentioned earlier). There has been

TABLE 6 Carpool Definitions *(1,5,6,8,11,14,24)*

Project	Type	Roadway Class	Carpool Definition (min. no. of occupants) Old	New
Boston, Southeast Expressway, 1977	Take a lane	Freeway	3	Same
Marin County, US-101	Contraflow/add a lane	Freeway	–[a]	3
Virginia-D.C., Shirley Highway	Separated	Freeway	4	3
Boston, I-93	Separated	Freeway	3	Same
Garden State Parkway	Add a lane	Freeway	3	2
Santa Monica, Diamond Lane	Take a lane	Freeway	3	Same
Miami				
I-95	Add a lane	Freeway	3	2
South Dixie Highway	Contraflow/add a lane	Arterial	2	Same
Houston North Freeway	Add a lane	Freeway	–[b]	Same
Portland, Banfield Expressway	Add a lane	Freeway	3	Same
San Bernardino	Separated	Freeway	–[a]	3
Honolulu				
Moanalua	Add a lane	Freeway	3	Same
Kalanianaole	Contraflow/add a lane	Arterial	–[a]	3
Seattle, SR-520	Concentrated flow	Freeway	3	Same
Arlington, Virginia, Arlington Boulevard (Route 50)	Curb lane	Arterial	–[a]	3

[a]No carpool.
[b]Vanpool.

TABLE 7 Pre-HOV-Lane Vehicles Eligible for HOV Lane *(6-8,12-15,18)*

Project	Type	Percentage of Vehicles: Peak Period	Peak Hour
Boston, Southeast Expressway, 1977	Take a lane	4.2	–
Virginia-D.C., Shirley Highway	Separated	14.0	3.7
Boston, I-93	Separated	4.2	–
Santa Monica, Diamond Lane	Take a lane	3.1	–
Miami			
I-95	Add a lane	16.2	11.2
South Dixie Highway	Contraflow/add a lane	18.0	–
San Bernardino	Separated	2.8	4.1
Honolulu, Moanalua	Add a lane	8.6	–

a trend toward lowering the minimum-carpool definition over the life of a project, and some analysts have explicitly stated that it is better to make the initial rules too restrictive and then relax them than to do the reverse (12). The federal perspective is that minimum-carpool definitions will very over time in response to political pressure, the intensity of development in the corridor, and other factors. FHWA's preference for HOV-3 (shorthand for a three-person-minimum rule) derives from the observation that a lower minimum does not en- courage HOV use but merely shifts a portion of existing traffic into the priority lane. In selecting a carpool definition, a balance must be sought between a too-lax rule that merely shifts existing traffic and a too-restrictive rule that results in underutilization of the HOV lane. Also, it should be recognized that the carpool definition is not unchangeable; flexibility in defining acceptable uses of the HOV lane can be an important factor in the continued success of the project.

Essentially, carpools are nearly always appropriate in HOV lanes. The following circumstances have been suggested as justifying inclusion of carpools (3,12):

- Little initial bus service,
- Plenty of excess capacity,
- Travel-time advantage to buses retained,
- Safety not jeopardized, and
- Adequate enforcement.

The last two points deserve some elaboration here. Enforcement requirements are obviously affected when carpools are allowed along with buses, and enforcement plans should be drawn up in advance. Regarding safety, carpools are not generally allowed on contraflow lanes and may not be appropriate on concurrent-flow lanes unless shoulders are provided. Houston allows vanpools in its I-45 contraflow lane, and a permit system for contraflow carpools is sometimes suggested but to date no contraflow lanes allow carpools. On concurrent-flow lanes, minimal separation is likely to result in an increase in accidents (17).

PROBLEMS IN HOV IMPLEMENTATION

HOV treatments can lead to or experience several types of problems. Enforcement, politics, and safety are three major potential problem areas. In addition, there are situations in which an HOV lane may not be an appropriate choice. All these factors are discussed in the following paragraphs.

Enforcement is difficult and expensive. Although physically separated treatments do not present enforcement problems, concurrent-flow lanes can be an enforcement headache. As mentioned earlier, allowing carpools on an HOV lane increases enforcement problems, because it becomes necessary not only to view the vehicle but to count the occupants. Consistency of enforcement is often cited as a key factor in HOV success, but this requires money (6,12,17). No treatment will achieve perfect compliance, but a 5 to 10 percent violation rate is suggested as a reasonable goal (1). Only about one-half of the treatments reported in the literature meet this goal (Table 8).

Accident rates are probably correlated with enforcement (1), but they also vary with type of HOV treatment and are influenced by design alternatives. For example, provision of a median, shoulder, or empty adjacent lane can reduce accidents (8,25). An HOV lane separated by a permanent concrete barrier is even safer and is likely to experience no problems with accidents. As far as different treatments are concerned, safety is worst for concurrent lanes, because of the speed differential between adjacent lanes and weaving traffic (8). As mentioned previously, carpools in nonseparated HOV lanes are likely to increase accidents. On arterials, increased density in nonpriority lanes is a potential cause of accident increases (12). Increases in accidents accompanied HOV lanes in slightly more than half of the studies reported in the literature, with roughly 15 percent reporting a decrease and the remaining 30 percent showing no change (Table 9).

An increase in accidents or a strict enforcement policy or both can lead to problems with public acceptance, as happened in Santa Monica and Boston (8,9,11). The major problem in both places, however, was that a general-purpose lane was taken away on an already congested highway in order to create the HOV lane. The political problems caused by this take-a-lane action were so acute as to lead to the termination of both projects and preclude implementation of take-a-lane anywhere else. One observer summarized the situation with the statement that operational changes are difficult to implement when the public goal conflicts with short-term private interests (9). Even in a situation where a lane is added, there will be political repercussions if the added capacity is perceived to be underutilized. The decision to implement an HOV project is essentially a political one, and HOV treatments are naturally subject to political pressure. This political dimension casts doubt on the usefulness of establishing warrants.

TABLE 8 HOV-Treatment Violation Rates *(6,8,10,12-14,18,21)*

Project	Type	Roadway Class	Violation Rate (%)
Boston, Southeast Expressway			
1971	Contraflow	Freeway	35
1977	Take a lane	Freeway	80
Marin County, US-101	Contraflow/add a lane	Freeway	35
Virginia-D.C., Shirley Highway	Separated	Freeway	<3
Boston, I-93	Separated	Freeway	Very low
Santa Monica, Diamond Lane	Take a lane	Freeway	15
Miami			
I-95	Add a lane	Freeway	37
South Dixie Highway	Contraflow/add a lane	Arterial	8
Houston, North Freeway			
Add a lane	Add a lane	Freeway	<2
Contraflow	Contraflow	Freeway	14
Portland, Banfield Expressway	Add a lane	Freeway	12
San Bernardino	Separated	Freeway	Low
Honolulu, Moanalua	Add a lane	Freeway	15
I-495, Lincoln Tunnel	Contraflow	Freeway	Near 0
Indianapolis, College Avenue	Curb lane	Arterial	High

TABLE 9 Accident Rates Before and After HOV Treatment *(1,6,10,12-15,18,21,22,24,26)*

Project	Type	Roadway Class	Accident Rate per Million Vehicle Miles Before	After
Boston, Southeast Expressway, 1977	Take a lane	Freeway		NC
Marin County, US-101	Contraflow/add a lane	Freeway	2.91	6.94
Garden State Parkway	Add a lane	Freeway	1.49	2.97
Santa Monica, Diamond Lane	Take a lane	Freeway	1.40	5.10
Miami				
I-95	Add a lane	Freeway	4.48	2.67
N.W. 7th Avenue	Reversed median	Arterial		NC
South Dixie Highway	Contraflow/add a lane	Arterial	6.40	12.10
Houston North Freeway				
Add a lane	Add a lane	Freeway	1.10	1.70
Contraflow	Contraflow	Freeway	2.40	2.10
Portland, Banfield Expressway	Add a lane	Freeway	1.29	1.68
San Bernardino	Separated	Freeway	1.11	1.14
Honolulu				
Moanalua	Add a lane	Freeway		NC
Kalanianaole	Contraflow/add a lane	Arterial		NC
I-495, Lincoln Tunnel	Contraflow	Freeway	3.00	3.70

Note: NC = no change.

First-cut warrants of the type proposed here, however, can be helpful to decision makers in providing a technical rather than political basis on which to weed out undeserving proposals, although politically popular proposals are likely to proceed regardless of warrants.

Arterial HOV treatments are particularly problematic: restricted deliveries adversely affect goods movement, turning movements are more difficult, accidents can be expected to increase, enforcement faces the same types of problems as those discussed earlier regarding concurrent-flow lanes, nonuser travel time is likely to increase, and the prohibition of curb parking may create political difficulties with the affected businesses (3,12). A public education program may be necessary for arterial HOV treatments to counter the opposition that can be expected. Measures to improve goods movements and traffic flow must be planned before implementation, and close attention to traffic operations and enforcement is necessary. An extensive marketing plan may also be useful.

Some analysts have also questioned whether HOV lanes are actually responsible for travel changes. These analysts suggest that other factors are at work (6,8,18,25). By this argument, increased use of express bus is due to expanded express bus service and provision of park-and-ride lots, and carpool or vanpool formation is not strongly influenced by HOV lanes. Limited experience indicates that the transit side of this argument may be valid, although there is no universal agreement on this point (18,27). Priority carpool treatment, with its associated travel-time savings, has in some cases affected carpool formation (15,23,28). The key issue here may be whether travel time or cost savings is more important in encouraging carpool formation. It would appear that under conditions of serious congestion, travel time is an important consideration. The major point to be emphasized is that ancillary actions are strongly recommended for a successful HOV treatment. Implemented in isolation, an HOV lane is likely to produce disappointing results.

Finally, it may be useful to deal specifically with discontinued HOV treatments. The Santa Monica diamond lane and the 1977 Boston Southeast Expressway HOV lane both encountered political opposition because of their take-a-lane nature, which resulted in sharply increased travel time for nonpriority vehicles (8,11). Interestingly, political opposition to the Southeast Expressway did not surface until strict enforcement began (9). An earlier contraflow project in the Southeast Expressway was suspended after 5 years of operation in warm weather months, and the South Dixie Highway HOV lane has recently been terminated. The HOV lane on New Jersey's Garden State Parkway has also been discontinued (24). The apparent reason for the failure of the Garden State HOV lane was the lack of a central destination; essentially, the HOV lane did not go anywhere. This reinforces the importance of a strong destination, usually the CBD. Experience with unsuccessful HOV projects suggests that take-a-lane treatments and unfocused projects should be avoided. An HOV treatment must provide a fair solution to a serious problem.

ANCILLARY ACTIONS CONTRIBUTING TO HOV SUCCESS

There are several actions that can significantly contribute to HOV success, certain conditions that are very favorable to HOV implementation, and some concerns that need to be acknowledged.

Express Bus Service

New or expanded express bus service is frequently cited as a key factor in HOV success (5,6,25). Provision of express bus service is costly because of the deadheading involved, but express bus riders appear willing to pay premium fares and are not affected significantly by fare increases (25). An HOV lane tends to encourage express bus use compared with non-priority-lane express bus ridership.

Park-and-Ride Lots

Park-and-ride lots can extend the market area for express bus service and thus are included as an ancillary action in nearly all HOV treatments on highways. The success of park-and-ride lots is dependent on their placement and design (8,25,27). They should be located adjacent to the freeway at some distance (10 mi is a minimum distance mentioned) from the CBD. Their location should preferably be a natural or well-established transfer point, with good access for both automobiles and transit and with a minimum of backtracking to the lot. The optimum size is between 400 and 700 spaces; one guideline in sizing the lots is that the design load should fill between 80 and 90 percent of available spaces (19). Use of these lots varies widely. One study of express bus/park-and-ride services reported a range of 23 to 100 percent of spaces filled (29). Only four HOV projects examined for this paper had data available on lot park-and-ride size and use: size ranged from 200 to 1,320, with a mean of 575 and a median of 300, whereas use ranged from 11 to 108 percent of capacity, with a mean of 62 percent and a median of 54 percent (Table 10). Provision of amenities such as paving, lighting, bus shelters, and security obviously encourages lot use. The importance of park-and-ride lots is indicated by findings that between 30 and 60 percent of express bus riders would not have used that mode without the accessibility provided by these lots (13,27). Finally, park-and-ride lots should be developed in the early stages on an HOV project, because its lead time can extend to 12 months (1).

TABLE 10 HOV Park-and-Ride Lot Use *(12,13,18,21,22)*

Project	Lot Capacity (no. of vehicles)	Lot Use	
		No.	Percent
Santa Monica, Diamond Lane			
Lot 1	220	103	46.8
Lot 2	300	Closed	11.0[a]
Lot 3	200	89	44.5
Miami			
I-95	1,320	545	41.3
South Dixie Highway	200	195	97.5
Houston North Freeway, Contraflow			
Lot 1	750	636	84.8
Lot 2	1,300	805	61.9
Lot 3	315	340	107.8

[a]Before closing.

Public and Institutional Involvement

The political problems facing HOV lanes have been noted. These can be exacerbated in an environment in which power and decision-making authority are fragmented, as in most metropolitan areas. It is possible to mitigate these problems by involving the appropriate agencies and the public at an early stage in the project and continuing their involvement as the project progresses. Early attention to the processes involved in building public support is of immeasurable help in achieving smooth implementation of an HOV treatment. In metropolitan areas where HOV lanes are already working, the process is easier; in many places, however, the HOV lane is still a new, unproven idea. A recent trend in increasing public acceptance is to institute a temporary HOV treatment during major reconstruction of a highway. The public responds positively when it views the HOV treatment as necessary (9), and a well-run HOV project, even if temporary, reinforces and strengthens this acceptance, with positive repercussions for future permanent projects. This approach has been used in Pittsburgh, Minneapolis, and Syracuse (30,31). In all HOV projects, early and continued involvement of the public and appropriate agencies is the key to mitigating political problems and gaining public acceptance (8,17).

Favorable Conditions

Aside from the question of warrants, certain situations that are ideal for HOV implementation can be identified. Major water barriers can create near-perfect opportunities for HOV treatment (5). A congested traffic corridor leading (via a toll bridge) into a major employment center is one such ideal situation, in which an HOV lane will encourage carpool or vanpool formation or both as well as express bus ridership (32). A second important situation is one in which there is an established, long-term reliance on transit and existing high levels of carpooling or vanpooling (5,18). In this case, a strong base already exists for initial HOV use, and the HOV treatment is likely to be a popular option. Policymakers should be aware of these extremely favorable situations and be willing to act quickly to implement an HOV treatment, which is likely under these conditions to be successful and popular.

PHYSICAL, DESIGN, AND OPERATIONAL CONSIDERATIONS

Physical and Design Considerations

A critical design concern is the entry and exit points for the HOV treatment. These should be clearly defined, with a smooth transition encouraged. Exclusive entry and exit ramps are ideal, but not always feasible (6,17). Physical characteristics may determine the termini of the HOV lanes (18), but if possible, it is a good idea to begin the HOV treatment outside the limits of normal peak-period congestion and to terminate it in a ramp or a lane continuation, not by merging it into nonpriority lanes (2,33). Safe entry and exit are of particular concern on contraflow treatments. Careful consideration must be given to questions surrounding access: a single access point is most suitable for operational purposes, but it can limit the number of potential users and restrict access for emergency vehicles (2,18).

Flexibility should be built into the design of HOV facilities to the greatest extent possible, particularly in cases where the HOV treatment is implemented in anticipation of serious future congestion problems. There should be no physical impediments in the facility design to the future expansion of the treatment or to its possible conversion to general use. Because HOV treatments are generally additions to existing facilities, it will often not be possible to achieve ideal flexibility. Nonetheless, the ability to adapt the HOV treatment to future conditions should be a prime consideration in facility design.

Design and Operations

Long HOV treatments are highly recommended because of the potentially greater travel-time savings (1,5,6,8,17,18,25,27). For arterial treatments outside the CBD, a minimum length of 10 blocks or 2,000 ft has been suggested unless a median lane is used (17). For a median HOV lane on an arterial, 2 mi is the suggested minimum (20). Typical freeway HOV lane lengths are in the 5- to 10-mi range, with a 3-mi suggested minimum (1).

The capacity of parallel roadways can be a factor, depending on type of HOV treatment. Parallel roadways should have sufficient capacity to offset any increase in non-HOV-lane demand associated with HOV-lane implementation. Also, an HOV lane should not be implemented on arterials if substantial traffic diversion to residential streets is likely (17).

There is no clear consensus on how to set hours of operation for an HOV treatment. One approach is to choose the maximum option where possible--for example, a 3-hr instead of 2-hr peak period--on the premise that it is easier to scale down restrictions if expected demand does not materialize than to impose new restrictions after a treatment is in operation (12). A second approach is to limit HOV-lane operation to the absolute peak hours to avoid unused capacity and adverse public reaction (6). The key factor in this decision is to ensure that the lane is in operation for the entire period of peak congestion (2). There has been a trend toward reducing the hours of HOV-lane operation, but FHWA indicates that as further development occurs along an already congested route, expansion of HOV-lane operating hours can be expected. A positive aspect of the HOV concept is its flexibility in this regard.

The widely noted success of the Shirley Highway and San Bernardino Freeway HOV lanes has revived interest in treatments of this sort (25), but they are most appropriate for the largest metropolitan areas with high-density residential neighborhoods, severe congestion problems, and extensive existing bus service (3,5). These treatments are very effective under these conditions, but they are capital-intensive, and unless they approach capacity, they are likely to be less cost-effective than adding an extra lane to the freeway (15).

SUMMARY AND RECOMMENDATIONS

The ideal candidate for HOV treatment might be described as a severely congested radial freeway leading over a bridge into a vibrant downtown in a city where parking is expensive and where there exists high demand for transit service. An HOV project is likely to be successful in proportion to the number of these characteristics that apply to it. In operationalizing this composite into first-cut warrants to use in evaluating HOV proposals, a distinction is made between primary and secondary warrants. Primary warrants address critical issues, most of which are discussed in the first section of this paper. Secondary warrants, although important to the success of an HOV project, are more concerned with contributing aspects as opposed to requirements and in some cases are not readily quantifiable. Included among secondary warrants are goals for certain aspects of HOV treatments.

Primary Warrants

1. Existing freeway traffic volumes should be 1,500 vehicles per lane per hour in the peak period or 1,600 vehicles per lane in the peak hour. If other conditions are favorable, a minimum peak-hour volume of 1,300 vehicles per lane is acceptable.
2. Existing arterial traffic volumes should be 650 vehicles per lane per hour in the peak period, with 900 vehicles per lane per hour desirable.
3. The level of service should be D or worse before an HOV lane is implemented. At LOS E or F, a physically separated HOV lane might be justified.
4. Average peak-hour speed should be 30 mph or less, or average peak-period speed should be 35 mph or less.
5. Existing bus volumes should be between 15 and 35 per hour in the peak period. If other conditions are favorable, 10 buses per hour in the peak period is acceptable. In the HOV-lane design year, a minimum of 40 buses per hour in the peak period is recommended. This design-year minimum figure should be higher for freeway concurrent-flow and arterial median treatments and can be lower for other arterial treatments.
6. In line with the foregoing, new express bus service should be provided or existing service should be expanded.
7. Contraflow treatment should be considered if the peak/off-peak directional split is at least 60/40, and it is recommended for a 65/35 split. Off-peak traffic should be maintained at LOS D at minimum, preferably LOS C.
8. The number of persons projected to use the HOV lane in the design year should exceed the average number of persons in each nonpriority lane. At the outset, the number of projected users of the HOV lane should at least approach (i.e., be within 10 percent of) the average number of persons in each nonpriority lane.
9. Person-minutes saved in the HOV lane should exceed person-minutes lost in the general lanes.
10. The HOV lane should provide at least a 5-min travel-time advantage over the general lanes.
11. The HOV lane should provide a travel-time advantage of at least 1 min per mile over the general lanes.
12. There should be a minimum employment level of 20,000 in the CBD. For an exclusive right-of-way busway, this warrant is stricter: 50,000 employment and either 20 million ft^2 of office space or 1 mi^2 of intensive development in the CBD.
13. Park-and-ride lots should be provided at a distance of at least 5 mi and preferably 10 mi from the CBD. Each lot should provide at least 200 and preferably 250 spaces and be well designed with full provision of amenities.
14. Demonstrations of at least a plan for early and continued involvement of the public as well as of coordination among affected agencies must be provided in order to ensure public acceptance.

Table 11 indicates how the various nationwide projects fare with regard to seven of these primary warrants for which data are available. Many projects meet all but one of the warrants. This suggests that a proposed project should meet nearly all of these primary warrants if it is to be considered further in the project development process. If a project falls short on two warrants, the analyst should consider which warrants are not being met. If three or more warrants are not met, the project should probably not receive further consideration.

Secondary Warrants and Goals

1. A 10 percent violation rate is a recommended goal in enforcing HOV-lane restrictions.
2. A recommended goal for accident rates is that they be held steady or (at worst) increase only slightly.
3. Carpools should be allowed in the HOV lane unless there are strong extenuating circumstances. Between 10 and 15 percent of existing peak-hour traffic should meet the project's definition of carpool and thus be eligible to use the HOV lane. This warrant can be modified in the event that extremely heavy express bus use is anticipated for the HOV lane.
4. Minimum lengths of 10 blocks or 2,000 ft for an arterial treatment, 2 mi for an arterial median lane, and 3 mi for a freeway treatment are recommended. A minimum length of 5 mi for a freeway is strongly suggested.
5. The hours of HOV-lane operation should be selected to cover the entire period of peak congestion.
6. Parallel roadways in the corridor should have some excess capacity.
7. An HOV lane should terminate in an exclusive exit ramp or a lane continuation, never in a merge into general lanes.
8. HOV treatments should receive primary consideration in traffic plans for freeways undergoing reconstruction.

TABLE 11 Success of HOV Projects in Meeting Selected Warrants

Project	Warrant							No. of Warrants Met	No. of Warrants Not Met
	1,2 (Peak Period Traffic Volume)	1 (Peak-Hour Traffic Volume)	4 (Peak-Period Speed)	5 (Peak-Period Bus Volume)	8 (Person Throughput per per Lane)	11 (Travel-Time Savings per Mile)	13 (Park-and-Ride Lot Size and Distance)		
Boston, Southeast Expressway									
1971	Yes	Yes	Yes	Yes		Yes		5	0
1977	Yes	Yes	Yes	Yes	Yes	No		5	1
San Franscio, Oakland Bay Bridge	Yes	Yes		Yes		Yes		4	0
Marin County, US-101	Yes	Yes	Yes	Yes	No	No		4	2
Seattle, I-5		No						0	1
Virginia-D.C., Shirley Highway	No	Yes	Yes	Yes		Yes		4	1
Boston, I-93	No				No	Yes		1	2
Santa Monica, Diamond Lane	Yes			Yes	No	No	Yes	3	2
Miami, I-95	Yes	No	Yes	Yes	Yes	No	Yes	5	2
Houston North Freeway									
Add a lane	Yes		Yes		Yes	No		3	1
Contraflow		Yes	Yes			Yes	Yes	4	0
Portland, Banfield Expressway		Yes	No	Yes	No	No		2	3
San Bernardino	Yes	Yes	Yes	Yes	Yes	No		5	1
Honolulu, Moanalua	Yes			Yes	No	Yes		3	1
I-495, Lincoln Tunnel		No	Yes	Yes		Yes		3	1
Miami, South Dixie Highway	Yes			No	No	Yes	Yes	3	2
Dallas									
Harry Hines Boulevard	No		Yes			No		1	2
Fort Worth Avenue	No		Yes			No		1	2
Honolulu, Kalanianaole	Yes			Yes	No	Yes		3	1
San Franciso bus lanes			Yes					1	0
Garden State Parkway						Yes		1	0
Miami, N.W. 7th Avenue						No		0	1
Baltimore, York Road						No		0	1
Long Island Expressway						Yes		1	0
Arlington, Virginia									
Arlington Boulevard (Route 50)						Yes		1	0
Wilson Boulevard						Yes		1	0
No. of projects meeting warrant	11	8	12	12	4	13	4		
No. not meeting warrant	4	3	1	1	7	11	0		

Note: Warrants are as follows (see text). 1–peak-period freeway traffic volume, 1,500 vehicles per lane per hour (Table 1); peak-hour freeway traffic volume, 1,600 vehicles per lane (Table 1); 2–peak-period arterial traffic volume, 900 vehicles per lane per hour (Table 1); 4–peak-period speed, <35 mph (Table 2); peak-hour speed, <30 mph (Table 2); 5–peak-period bus volume, 10/hr (Table 3); 8–ratio of person throughput per HOV lane to general lane >1 (Table 4); 11–travel-time savings per mile, 1 min (Table 5); 13–park-and-ride lot size, 200 vehicles, and distance, 5 mi (Table 10).

HOV lanes have demonstrated their feasibility in the various applications during the past decade. The warrants presented here can determine whether traffic conditions justify further consideration of HOV alternatives. It should be noted that, to date, HOV freeway treatments have been undertaken in very large Standard Metropolitan Statistical Areas with serious congestion problems. At present, it is unlikely that there are many locations in New York State outside of the New York City metropolitan area that meet the criteria set forth in these warrants. If flexibility is designed into the proposed HOV treatment, however, and if there is strong local support, approval on an experimental basis may be justified at promising locations that fall short on more than one criterion.

REFERENCES

1. M.J. Rothenberg and D.R. Samdahl. High Occupancy Vehicle Facility Development, Operation and Enforcement, Vol. 7. JHK and Associates, Washington, D.C., April 1982.
2. Implementation and Operational Considerations for HOV Priority Treatments on Freeways. FHWA, U.S. Department of Transportation, Aug. 1982.
3. A Review of the Preferential Treatment Concept and Planning Guidelines. Technical Report 16. North Central Texas Council of Governments, Arlington, Dec. 1978.
4. Transportation and Traffic Engineering Handbook. Prentice-Hall, Inc., Englewood Cliffs, N.J., 1976.
5. H.S. Levinson et al. Bus Use of Highways: State of the Art. NCHRP Report 143. HRB, National Research Council, Washington, D.C., 1973.
6. F. Spielberg et al. Evaluation of Freeway High Occupancy Vehicle Lanes and Ramp Metering. U.S. Department of Transportation, Aug. 1980.
7. T.E. Parody. Predicting Travel Volumes for High-Occupancy-Vehicle Strategies: A Quick-Response Approach. In Transportation Research Record 976, TRB, National Research Council, Washington, D.C., 1984, pp. 49-60.
8. H.J. Simkowitz. A Comparative Analysis of Results from Three Recent Non-Separated Concurrent-Flow High Occupancy Freeway Lane Projects: Boston, Santa Monica and Miami. Transportation Systems Center, Cambridge, Mass., June 1978.
9. D. Brand et al. Southeast Expressway Reserved Lane for Buses and Carpools. In Transportation Research Record 663, TRB, National Research Council, Washington, D.C., 1978, pp. 29-40.
10. C.A. Fuhs. Concurrent-Flow High-Occupancy Vehicle Treatment on Freeways: Success Story in Houston. In Transportation Research Record 854, TRB, National Research Council, 1982, pp. 43-54.
11. J.W. Billheimer. The Santa Monica Freeway Diamond Lanes: Evaluation Overview. In Transportation Research Record 663, TRB, National Research Council, Washington, D.C., 1978, pp. 1-7.
12. Manual on Planning and Implementing Priority Techniques for High Occupancy Vehicles: Technical Guide. Public Technology, Inc., Washington, D.C., July 1977.
13. J.A. Wattleworth et al. I-95/NW 7th Avenue Bus-Car Pool Systems Demonstration Project Report II-I: Evaluation of the I-95 Express Bus and High Occupancy Vehicle Priority Systems.

Transportation Research Center, University of Florida, Gainesville, Sept. 1978.
14. Banfield High Occupancy Vehicle Lanes: Final Report. Oregon Department of Transportation, Salem, March 1978.
15. L.J. Glazer. San Bernardino Freeway Express Busway: Evaluation of Mixed-Mode Operations. Crain and Associates, Los Angeles, Calif., July 1978.
16. M. Cox. Reserved Bus Lanes in Dallas, Texas. Transportation Engineering Journal of ASCE, Vol. 101, No. TE4, Nov. 1975.
17. Proposed Recommended Practice: Guidelines for High-Occupancy-Vehicle (HOV) Lanes. ITE Journal, Vol. 52, No. 2, Feb. 1982.
18. T.J. Atherton and E.S. Eder. Houston North Freeway Contraflow Lane Demonstration. Cambridge Systematics, Inc., Cambridge, Mass., Dec. 1982.
19. H.S. Levinson, C.L. Adams, and W.L. Hoey. Bus Use of Highways: Planning and Design Guidelines. NCHRP Report 155, TRB, National Research Council, Washington, D.C., 1975.
20. J.J. Roark. Enforcement of Priority Treatment for Buses on Urban Streets. NCTRP Synthesis 2, TRB, National Research Council, Washington, D.C., May 1982.
21. H.S. Rose and D.H. Hinds. South Dixie Highway Contraflow Bus and Car-Pool Lane Demonstration Project. In Transportation Research Record 606, TRB, National Research Council, Washington, D.C., 1976, pp. 18-22.
22. R.N. Taube and C.A. Fuhs. Houston's I-45 Contraflow Transit Project. In Transportation Research Record 798, TRB, National Research Council, Washington, D.C., 1981, pp. 39-45.
23. J.M. Goodman and D.A. Morin. Preferential Treatment for High-Occupancy Vehicles. In Special Report 172, TRB, National Research Council, Washington, D.C., 1977.
24. J.C. Powers. Garden State Parkway HOV Lane. In Transportation Research Record 906, TRB, National Research Council, Washington, D.C., 1983, pp. 54-56.
25. R.J. Fisher and H.J. Simkowitz. Priority Treatment for High Occupancy Vehicles in the United States: A Review of Recent and Forthcoming Projects. Transportation Systems Center, Cambridge, Mass., Aug. 1978.
26. J.W. Billheimer. The Santa Monica Freeway Diamond Lanes: Freeway Accident Analysis. In Transportation Research Record 663, TRB, National Research Council, Washington, D.C., 1978, pp. 8-16.
27. G.K. Miller and J.T. McQueen. Park and Ride in the Shirley Highway Corridor. In Transportation Research Record 606, TRB, National Research Council, Washington, D.C., 1976, pp. 23-29.
28. J.T. McQueen and R. Waksman. Increasing the People-Moving Capability of Shirley Highway. In Transportation Research Record 626, TRB, National Research Council, Washington, D.C., 1977, pp. 21-27.
29. F.A. Wagner and K. Gilbert. Transportation System Management: An Assessment of Impacts. Alan M. Voorhees, Inc., Washington, D.C., Nov. 1978.
30. R.B. Anderson et al. Study of Alternative Transportation Strategies During Reconstruction of the Parkway East, I-376, Pittsburgh, Pennsylvania: Final Report. FHWA, U.S. Department of Transportation, March 1983.
31. A.J. Neveu and L. Maynus. Incorporating TSM Actions into Traffic Maintenance Plans for Reconstruction Projects: General Guidance. New York State Department of Transportation, Albany, 1985.
32. E. Dorosin, P. FitzGerald. and B. Richmond. Golden Gate Vanpool Demonstration Project. Crain and Associates, Washington, D.C., July 1979.
33. J.J. Roark. Experiences in Transportation System Management. NCHRP Synthesis of Highway Practice 81, TRB, National Research Council, Washington, D.C., Nov. 1981.
34. Priority Techniques for High Occupancy Vehicles: State of the Art Overview. Transportation Systems Center, U.S. Department of Transportation, Nov. 1975.

Publication of this paper sponsored by Committee on Transportation System Management.

Commuter Attitudes Toward Proposed High-Occupancy-Vehicle Lanes in Orange County, California

SHARON M. GREENE and KENNETH L. BARASCH

ABSTRACT

A telephone attitudinal survey was made of commuters on two freeways in Orange County, California--the Santa Ana Freeway (I-5) and the Newport-Costa Mesa Freeway (Route 55). The survey was undertaken as part of an interagency effort to evaluate the potential effectiveness and public acceptability of high-occupancy-vehicle (HOV) lanes under consideration for these freeways. Telephone surveys were conducted with persons who regularly use these freeways three or more days per week during the morning or evening peak periods, or both. Respondents were identified by a combination of videotaping of midstream freeway movements and selected on-ramp monitoring. The findings provide insight into the reaction of the public toward HOV lanes, offer guidance on lane design and operation, and will assist in formulating a program to increase public awareness and lane use. The major conclusion is that more than 75 percent of the regular freeway commuters surveyed are in favor of testing HOV lanes on these freeways, despite the relatively low rate of ridesharing among current freeway users and despite the fact that most commuters consider other types of improvements to be more effective methods of reducing freeway congestion. Respondents expressed concerns about the HOV-lane concept, in particular with respect to safety and enforcement, but also believed that the lanes would serve to reduce congestion and driving time and provide an incentive to carpool.

The Orange County Transportation Commission has been participating in an interagency effort to evaluate the potential effectiveness and public acceptability of high-occupancy-vehicle (HOV) lanes in Orange County. Known also as carpool or commuter lanes, HOV lanes are special lanes that are added for use by motor vehicles occupied by more than one person, which includes carpools, vanpools, taxis, and public and privately operated buses. HOV facilities are currently under consideration for many of the county's most severely congested freeways, including the Santa Ana Freeway (I-5), the Newport-Costa Mesa Freeway (Route 55), the San Diego Freeway (I-405), and the Orange Freeway (Route 57). Such facilities are considered to provide a cost-effective means of increasing the person-carrying capacity of the county's transportation system in that they allow more people to be carried in fewer vehicles.

To assist the commission in this interagency effort, this study was conducted to provide input concerning the public acceptability of HOV commuter lanes under consideration for I-5 and Route 55, to provide guidance on how such lanes should be operated, and to assist in formulating recommendations to increase public awareness and lane use. A telephone-administered attitudinal survey was specially designed and conducted to address the following key objectives:

- Identify potential users and nonusers of HOV commuter lanes proposed on these two freeways;
- Provide insight on the attitudes and expectations of potential HOV-commuter-lane users and nonusers concerning Orange County's transportation problems and proposed solutions, with particular emphasis on the HOV-commuter-lane concept;
- Clarify current attitudes toward ridesharing; and
- Identify key policy concerns and marketing-related issues with respect to HOV commuter lanes.

The major findings resulting from the telephone survey and evaluation effort are presented in this paper.

SURVEY DESIGN CONSIDERATIONS

A combination of observation, focus groups, and telephone and direct-mail surveying of persons currently using I-5 and Route 55 was utilized in this study. Traffic movements on both of these freeways were monitored by video cameras supplemented by manual data recording at selected freeway on ramps. In an effort to identify current freeway users, license plates of all vehicles passing observation points were recorded and transmitted to the California Department of Motor Vehicles to obtain the names and addresses of registered vehicle owners. From these names, a sample was selected for participation in a telephone survey. The sample was stratified by zip code and by on ramp in order to obtain a representative cross section of those who regularly use these freeways during the morning and evening peak periods.

Before the questionnaires used in the telephone survey effort were put into final form, focus groups were conducted to help identify key issues and con-

S.M. Greene, Orange County Transportation Commission, 1055 North Main Street, Santa Ana, Calif. 92701. K.L. Barasch, Kenneth L. Barasch and Associates, 10682 Dorothy Circle, Villa Park, Calif. 92667.

cerns related to transportation problems and proposed solutions and attitudes about ridesharing and special HOV commuter lanes. The focus groups also served to clarify terminology used in the survey questions.

These questionnaires were specifically designed to identify public attitudes, opinions, and current travel characteristics before the HOV-commuter-lane concept was introduced. In this way, the respondents' reactions to the proposed concept could be viewed in light of current travel behavior. To reflect the fact that different HOV-commuter-lane concepts are being considered for I-5 and Route 55, respondents were given freeway-specific descriptions of proposed projects. The project under consideration for Route 55 involves restriping the existing freeway and using the median area to provide an additional lane in each direction for use by HOVs only. The I-5 project, on the other hand, involves widening the freeway to add two more lanes in each direction. One of these new lanes would be available for all traffic, all day; the other would be used by HOVs only.

During June 1985, approximately 600 telephone surveys were conducted with persons who regularly use I-5 and Route 55 three or more days per week during the morning or evening peak periods, or both, peak periods defined as being from 6:00 to 9:00 a.m. and from 2:30 to 7:00 p.m. Roughly half of the surveys were conducted with users of I-5 and half with users of Route 55, with adjustment made for persons who used both freeways as part of their trip. To account for persons with unlisted telephone numbers, a mailback survey was also conducted.

In reviewing the findings of the telephone survey, the following factors related to survey design and sample selection should be noted. First, among users of both Route 55 and I-5, surveys were conducted only with those who were regular peak-period freeway users; such persons were considered to constitute the bulk of the potential user market for HOV-commuter-lane facilities. Thus, the findings reported here do not represent the views of all freeway users. Second, the Route 55 and I-5 surveys were conducted with slightly different interests. On Route 55, interest focused on obtaining a full profile of users along the freeway's entire 13-mi length. Thus, midstream freeway observation and observations at on ramps were combined in order to obtain a full-stream view of regular peak-period users. On I-5, on the other hand, interest focused only on persons using the freeway through one of its most critically congested sections. Thus, the I-5 data represent a snapshot view obtained only by midstream freeway observation of those persons already on the facility and passing through one of its most congested points.

An additional factor that should be noted is that in some cases, small sample sizes preclude use of the data for certain types of analyses. For example, although the data can be used to obtain an overall view of commuters' opinions, they may not be usable for contrasting the opinions of small group A with small group B and obtaining results that would be statistically significant. To assist the reader who may be interested in obtaining greater detail, a separate volume comprising the Technical Appendix to this paper and the computer printouts of tabulated and cross-tabulated detailed data are available for review. A more detailed description of the methodology used in this study is also found in the Technical Appendix.

REVIEW OF SURVEY FINDINGS

The major findings from the telephone survey effort follow. Consistent with the general organization of the survey instrument, the discussion is organized according to the following main areas of interest:

1. Profile of respondents using I-5 and Route 55,
2. Attitudes toward Orange County's transportation problems and proposed solutions,
3. Behavior of carpoolers versus those who drive alone,
4. Attitudes toward special new HOV commuter lanes,
5. Current employer involvement in encouraging ridesharing, and
6. Current media used by commuters.

In the presentation of the data, a slash mark is frequently used; findings related to I-5 are reported on the left and Route 55 on the right of the slash.

Profile of Respondents Using I-5 and Route 55

In this section a profile of the regular peak-period user of I-5 and Route 55 is presented. Of interest is the extent to which the freeways are used by Orange County residents compared with residents of other counties and the demographic and travel characteristics of those users.

As reported in the survey, the typical commuter on both I-5 and Route 55 tends to be male (63/56 percent) with a mean age of 40 and mean family income of approximately $47,000 per year. More than 70 percent of the respondents on both freeways have at least some college education, and more than 85 percent come from households with at least two licensed drivers and at least two registered motor vehicles. Roughly 45 percent work at places employing 50 or fewer employees and 20 percent work at places employing more than 500 employees. The majority of I-5 commuters are employed in professional and technical positions (32 percent), management (25 percent), and sales (15 percent), whereas the majority of Route 55 commuters are in professional and technical (35 percent), secretarial and clerical (35 percent), and management (30 percent) positions.

As indicated in Table 1, between 70 and 80 percent of the respondents on both freeways reside in Orange County, and 20 to 30 percent reside outside Orange County. On the basis of the county of registration of all vehicles using the freeways during peak travel times, roughly 70 percent are from Orange County, whereas on the basis of the place of residence reported by regular users (those using the freeway at least three days per week), approximately 80 percent are from Orange County.

Within Orange County, regular peak-period users of I-5 tend to reside in the county unincorporated

TABLE 1 Residential Location of I-5 and Route 55 Commuters

	Vehicle Registrations (%)		Residence (%)	
Location	I-5	Route 55	I-5	Route 55
Orange County	63	68	83	81
Los Angeles County	19	10	17	5
Riverside County	1	8	3	14
San Bernardino	2	3	–	2
San Diego	5	2	2	–
Other California	9	8		
Outside California[a]	2	1		
	100[b]	100	100[b]	100[b]

[a]Refers to vehicles with California registrations held by leasing companies outside of California. Vehicles registered out of state were not included in the data but are considered to constitute approximately 7 percent of average daily traffic on both freeways.
[b]Rounding error.

area (26 percent), Irvine (12 percent), and Anaheim (12 percent), whereas regular users of Route 55 tend to reside in Santa Ana (14 percent), Anaheim (13 percent), Orange (12 percent), and Tustin (10 percent). Residents from each of the remaining jurisdictions constitute less than 10 percent of the users of these facilities.

Roughly 90 percent of the respondents on both freeways work in Orange County, chiefly in the cities of Santa Ana (15/21 percent), Irvine (17/14 percent), and Anaheim (12/13 percent).

In terms of travel characteristics, nearly 80 percent of the regular peak-period users included in the sample use I-5 or Route 55 five days per week; the balance use it three or four days per week. More than 80 percent travel during both the morning and evening peak periods. Persons who use I-5 for part of their trip tend to have total travel times of 40 min in the morning and 46 min in the afternoon, with the average number of miles traveled on I-5 itself being 19 mi. Those who use Route 55 for part of their trip have shorter total travel times than users of I-5; average total travel time for Route 55 users is 34 min in the morning and 38 min in the afternoon. The average number of miles traveled on Route 55 itself is 6.

For users of both freeways, travel times are reported to be longer in the afternoon peak period than in the morning. When traffic is perceived by the respondents at being "exceptionally bad," travel times on both freeways are reported to increase by roughly one-third.

When freeway traffic is bumper to bumper, 66 percent of the respondents using I-5 stay on the freeway and 26 percent use the local streets. Among users of Route 55, on the other hand, 54 percent stay on the freeway and 43 percent use the streets instead. Possible inferences that may be drawn from the data are that I-5 lacks good parallel arterial relief routes; that traffic is worse on Route 55, forcing more people into alternative routes; or that the shorter trip lengths on Route 55 enable local alternative routes to suffice.

Because more than 90 percent of the respondents report their primary trip purpose to be commuting to and from work, the data indicate that in the aggregate, considerable variation currently exists within the county with respect to work start and stop times. In terms of trip start times, users of both I-5 and Route 55 begin their morning and afternoon peak-period trips over an extended period of time. Roughly 20 percent of the I-5 users begin their morning trips before 6:00 a.m., 30 percent between 6:00 and 7:00 a.m., 30 percent between 7:00 and 8:00 a.m., and 20 percent after 8:00 a.m. In comparison, 10 percent of the users of Route 55 begin their morning trips before 6:00 a.m., 25 percent between 6:00 and 7:00 a.m., 40 percent between 7:00 and 8:00 a.m., and 25 percent after 8:00 a.m.

Afternoon trip start times are similarly extended over a long peak period. Roughly 20 percent of both I-5 and Route 55 users begin their afternoon trips before 4:00 p.m., 30 percent between 4:00 and 5:00 p.m., 30 percent between 5:00 and 6:00 p.m., and 20 percent after 6:00 p.m.

Attitudes Toward Orange County's Transportation Problems and Proposed Solutions

When asked to identify what they considered to be the most heavily congested freeway in Orange County, 55 percent of the respondents were likely to mention the freeway they travel. For users of I-5, 57 percent noted I-5 and 37 percent mentioned Route 55. Among users of Route 55, 56 percent mentioned Route 55 and 35 percent, I-5. Nearly two-thirds of the respondents on both freeways believe that traffic on the freeway they use is "always" or "almost always" "exceptionally bad."

A comparison of how respondents on I-5 and Route 55 rated the effectiveness of possible improvements to the two freeways is given in Table 2. For both freeways, respondents considered "add one lane in each direction for use by all traffic" to be most effective, followed by "spread out work start/stop times." In the Route 55 survey, "using the median next to the center divider as another lane of traffic" scored third, although the improvement did not specifically call for exclusive use by carpoolers. On both freeways, the improvement related to the addition of lanes exclusively for HOVs ranked third from the least effective and ranked 6 out of 8 in the I-5 survey and 7 out of 9 in the Route 55 survey.

Behavior of Carpoolers Versus Those Who Drive Alone

A discussion of the extent of current carpooling activity among users of I-5 and Route 55 and the opinions of carpoolers and noncarpoolers about ridesharing follows.

On both the I-5 and Route 55 surveys, roughly 90 percent of the respondents using these freeways currently drive alone, 12 to 14 percent carpool at least one day per week, and 1 percent use transit. The 12 to 14 percent for carpooling is slightly below the countywide average of nearly 17 percent reported in the 1980 census journey-to-work data. Among those who currently carpool on I-5 and Route 55, respectively, 73/66 percent drive with one other person, and 15/23 percent with two other persons; the remaining 12/11 percent drive with three or more other persons. Roughly one-third now carpool with members of their family. Most carpools were established either by knowing a fellow employee or student or by employer arrangement.

TABLE 2 Effectiveness Rank of Possible Improvements to I-5 and Route 55

Improvement	Rank by Freeway: I-5	Rank by Freeway: Route 55
Add one lane in each direction for use by all traffic	1	1
Spread out work start and stop times	2	2
Use median next to center divider as another lane of traffic	n.a.	3
Build new freeways	3	5
Build rail system	4	6
Employers should encourage employees to share rides with others	5	4
Add one lane in each direction for use by those whose vehicles have two or more people in them	6	7
Improve local streets and roads	7	8
Improve and expand bus service to get people on freeway out of their cars	8	9

Note: n.a. = not applicable.

Few demographic variables tested in this survey directly affect or correlate with the likelihood of carpooling. Carpoolers appear to come from all income levels, both sexes, and various demographic profiles. Carpoolers in this survey had mean incomes that were comparable with those of persons who drive alone. Both carpoolers and noncarpoolers generally had similar average trip lengths, with one exception; afternoon carpoolers on Route 55 had significantly longer trips than noncarpoolers. The single demographic factor that can consistently be pointed to is employer size; that is, carpoolers tend to work for bigger companies than do those who drive alone. Because the larger companies reported in this survey also tend to be more involved in rideshare promotional activities, the combination of opportunity and supportive rideshare services has apparently had an effect on getting employees to rideshare.

Because of small sample size, it is generally not possible to identify statistically significant differences between counties or cities of residence with respect to rates of current carpooling activity. The one exception that can be reported is that a significantly larger percentage of Riverside County residents using Route 55 carpool than do Orange County residents (19 percent compared with 13 percent).

Among those who currently carpool, key motivators are cost savings (by far the most important), less wear and tear on the car, reduced driving stress, and opportunity to socialize.

In contrast to the carpoolers, those who drive alone gave a variety of reasons for not carpooling or vanpooling or not doing so more often. On both freeways, the three predominant reasons were that the work schedule does not permit it, they don't know anyone to ride with, or they use the car at or during work. It should be noted that in the absence of supportive ridesharing information and promotional services, most of these reasons would continue to prevail regardless of what is done to improve traffic on the freeways. Of the reasons given for not carpooling, 35/50 percent are issues that could potentially be addressed by extensive rideshare program development and marketing efforts. An additional 10 percent are intangibles based on attitudes that would be difficult to reverse.

Of those who currently drive alone, 65 percent noted that they would not carpool in any case, even if it would save them travel time. Among the remaining respondents, users of both freeways identified similar motivators to carpool. Approximately 25 percent of these motivators could be provided with the assistance of employers; they include knowing someone with the same work schedule, knowing someone to carpool with, saving costs, and being given employer assistance. For those respondents for whom travel-time savings could provide motivation to carpool, the mean travel-time savings reported as desirable was 21 min for users of I-5 and 12 min for users of Route 55.

Attitudes Toward Special New HOV Commuter Lanes

The attitudes and concerns of current peak-period commuters toward the testing of HOV-commuter-lane projects on I-5 and Route 55 of particular interest are the following:

- What is the extent of public support for the proposed demonstration projects?
- What are the perceived advantages and disadvantages of such facilities?
- What would commuters call such facilities?
- How do regular freeway users think the new lanes should be designed and operated?
- To what extent would persons who do not currently carpool consider increasing the number of people they currently ride with in order to be able to use the new lanes?

As part of the telephone survey, a description of the new lane concept being considered for each of the two freeways was presented to respondents. Descriptions were different for I-5 and Route 55. For I-5, the description was as follows:

> Caltrans is thinking about adding two new lanes in each direction to the Santa Ana Freeway (I-5), from I-605 on the north to I-405 on the south. One of these new lanes would be available for use by all traffic, all day. The other new lane would be used by people who have more than one person in their vehicle.

The description used to describe the HOV-commuter-lane project under consideration for Route 55 was as follows:

> Caltrans is thinking of adding a lane in each direction to the entire length of Route 55. The lanes would be added by using the area between the center divider and the left traffic lane. These lanes would be used only by people who have more than one person in their vehicle, and only during peak hours, for example, 6:00 to 9:00 in the morning, and 2:30 to 7:00 in the afternoon/evening.

The project descriptions used terminology demonstrated to be understandable to the public through the focus groups and avoided the introduction of bias that could have resulted if words like "use the emergency shoulder" had been used to describe the projects.

Despite the low rate of ridesharing among current freeway users, more than 75 percent of the respondents on both freeways were in favor of testing HOV commuter lanes on I-5 and Route 55. Although respondents residing in Riverside and Los Angeles counties were more likely to be in favor of the HOV-commuter-lane demonstrations than were residents of Orange County, sample sizes were generally too small for use in identifying significant differences in the level of public support by county or city of residence or by place of employment. Support for the demonstrations was shared equally by morning and afternoon peak-period commuters.

For I-5 and Route 55, respectively, 83 and 72 percent of respondents noted advantages associated with the HOV-commuter-lane concept. The major advantages perceived by users of these freeways were "reduce congestion," 40/46 percent of all respondents; "good incentive to carpool," 23/27 percent of all respondents; and "will reduce driving time," 20/21 percent of all respondents. All other advantages were each mentioned by less than 4 percent of the respondents.

Disadvantages of the HOV-commuter-lane concept were noted by 67 percent of the respondents using I-5 and by 72 percent of the respondents using Route 55. The main disadvantages cited differed by freeway. On the I-5 survey, the primary disadvantages perceived were "inability to enforce it" (20 percent), "should be for all vehicles to use, not just carpoolers" (17 percent), "too expensive" (8 percent), "will not reduce congestion" (8 percent), and "construction hassle" (7 percent). On Route 55, there was concern that the new lanes would be "unsafe without the median for emergencies" (34 percent) and "unsafe for lane changing and getting on/off the lane" (17 percent). These were followed by "difficult enforceability" (15 percent) and "should be for all vehicles to use, not just carpoolers" (14 percent).

Survey respondents were asked two questions about possible names that could be given to lanes for use by vehicles with more than one person. First, respondents were asked to personally select a name for such facilities; they were then asked to respond to a list of names provided by an interviewer. These questions were included in order to see whether a respondent's attitude would be reflected in the name suggested. In addition, these questions assisted in identifying terminology that would be acceptable and understandable to the public in the absence of marketing. On the basis of the results of the survey, the term "carpool lane" was initially more acceptable to the public than any other terminology. The top three proposed names for the new lanes on both surveys were "carpool lane" (17/18 percent), "diamond lane" (13/14 percent), and "express lane" (7/8 percent). From a list of names presented, respondents most frequently chose "carpool lane" (33/35 percent), "express lane" (26/27 percent), and "commuter lane" (17/20 percent).

Freeway users were also asked their opinion on how the proposed new lanes should be designed and operated. In identifying design features considered to be important, respondents tended to mention those that would avoid confusion and increase safety. On I-5 items mentioned most frequently were "special restricted exits and entrances" (8 percent), "traffic officer controlled/enforced/give fines" (7 percent), and "special electronic overhead signs or green-red" (7 percent). On Route 55 the most frequently mentioned design features were "special electronic overhead signs" (9 percent) and "special lane markings/arrows in pavement" (7 percent).

Roughly 70 percent of the respondents on both freeways identified two or more persons as the required vehicle occupancy for an HOV commuter lane. Respondents were about equally divided as to whether the new lanes should be available during peak hours only or for use all day.

To assist in identifying the level of interest of potential users, respondents were asked the likelihood of their increasing the number of people they currently ride with in order to use the new lanes. Of the respondents who do not now carpool, 8 percent indicated that they would be "very likely" to increase the number of people in their vehicle in order to use the new lanes; an additional 18 percent reported that they would be "somewhat likely" to do so. Roughly 65 percent reported that they would be "not at all likely" to change their current travel behavior and would not carpool.

Current Employer Involvement in Encouraging Ridesharing

Respondents were asked what their employers or schools now do to encourage carpooling and what else they could or should do. In both the I-5 and Route 55 surveys, 72 percent of the respondents noted that their employers now do nothing to encourage ridesharing, and roughly 50 percent believed that employers should do nothing. Smaller establishments were significantly less likely to offer services to encourage ridesharing than were larger employers. For example, although 86 percent of the companies employing 50 or fewer employees did nothing, this number drops to 46 percent of employers of 500 or more.

In terms of the types of services currently offered, carpool-matching services were most frequently mentioned (11/9 percent). Few other activities are now offered by employers. Respondents noted that employers could do more by offering matching services, providing publicity for carpoolers, adjusting start and stop times, and helping to pay for carpools and vanpools.

As noted earlier, there is a direct relationship between size of employer and the likelihood that the employer will offer carpool encouragement to employees. Larger companies were not only more likely to provide ridesharing services, they also varied from smaller companies in terms of the types of services offered. In addition, respondents employed by larger companies were significantly more likely to expect their companies to offer such services than were respondents from smaller firms.

Current Media Used by Commuters

Respondents were asked a variety of questions about their most important sources of information about transportation, including their most frequently read newspapers and most frequently listened-to radio stations. These data were compiled for possible future use in the development of a marketing and information dissemination program in support of the proposed HOV-commuter-lane demonstrations.

Survey respondents identified newspapers as their single most important source of information about local transportation issues (45 percent), followed by radio (29/33 percent), television (18/21 percent), and direct mail (8/9 percent).

The Register was the newspaper most frequently read. Fifty percent of the respondents on both I-5 and Route 55 read this paper, followed by roughly 40 percent who read the Los Angeles Times. No other newspaper was mentioned by more than 2 percent of the respondents.

Leading radio stations listened to by commuters on both freeways were KIIS, KABC, and KFWB. The data indicate that any purchase of radio time for promoting the proposed new lanes would require the use of both Los Angeles and Orange County stations in order to effectively penetrate the market. Typically, 8 to 10 stations are required to do even a marginal campaign. In order to better target the peak-period commuter market, consideration would have to be given to buying radio time during commuting hours coupled with encouragement of radio stations to cooperate in providing public service announcements.

SUMMARY AND CONCLUSIONS

The results of the telephone survey were tabulated and evaluated and will be used to assist the commission, the California Department of Transportation (Caltrans), and the specially created Route 55 Corridor Operation Advisory Committee in addressing design, operational, and public awareness issues related to proposed HOV-lane projects on these freeways.

The following key conclusions about attitudes and opinions concerning tests of the HOV-commuter-lane concept were found:

1. Despite the low rate of ridesharing among current freeway users, more than 75 percent of all respondents would be in favor of testing the HOV-commuter-lane demonstration projects proposed on Route 55 and I-5.
2. Nearly two-thirds of the respondents on both freeways perceive traffic as always or almost always

being "exceptionally bad." When asked to rank the relative effectiveness of various improvements, respondents on both Route 55 and I-5 considered that to "add one lane in each direction for use by all traffic" would be most effective, followed by "spread out work start/stop times." In the Route 55 survey, "using the median next to the center divider as another lane of traffic" scored third, although the improvement did not specifically call for exclusive use by carpoolers. The improvement related to the addition of lanes exclusively for carpools ranked 7 out of 9 in the Route 55 survey and 6 out of 8 in the I-5 survey.

3. Respondents were equally divided about whether the commuter lane should be used during peak periods only or all day. More than 70 percent of the sample believed that the lane should be available for use by vehicles with two or more persons.

4. Eight percent of the respondents indicated that they would be "very likely" to increase the number of people in their vehicle in order to use the new lanes; an additional 18 percent reported that they would be "somewhat likely" to do so. Roughly 65 percent reported that they would be "not at all likely" to change their current travel behavior and would not carpool.

5. Eighty-three percent of those using I-5 cited advantages with the HOV-lane concept compared with 67 percent who cited disadvantages. Among users of Route 55, 72 percent of the respondents cited both advantages and disadvantages. The major advantages perceived by users of I-5 and Route 55, respectively, were "reduced congestion," 40/46 percent of all respondents; "good incentive to carpool," 23/27 percent of all respondents; and "will reduce driving time," 20/21 percent of all respondents.

6. The major disadvantages with the HOV-commuter-lane concept noted by respondents differed by freeway. In the I-5 survey, the primary disadvantages perceived were "inability to enforce it" (20 percent), "should be for all vehicles to use, not just carpoolers" (17 percent), "too expensive" (8 percent), "will not reduce congestion" (8 percent), and "construction hassle" (7 percent). On Route 55, there was concern that the new lanes will be "unsafe without the median for emergencies" (34 percent), and "unsafe for lane changing and getting on/off the lane" (17 percent). These are followed by "difficult enforceability" (15 percent) and "should be for all vehicles, not just carpoolers" (14 percent).

7. The predominant name used to describe the new lanes was "carpool lane" (33/35 percent), followed by "express lane" (26/27 percent) and "commuter lane" (17/20 percent).

8. In terms of current travel behavior, roughly 90 percent of all respondents currently drive alone, 14 percent carpool at least one day per week, and 1 percent use transit. Among those who currently carpool on I-5 and Route 55, respectively, 73/66 percent drive with one other person and 15/23 percent with two other persons. Total travel times are longer for those who use I-5 than for those who use Route 55; the average times are roughly 45 min and 35 min, respectively. For users of both freeways, travel times are significantly longer in the afternoon peak period than in the morning.

9. Peak-period travel is spread across an extended peak that lasts roughly from 6:00 to 9:00 a.m. and from 2:30 to 7:00 p.m. Because more than 90 percent of the respondents report their primary trip purpose as commuting to and from work, the data indicate that in the aggregate, considerable variation currently exists within the county with respect to work start and stop times.

10. The predominant reasons given for not carpooling or vanpooling were "work schedule doesn't permit it," "don't know anyone to ride with," and "use car at/during work." It should be noted that in the absence of supporting ridesharing information and promotional services, most of these reasons will continue to prevail regardless of what is done to improve traffic on the freeways. Some 35/50 percent of the reasons identified are issues that could potentially be addressed by extensive rideshare program development and marketing efforts.

11. Among those who carpool, the key motivators were cost savings (34 percent), less wear and tear on the car, reduced driving stress, and opportunity to socialize. Few demographics in the survey directly affected or correlated with the likelihood of carpooling. Carpoolers come from all income levels, both sexes, and various demographic profiles. The only demographic factor that one can consistently point to from this survey is "employer size"--carpoolers tend to work for bigger companies than do those who drive alone. In addition, consistent with the findings of other studies, persons who carpool (on Route 55 only) tend to have longer total travel times than those who drive alone.

12. About 72 percent of all respondents noted that their employers or schools currently do nothing to encourage carpooling, and about 50 percent believe that employers should do nothing. The most frequent carpool promotional activity now offered is carpool matching, which is offered by 9/11 percent of the respondents' employers. Few other activities are now offered by employers. Respondents noted that employers could do more by offering matching services, providing publicity for carpoolers, adjusting start and stop times, and helping to pay for carpools and vanpools.

13. Commuters rely primarily on newspapers for information about local transportation improvements and to a lesser extent on radio and television. Although direct mail was not reported to be a major source of information, direct mail targeted through employers could provide a cost-effective way to supplement more broad-scale marketing activities to reach potential HOV-commuter-lane users within the I-5 and Route 55 corridors.

RECOMMENDATIONS

The results of the attitudinal surveys conducted as part of this study point to the following recommendations for consideration by the commission, Caltrans, and the Route 55 Corridor Operations Advisory Committee. These recommendations should be integrated into activities currently under way to evaluate the potential role of HOV-commuter-lane facilities in Orange County.

1. Although there is support by more than 75 percent of the survey respondents for testing the HOV-commuter-lane projects being considered for I-5 and Route 55, it is important that the lane concept be thought of as a test, particularly on Route 55. Freeway users are concerned about traffic congestion on these roadways, but they perceive HOV lanes to be less effective than additional lanes for all traffic. Officials must be willing to terminate the project if operational feasibility or effectiveness or both are not demonstrated. An evaluation program, with frequent reporting of results, should be part of the test.

2. In light of the concerns of the public demonstrated in this survey, it is essential that the safety and enforcement issues associated with HOV-commuter-lane operation be adequately addressed in the project planning process. Although use of the

median as an additional lane for traffic was ranked among the top three most effective ways to reduce congestion, when this was proposed for HOV use, respondents were concerned about loss of an emergency breakdown area, lane access and egress, and lack of enforcement. Freeway users also need to be made aware of the fact that many of the county's freeways--including sections of I-5--now lack a standard median.

3. If a decision is made to proceed with a commuter-lane demonstration, the lane should be used by vehicles with two or more persons. To encourage greater lane use, consideration should be given to allowing all forms of HOVs, including private and public buses. Either 24-hr operation or use over extended morning and evening peak periods should be considered.

4. In addition to capital projects aimed at providing new HOV commuter lanes, supportive marketing efforts and ridesharing information and promotional services should be designed to disseminate information, monitor public concerns, and encourage HOV facility use. In particular, there is a need for extensive publicity and promotion before introduction aimed at overcoming preestablished attitudes about the convenience, independence, and other perceived advantages of driving alone that are shared by most commuters. Successful project implementation will also require heavier Orange County transit district rideshare program promotion, awareness, and outreach for the general public and corridor-based employers.

5. Employer support should be encouraged as an essential component of the overall HOV-commuter-lane program. Working through employers offers a cost-effective way to reach the target commuter market, both demographically and geographically.

6. In addition to an employer-targeted effort and rideshare program promotion, a broad media campaign should be developed. Newspaper articles and advertisements, public service announcements, and radio announcements concentrated during driving times should be considered.

ACKNOWLEDGMENTS

Over the course of this study effort, invaluable assistance was provided to the commission by the consulting firm of Kenneth L. Barasch and Associates. The consultant was involved in all phases of the study, including survey design, questionnaire development, conduct of the focus groups, sample selection, administration of the survey, data analysis, and report preparation. The Orange County Transit District, County of Orange Environmental Management Agency, Caltrans, California Department of Motor Vehicles, and the cities of Santa Ana and Orange also participated in various aspects of the study.

Publication of this paper sponsored by Committee on Transportation System Management.

The Commuter Lane: A New Way To Make the Freeway Operate Better

DAVID H. ROPER

ABSTRACT

In an attempt to improve traffic flows on urban freeways, the California Department of Transportation (Caltrans) has recently implemented a demonstration project on a Southern California freeway to test the traffic operational features of a special commuter lane. The lane is being provided by allowing high-occupancy vehicles to drive on the median shoulder during peak commuter hours when the freeway is congested. In developing the project, Caltrans took into consideration several points relative to the operation of high-occupancy-vehicle lanes, the need for added capacity, and the conversion of shoulders into traffic lanes, which are discussed. Several factors are being reviewed in evaluating the operation of the project: accident experience, violation rates, operations associated with weaving and merging movements, travel times, congestion relief, and public acceptance. Results are presented and discussed.

On June 10, 1985, the California Department of Transportation (Caltrans) implemented a demonstration project to test the traffic operational features of a special commuter lane. The lane, stretching along 8 mi of the Artesia Freeway in southern Los Angeles County and costing about $200,000, was created by permitting high-occupancy vehicles (HOVs) to drive on the median shoulder during the peak period. At all other times, the shoulder is restored for emergency parking only.

For several years, Caltrans has been seeking low-cost ways to add critically needed people-moving capacity to congested freeways. The advantages of HOV lanes have been repeatedly demonstrated on a host of projects across the nation, including the El Monte Busway in Los Angeles. After more than 10 years of operation, the busway is now carrying almost three times as many people during a peak hour as an adjacent freeway lane. But construction of the 11-mi busway took several years, and it cost in excess of $60 million in the early 1970s. Similar widening of the freeway and construction of the lanes in the median of the freeway would exceed $150 million today, which is not exactly a low-cost solution.

In reviewing successful HOV-lane projects throughout California and other states, it was concluded that several features were highly desirable in such an installation:

- The lane should be a through or express lane, with a limited number of ingress and egress points.
- The lane should be separated from adjacent freeway lanes, either by a physical barrier or by a buffer formed with delineation or traffic control devices or both.
- The lane should be located along a congested freeway, so that HOVs can bypass congestion on the freeway lanes. Ideally, the special lane should be operated so that free flow is maintained. Without these conditions, the HOV lane will provide little or no incentive to rideshare, and the fundamental idea of the special lane is voided.
- Areas to conduct enforcement activities should be provided adjacent to the special lane, so that violators do not have to be escorted across freeway lanes to the right shoulder.

As may be expected, the greatest use of HOV lanes--and thus the most ridesharing--occurs during the commute hours on the trip to or from work. Accordingly, if ridesharing is to be increased, it is the home-to-work trip that provides the greatest potential; the best payoff from special lanes to encourage sharing rides will be during the commuter hours.

Experience with the ill-fated Santa Monica Diamond Lane project in 1976 had clearly shown Caltrans that two other features are essential if HOV-lane projects are to be acceptable to the public:

1. Lanes must be provided without taking any capacity away from mixed-flow traffic, and
2. Enough vehicles must travel in the lane so that it is not perceived by the public to be an empty lane.

It is believed at this time that peak volumes in the range of 800 to 1,000 vehicles per hour will be seen as reasonable use.

For several years Caltrans has eliminated bottlenecks on many freeways by converting shoulders to lanes, particularly in the Los Angeles area. The added lanes have been created by slightly narrowing the freeway lanes and adding the width gained to the shoulder width. Without exception, the accident experience of the overall freeway has improved with this type of installation; any reduction in safety resulting from loss of the shoulder has been more than offset by an improvement in the accident picture due to reduced congestion.

Looking at the need for added capacity, it is apparent that the increase is needed only during the hours of congestion, generally during the commuting hours. On the other hand, for motorists with disabled vehicles, the safety features of shoulders are probably most needed during the high-speed off-peak hours, particularly during darkness. These facts suggest that the space occupied by a shoulder can play a dual role that best serves the needs of the

California Department of Transportation, 120 S. Spring Street, Room 442, Los Angeles, Calif. 90012.

FIGURE 1 Route 91 commuter lane.

motoring public at a particular time--as a lane during peak traffic hours when the addition of capacity is critical and as a shoulder during off-peak hours to provide needed safety features.

Caltrans brought all of these concepts together into the commuter lane developed for the demonstration project on the Artesia Freeway.

PROJECT FEATURES

The demonstration project, about 8 mi long, allows carpools, vanpools, and buses to use the median shoulder of the eastbound Route 91 (Artesia Freeway) from 3:00 to 7:00 p.m. each weekday. Two north-south freeways, the Long Beach Freeway and the San Gabriel River Freeway, intersect the Artesia Freeway within the project limits (Figure 1).

Buffer

A buffer area 2 ft wide has been striped between the freeway lanes and the commuter lane, using special striping (Figure 2). No other traffic control devices have been placed within the buffer area. It is illegal to cross this special striping during hours when the shoulder is being used as a commuter lane.

Definition of HOV

Counts of the existing traffic stream revealed that during the peak, about 250 vehicles per hour (about 3 percent) carried three or more occupants; slightly in excess of 1,000 vehicles per hour, or 15 percent, had two or more. The two-or-more category provided enough vehicles to present a reasonably full lane, yet not so many that flows in the lane would become congested; therefore, a two-or-more definition is being used. Under this definition and the expected use, the commuter lane would carry more people during the peak than each adjacent lane.

Hours and Limits of Operation

Commuter-lane hours were selected to correspond to the hours when congestion existed on the freeway,

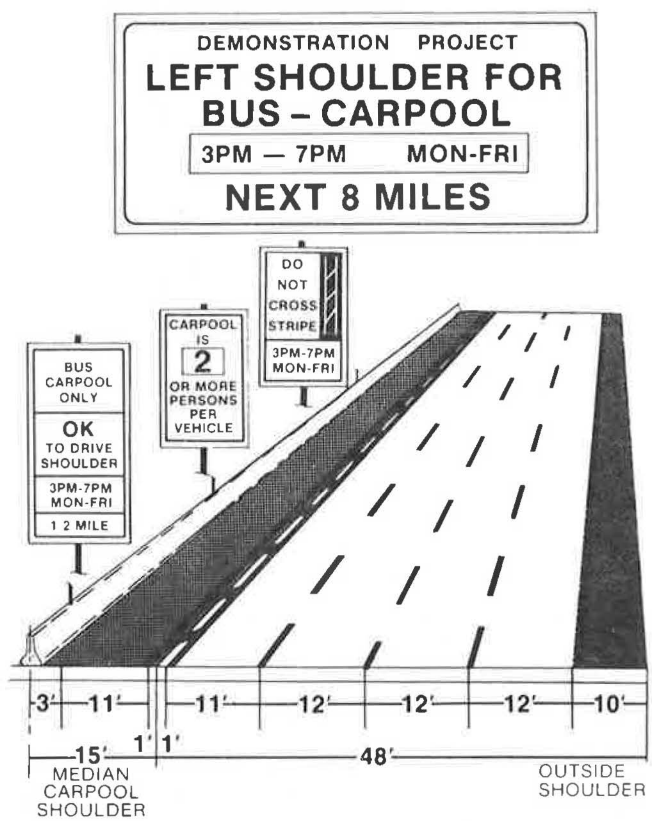

FIGURE 2 Project details.

between 3:00 and 7:00 p.m. At all other times, the shoulder area is available for emergency parking only. The location of congestion on the freeway dictated the limits of the lane.

Lane Width

The commuter lane is 11 ft wide, with a side clearance to the median barrier wall of 2 ft. The left-most freeway lane has been narrowed to 11 ft (Figure 2).

Signing

Static signing was installed atop the median barrier wall and overpasses (Figure 2). Since the initial installation, signing has been modified; changeable-message signs to provide "real-time" operation information have been installed (Figure 3). These flip-type signs, which are manually changed twice each day, provide messages relative to the proper use of the shoulder at any particular time. Plans are currently under way to provide power to the new signs and to add signal-head indicators (red X's and green arrows) to reinforce sign messages (Figure 4).

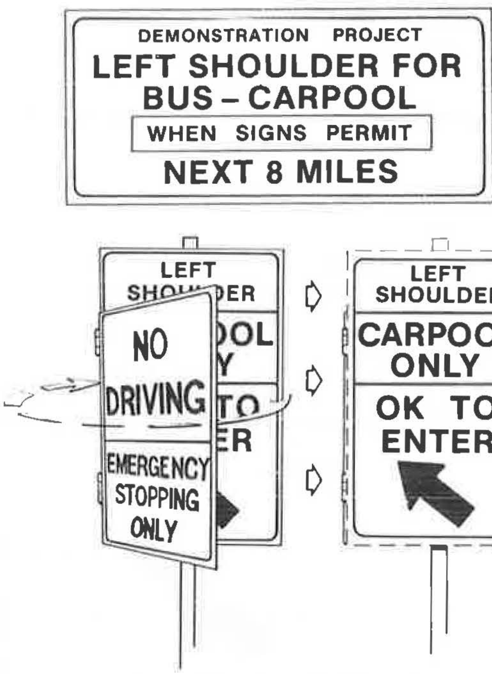

FIGURE 3 Changeable-message real-time signing.

Points of Ingress and Egress

Two entry points and two exit points have been provided by discontinuing the special striping and leaving openings in the buffer (Figure 5). No direct connections into the commuter lane have been provided; HOVs simply move into or out of the commuter lane by using the adjacent freeway lane.

Drivers making a normal right-hand entry into the freeway who wish to use the commuter lane must weave across four regular freeway lanes to reach the ingress points. Similarly, a commuter-lane user wishing to exit the freeway must make his way across the freeway lanes.

Enforcement Area

An enforcement area has been provided adjacent to the median barrier wall by shifting (through re-striping) the entire freeway onto the right-hand shoulder (Figure 5). A barrier wall has been installed to shield this area from oncoming traffic.

The California Highway Patrol is providing enforcement of the commuter lane. Motorcycle officers

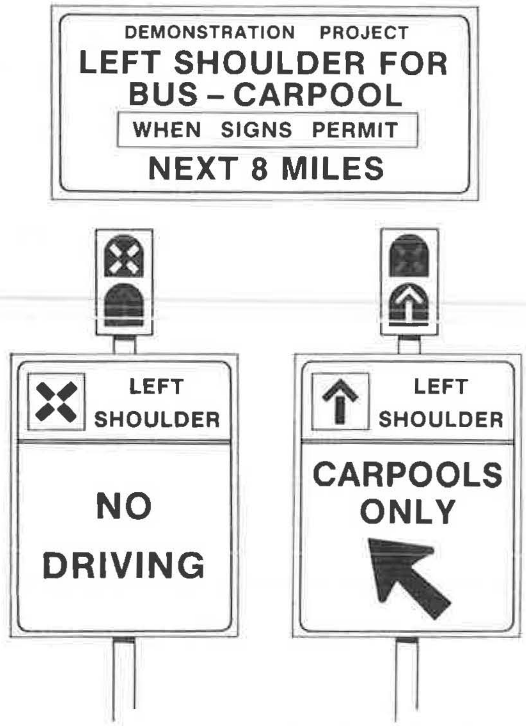

FIGURE 4 Powered real-time signing with signal-head indicators.

patrol throughout its length; other officers are stationed at the enforcement area and direct any single-occupant automobiles into the enforcement area.

Public Awareness Program

During the development of the project, an extensive public awareness program was conducted to build the public support needed to implement and operate the commuter lane. A Public Advisory Committee, made up of representatives of elected officials, major employers, and the transportation community, was formed early in the project. The committee has provided input to the design and has helped develop criteria by which to evaluate the project: lane use, safety, delays, violation rates, and public attitudes. The committee continues to meet to review and evaluate the operation and to make suggestions for the improvement of the project.

The committee has been instrumental in developing a public awareness of the commuter lane, its purposes, and its proper use. Much of the community acceptance of the project and the support for its continued operation are directly attributable to the activities of the advisory committee.

PROJECT OPERATION

After almost 1 year of operation, the project continues to perform extremely well. Use of the commuter lane has shown some growth; the safety experience has been excellent; travel times in both the commuter lane and on the freeway lanes have been significantly reduced; violation rates have not seriously affected the operation; the weaving and merging movements have operated well; and public attitudes and support for the project have been very high.

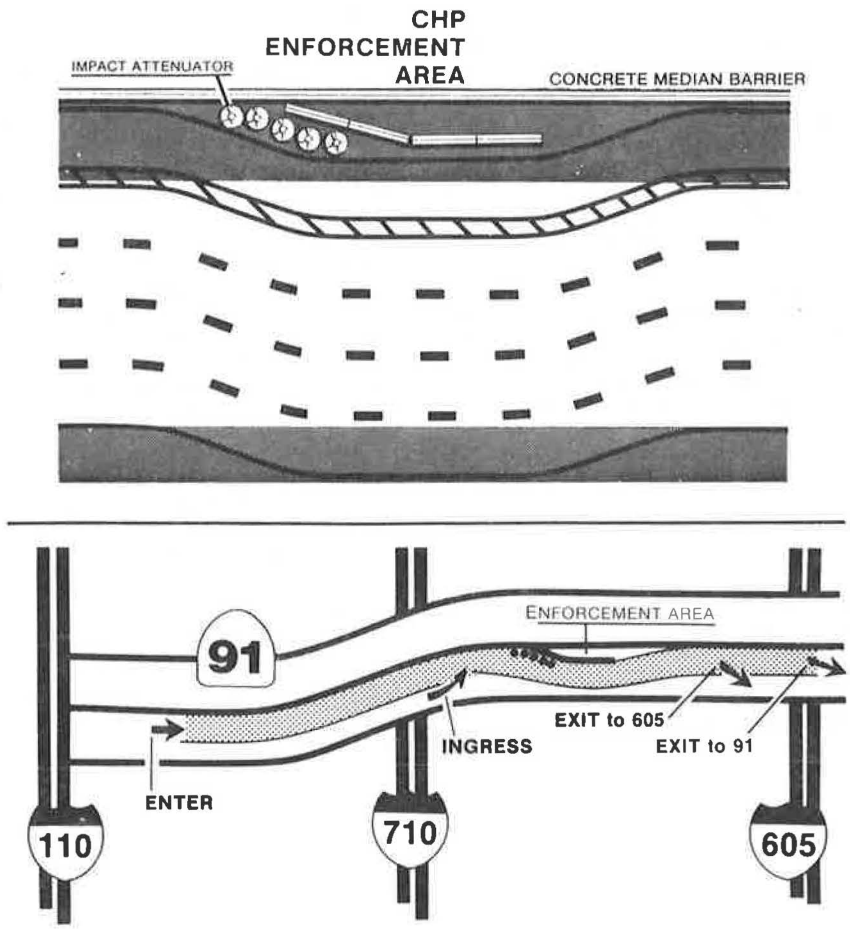

FIGURE 5 Entry and exit points and enforcement area.

Commuter-Lane Use

Following the initial break-in period, there was a growth in the use of the commuter lane, increasing from about 1,000 vehicles during the peak hour to 1,400 to 1,500 vehicles per hour after 2 months of operation. Use during the peak hour then leveled off at about the 1,350-vehicle/hr level and has now climbed to about 1,450 vehicles/hr.

More people are now moving through the corridor in a given time than before the project. During the average peak hour, the commuter lane carries about 3,200 persons (2.2 persons per vehicle); the adjacent freeway lanes each carry more than 2,200 persons (1.17 persons per vehicle) during the peak hour. During the 4-hr peak period, the commuter lane carries about 24 percent of those moving along the freeway; each freeway lane carries about 19 percent of the remaining 76 percent.

Freeway Use

Operation on the mixed-flow freeway lanes has improved somewhat with the implementation of the commuter lane. As carpools and vanpools have shifted to the commuter lane, both the limits of congestion and the hours of congestion have been reduced. Freeway volumes have remained much the same as they were before the project.

Travel Times

Delays through the corridor have been significantly reduced with the introduction of the commuter lane. On the regular freeway lanes, travel times have been cut from about 30 to 35 min before the project to a current 15 to 20 min for the 8-mi trip. Travelers in the commuter lane experience little or no delay, with travel times now averaging 8 to 9 min.

Violations

Three types of violations are being monitored: vehicle-occupancy violations (single-occupant vehicles using the commuter lane), buffer violations (vehicles entering or leaving the commuter lane, or both, at other than designated entry or exit points), and time-of-day violations due to driving on the shoulder when it has been designated for emergency parking only.

Occupancy violations have held steady at 3 to 7 percent. It has been noted that this type of violation is directly tied to the level of congestion on the freeway (the more congestion, the greater the number of violations).

Buffer violations vary greatly depending on the specific location. In some reaches, more than 30 percent of the commuter-lane users enter or leave the lane illegally. It is noted, however, that no significant safety or operational problems have resulted from illegal buffer crossings. Better signing and increased levels of enforcement are now being considered as steps to reduce these violations.

Time-of-day violations have presented a significant problem in the operation, for they indicate that attempts to regain the shoulder for emergency parking have not proven totally successful. Most of the violations occur during daylight hours, both weekdays and weekends, when traffic volumes on the freeway lanes are fairly high (even though congestion does not exist). During operation with static-type signing, an average of 600 to 700 motorists illegally traveled on the shoulder each day.

Since flip-type real-time signing has been added and additional levels of enforcement have been provided, time-of-day violations have been dramatically reduced. Immediately after the changes were made, violations dropped into the range of 65 to 75 per day, held fairly stable at that level for a couple of months, and then gradually grew to about 130 violations per day. Steps are now being taken to add signal-head indicators (red X's and green arrows) to supplement sign messages in an attempt to further reduce this type of violation. In a further attempt to reduce violations during hours of nearly congested operation, the hours of commuter-lane operation have recently been broadened to 2:00 to 7:00 p.m.

Safety

There has been no perceptible change in accident rates nor in severity of accidents since the introduction of the commuter lane. Normally about six to eight accidents per week occur on this stretch of the freeway. To date, there have been no fatalities associated with the commuter-lane operation.

Public and Media Reaction

Many positive newspaper articles and editorials dealing with the project have been published; more than 90 percent of the contacts from the public have expressed support for the project. Recently there has been virtually no media attention and very few calls or letters regarding the project. There has been a request by the community to implement a similar lane in the westbound direction.

The commuter-lane project cannot yet be declared an unqualified success; it is premature for that. Much more operating experience under a variety of conditions is still needed. The results to date have been most encouraging, though, so much so that a second step in the evolution of the concept has been taken. Similar commuter lanes, in use full-time, were implemented in November 1985 in both directions on about 12 mi of the Costa Mesa Freeway in Orange County; similar excellent results are being observed.

Results to date suggest that the part-time use of shoulders for added capacity and operating the added lane for HOVs may well be one of the best transportation system management techniques yet to come down the freeway.

Publication of this paper sponsored by Committee on Freeway Operations.

High-Occupancy-Vehicle Lanes: Some Evidence on Their Recent Performance

FRANK SOUTHWORTH and FRED WESTBROOK

ABSTRACT

The results of a 1985 survey of high-occupancy-vehicle (HOV) project performance are presented. Despite the lack of the energy crises that spurred HOV-lane promotion during the 1970s, HOV-lane planning has continued to remain active in a number of states. Most currently operational main-line HOV lanes were found to be very effective as people movers during peak commuting hours and to save fuel by removing significant numbers of automobiles from the road through high levels of ridesharing and bus patronage. Bus ridership has managed to compete effectively with carpooling and vanpooling on a number of lanes. Continued traffic growth during the 1980s is strengthening the case for HOV-lane use in many urban corridors.

The major findings from an April-June 1985 nationwide survey of U.S. federal, state, and local transportation and energy planning offices are presented. The objectives of this survey, which was commissioned by the Office of Transportation Systems of the U.S. Department of Energy, were to collect the most up-to-date evidence on the performance of carpool- and vanpool-supporting high-occupancy-vehicle (HOV) projects and to identify existing plans for future rideshare-supporting HOV-lane implementations.

Although the survey was carried out in conjunction with associated analytic work in the form of computer simulation modeling of HOV-lane operations, only the empirical evidence for HOV-lane performance is reported. As such this evidence reflects the realistic state of the art in HOV-lane project data collection. As will become evident, a number of problems remain to be solved before the appropriate statistics are available from which to evaluate HOV-lane benefits and costs rigorously. All the tables presented are taken from a report by Southworth and Westbrook (1). In the main, the data contained in these tables comes from two sources: the most recently published data on a particular HOV-lane project or recent traffic count and related engineering data forwarded to the authors by the appropriate planning agency, usually the state department of transportation or the metropolitan planning organization. In this paper the emphasis is on bringing out the highlights of this survey. The full report is available from the authors on request.

Three major findings came from the survey:

1. HOV-lane planning remains very active in some states. Since 1982, 8 of the 18 currently operational main-line HOV lanes were started, two other lanes were abandoned, and operations on two were suspended to allow construction. Four of these 18 operational lanes are on arterials (on the recently opened San Tomas and Montague Expressways in San Jose, California; on North Washington Street in Alexandria, Virginia; and along Honolulu's Kalanianaole Highway). The remaining 14 freeway lanes are the major focus of this paper. In all, some 123.5 mi of HOV lane operates currently nationwide, with another 129 or so additional lane miles in construction and planned to be opened by 1989.
2. The quality of the existing data on HOV-lane operations is less than adequate in most, if not all, cases, for the purposes of project evaluation. This lack of sufficient traffic count data, not only for the HOV-lane highway but for the corridor as a whole, prevents definitive statements on lane impacts.
3. Despite the quality of the available evidence, enough data are available to support a contention that the majority of these HOV lanes are very effective people movers during the daily traffic peaks and that the most successful lanes save travel time for all commuters using these roads. Also, as traffic has continued to grow in those corridors with well-established lanes, these lanes have become increasingly effective in reduction of traffic congestion.

Shown in Table 1 for each freeway HOV project are the type of HOV treatment given priority, the lane length, the number of HOV and adjacent general-traffic lanes, and the lane types. Times of daily HOV restriction vary by project, the most common being 2 to 3 hr in the a.m. and p.m. peak commuting hours; on I-10 in Los Angeles, I-280 in San Francisco, I-5 in Seattle, and Moanalua Freeway in Honolulu, the lanes operate continuously.

The major lane types are defined as (a) physically separated (I-10 and I-91 in Los Angeles, I-10 in Houston, I-395 in Virginia, and I-93 in Boston), where the HOV lanes are separated from other lanes by a concrete barrier, narrow buffer lane, or raised berm; (b) nonseparated, which are mainly median lanes; and (c) dedicated lanes (I-66 in Virginia), the newest experiment, in which a complete (two-lane) freeway is devoted to HOV-only traffic during selected hours of the day. Only two of the lanes, on Houston's I-45N and Honolulu's Kalanianaole Highway, are contraflow (CF) lanes; the rest operate in the same direction as their adjacent general lanes. Houston's I-45N lane also has the distinction of being the only lane to bar carpools in favor of higher-occupancy vans.

In the following sections the evidence available for evaluating lane performance is reviewed and the implications to be drawn from it are discussed.

F. Southworth, Energy Division, Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, Tenn. 37831. F. Westbrook, Camden Corporation, 1495 Chain Bridge Road, Suite 300, McLean, Va. 22101.

TABLE 1 Freeways with HOV Lanes Available to Ridesharers, 1985

Project	HOV modes available	Route miles	Number of lanes		Type
			General	HOV	
Route 101 Marin Co., CA.	Bus, +3CP	3.7	3	1	median
I-280 San Francisco, CA.[a]	Bus, +3CP	1.6	3	1	median
Route 237 Santa Clara Co.,CA.	Bus, CP	4.6(east) 4.4(west)	2		1 right lane (shoulder)
I-10 San Bernardino Fwy. Los Angeles, CA.[a]	Bus, +3CP	11.0	4-6	1	median (separated)
Route 91 Los Angeles, CA.	Bus, CP	8.0	3	1	median (separated)
I-95 Miami, FL.	Bus, CP	7.5	4	1	median
I-4 Orlando, FL.[b]	Bus, CP	31.0	2	1	median
Moanalua Fwy. Honolulu, HI.[a]	Bus, +3CP	2.7(east) 1.3(west)	2	1	medians (1 each way)
I-93 Boston, MA.	Bus, +3CP	1.4	2	1	median (separated)
Banfield Fwy. Portland, OR.[b]	Bus, +3CP	1.7(west) 3.3(east)	2	1	median
I-45N Houston, TX.	Bus, +4CP	9.6CF +3.3	3-4	1	median
I-10 Katy Fwy. Houston, TX.	Bus, +4C	6.5	3-4	1	median (separated)
I-395, Shirley Hwy., VA.	Bus, +4CP	12.0	4	2	median (separated)
I-66, VA.	Bus, +3CP	10.0	0	2	dedicated
I-5 Seattle, WA.[a]	Bus, CP, +3C Motor Cycle	6.9(sou) 5.0(nor)	3-4	1	medians (1 each way)
Route 520 Seattle, WA.	Bus, +3CP	2.0	2	1	right lane (shoulder)

Notes:

a In operation continuously (versus peak periods only use).

b Currently not enforced, due to construction.

CP=2 or more persons per vehicle required.

+3CP=3 or more persons per vehicle required.

CF=contraflow lane (as opposed to concurrent flow).

PERSON THROUGHPUT, VEHICLE OCCUPANCY, AND LANE VIOLATION RATES

Table 2 (1) shows the person throughput, measured in terms of the number of travelers passing along all or part (usually all) of each HOV-lane-supporting highway project, for the duration of the a.m. peak hour, a.m. peak period, or both. Person throughput rather than vehicle throughput is the appropriate measure here because in the final analysis it is the number of commuters served that is of concern. Shown are the average weekday peak volumes of persons per lane for the HOV lane (or in the cases of Shirley Highway and I-66 in Virginia, averaged across the two HOV lanes) compared with that for the general, mixed-traffic lane. Also shown are the average vehicle occupancies on the various lanes as well as those averaged over all traffic on the highway (i.e., including both HOV and non-HOV lanes).

It is important to note, in looking at Table 2, that those per-lane person volumes associated with peak period flows (i.e., the row-a data) refer to a period that varies from 2 to 4 hr. Hence much higher values are reported for "a" rows than for "b" rows (peak-hour volumes).

For the purpose of assessing the contributions of carpooling or vanpooling or both (ridesharing, denoted RS) to these person volumes, Table 2 also contains a separate column for the number of peak bus users (Column 1). To complement this information there are also two separate HOV-lane vehicle occupancy values: one for all HOV-lane users and one for carpool and vanpool users only.

Scrutiny of Table 2 will indicate that in some places summing the number of bus and RS HOV-lane users gives a total that is lower than that in the column labeled "All" travelers using the lane. In such cases the discrepancy is accounted for by the number of violators using the lane, which in the case of a two-person-plus (CP) rule implies drive-

TABLE 2 Person Throughput and Vehicle Occupancies

Project[d]		Average Person Volumes/Lane				Average Vehicle Occupancies			
		HOV Lane(s)			General Lane(s)	HOV Lane(s)		General Lane(s)	All Lanes (inc. Bus)
		Bus	RS	All[c]		RS	All		
Rt-101 Marin Co.	a.	4,915	2,140	7,080	5,253	3.90	9.80	1.44	2.00
(April 1984)	b.	2,910	1,315	4,235	2,865	3.70	9.70	1.50	2.10
I-280, S.F. (May 1984) (a=p.m.)	a.	400	545	970	5,502	3.11	4.41	1.50	1.56
Rt-237 Santa Clara Co.	a.	380	4,000	4,540	4,190	2.14	2.22	1.00	1.24
(Nov.1984)	b.	160	1,705	1,950	1,513	2.15	2.20	1.00	1.30
I-10, San Bernardino.	a.	8,470	6,865	15,800	9,400	3.17	6.01	1.22	1.59
L.A. (1984)	b.	3,450	2,855	6,490	2,588	3.15	5.95	1.22	1.76
I-95, Miami. (1984)	b.	700	3,005	3,705	2,162	1.51	1.85	1.20	1.34
I-45N Fwy. Houston.	a.	3,274	4,526	7,800	4,700	12.3	16.56	1.21	1.81
(contraflow) (May 1982)	b.	1,300	2,830	4,130	2,400	12.3	15.20	1.21	1.82
Katy T'way, Houston.	a.	2,030	886	2,916	4,703	10.9	22.8	1.18	1.49
(Dec.1984)	b.	1,020	745	1,765	1,918	10.9	19.4	1.16	1.38
I-5, Seattle. (May 1985)	b.	1,800	1,490	3,290	2,311	3.75	7.20	1.20	1.53
Shirley Hwy. VA.(March	a.	7,512	9,228	16,740	6,725	4.96	8.05	1.25	2.35
1985)	b.	3,672	4,942	8,614	2,400	5.06	7.94	1.34	2.88
I-66, VA. (Spring	a.	701	4,652	5,353	-	1.99	2.23	-	2.23
1984)	b.	374	2,577	2,951	-	2.17	2.46	-	2.46
I-93, Boston. (1980)	a.	2,170	3,220	5,390	3,256	2.61	3.40	1.22	1.72
Banfield Fwy. Portland.	a.	633	864	1,497	4,046	2.72	6.07	1.18	1.58
(1977)	b.	570	505	1,075	2,272	2.81	4.87	1.18	1.38
US-1/S.Dixie Miami.(1984)	b.	600	2,416	3,016	1,470	2.17	2.67	1.08	1.55
San Tomas Expwy.,San Jose. (Spring 1985)	a.	195	2,477	2,612	2,443	2.07	2.16	1.00	1.16

Note: RS denotes ridesharing, i.e., carpools and vanpools.

a. = per peak period b.= per peak hour

c Bus + RS + Violators = All where (1) + (2) = (3).

d Project dates refer to time of latest reported survey.

alone violators but may in the case of a three-person-plus rule include two-occupant vehicles, and so on.

Data on violation rates exist for 14 of the projects. Only a 50 percent rate on the unenforced I-95 in Miami stands out. With regular enforcement, violation rates tend to be less than 3 percent of all HOV-lane traffic (1). No systematic cost-benefit analysis of enforcement versus violation rate appears to have been carried out to date.

Using the information on person throughput presented in Table 2, the following measure of HOV-lane effectiveness, termed the measure of highway capacity usage (MCU), was derived and is reported in Table 3:

MCU = [percentage of persons per peak period (or hour) on HOV lane]/(percentage of road capacity devoted to HOV traffic)

For example, US-101 in Marin County has three general-traffic lanes alongside a concurrent-flow median HOV lane. Hence from the data in Tables 2 and 3 for the a.m. peak period:

$$MCU = \{7{,}080/[(5{,}253 \times 3) + 7{,}080]\}/(1/4) = 0.31/0.25 = 1.24$$

The MCU shows how effective the HOV lane is at moving people when compared with an average adjacent

TABLE 3 Highway Capacity Usage Associated with HOV-Lane Operations

Project		MCU	MEC[c]	Mix[d]	
Rt-101 Marin Co.	a.	(31.0/25)=1.24	78%	125/720	(17%)
	b.	(33.0/25)=1.32	73%	75/435	(17%)
I-280 S.F.	a.	(5.5/25)=0.22	94%	20/220	(9%)
Rt-237 Santa Clara Co.	a.	(35.1/33)=1.06	62%	20/2045	(1%)
	b.	(39.2/33)=1.19	50%	10/888	(1%)
I-10 San Bernardino.	a.	(29.6/20)=1.48	62%	190/2630	(7%)
	b.	(38.5/20)=1.93	37%	75/1090	(7%)
I-95 Miami.	b.	(30.0/20)=1.50	0%	15/2005	(<1%)
I-45N Houston	a.	(29.3/25)=1.17	85%	103/471	(22%)
	b.	(36.0/25)=1.44	84%	55/250	(22%)
I-10,Katy, Houston.	a.	(13.4/25)=0.54	96%	47/128	(37%)
	b.	(18.7/25)=0.75	94%	39/91	(30%)
I-5, Seattle.	b.	(26.2/20)=1.31	73%	45/457	(10%)
Shirley Hwy. Virginia.	a.	(55.4/33)=1.66	65%	435/4158	(10.5%)
	b.	(64.2/33)=1.93	36%	216/2169	(10%)
I-93 Boston.	a.	(45.3/33)=1.37	83%	50/650	(8%)
Banfield Fr. Portland.	a.	(15.6/33)=0.47	90%	28/346	(8%)
	b.	(19.1/33)=0.58	88%	20/200	(10%)
US-1 Miami.	b.	(50.6/33)=1.53	24%	18/1130	(<2%)
San Tomas, San Jose.	a.	(26.2/25)=1.05	64%	11/1208	(1%)

a. = a.m. peak period b.= a.m. peak hour

c Assuming 1800 autos per lane per hour as an acceptable design capacity for a freeway HOV lane (1500 per lane on arterials) (i.e. allows average speed of approx. 50 mph), and assuming that 1 bus = 1.6 autos.

d Number of Buses/ All Vehicles in HOV Lane (and % Buses). This includes reported violators in HOV lane(s).

general traffic lane that has the same road capacity. An effective HOV lane in terms of throughput is one for which the MCU equals or is greater than 1.0.

According to this criterion eight of the existing freeway HOV lanes (Marin County, Santa Clara County, San Bernardino Freeway, I-95 Miami, I-45N Houston, I-5 Seattle, Shirley Highway in Virginia, and I-93 Boston) as well as the San Tomas arterial lane in San Jose are all very effective people movers, even when the full peak a.m. period is considered. Also effective, with an MCU of 1.53 in the a.m. peak hour, was the recently closed US-1/South Dixie Highway in Miami. It also appears likely that the Katy Freeway in Houston will attain an MCU of at least 1.0 given its very recent (1985) inception, its corridor's potential for traffic growth, and Houston's success with vanpooling promotions. Of the projects listed in Table 3, only the recently discontinued Banfield HOV lane in Portland and I-280 in San Francisco show MCUs much less than 1.0, and the peak-hour data for I-280, which might reflect a more effective lane, were not available at the time of the survey.

Most recent evidence reported in the literature suggests an improvement in the effectiveness of some of these lanes during their respective 2- to 3.5-hr a.m. peak periods. That is, growth of traffic in these corridors in recent years has served to make use of these HOV lanes more important in the "shoulders" around the peak traffic hour. Should this trend continue, an even more positive case for HOV main-line lanes would be justified.

It has been assumed for Table 3 that all HOV lanes are concurrent-flow lanes and that it is the with-peak direction volumes that are of concern. The same use of the MCU can be applied to a contraflow HOV lane, except that here it would always be expected that the lane would have a value much higher than 1.0, because the peak-flow HOVs are replacing an off-peak flow that is usually of much reduced volume. This, however, may not always be the case. For example, there has been significant growth in the "off-peak direction" traffic along the I-45N corridor in Houston that may have caused delays for this "reverse commuting" traffic had this contraflow/concurrent-flow HOV lane not been replaced by a barrier-separated transitway in 1985.

Table 3 also contains a measure of extra HOV-lane capacity (MEC), given as

MEC = 100 - percentage of HOV-lane design volume in use

where design volume refers here to the lane's capacity to move traffic under acceptably safe driving conditions (based on between-vehicle distance). To ensure an average speed of 50 mph, and thereby maintain a clearly uncongested trip advantage for the HOVs, a base of 1,800 vehicles per hour (vph) is used in Table 3. Although higher volumes are possible in practice, as reported in Table 2, under such traffic concentrations (i.e., number of vehicles contained in a given road space at a given time) the flow characteristics of the highway become increasingly unstable.

To obtain passenger-car equivalents (pce's) for the purpose of assessing the level of HOV-lane congestion, a flat-terrain equivalence of 1.6 automobiles = 1 bus is used to derive the MECs in Table 3. This value assumes a lane with relatively free-flowing traffic, as would be required to encourage commuters to take advantage of the time saving offered by the prioritized lane. Thus, for example, in Table 3 the third column gives the mix, or proportion of buses to all HOV-lane vehicles; of 720 HOVs on US-101 in Marin County during the a.m. peak period (from an April 1984 traffic count) between 6:30 and 8:30 a.m., 125 were buses. Therefore

$$(720 - 125) + (125 \times 1.6) = 795 \text{ pce}$$

which gives

$$MEC = 100 [1 - (795/3{,}600)] = 78 \text{ percent}$$

Note that all peak-period values are necessarily reduced to a measure based on hourly traffic volumes, and it is most appropriate to use the peak-hour figures (i.e., the "b" rows in Table 3) to assess remaining HOV-lane capacity. Note also that whereas a 6:00 to 9:00 a.m. peak period is shown for Marin County in Table 3, only data for the 2-hr period 6:30 to 8:30 were available. Hence it is not always possible to derive the results in Table 3 directly from those in Table 2.

In assessing the respective project MECs reported in Table 3 some caution must again be exercised. Figures for Houston's Katy Transitway were taken after only 3 months of operation and therefore do not reflect the likely eventual use of this separated lane. Looking only at the peak-hour capacity use (the "b" rows), the MECs range in value from zero on

Miami's I-95 (where violation rates were as high as 50 percent) to 88 percent on the Banfield Freeway in Portland. Virginia's Shirley Highway and Los Angeles' San Bernardino Freeway have clearly the heaviest peak-period, and especially peak-hour, use. Even the Santa Clara County HOV lane on Route 237, which allows ridesharing by two-person carpools, still has 50 percent of its capacity available for further HOV traffic growth, whereas those other freeway projects barring two-person carpools have MECs in the range 76 to 88 percent.

Even with the foregoing statistics, care must be taken in making comparisons across projects. What may be a success in one area of the country or on one corridor within a city may appear less so in a different urban context. In all cases the bottom line should be whether the HOV lane is more efficient and economical than its alternative, an additional general-traffic lane. The MCU, it is argued, is a single statistic that comes close to indicating this efficiency condition. The MEC then indicates how much room is left in a given situation for absorbing extra traffic with no further expansion in highway capacity (no further construction). The overall conclusion from Table 3 is that these lanes are effective people movers with still more capacity available for HOV traffic growth.

IMPACTS ON TRAFFIC SPEEDS

Table 4 shows the reported a.m. peak-hour speeds on the HOV lane and adjacent general traffic lanes for many of the projects discussed earlier, where data were available. It has been usual to introduce HOV lanes on highways suffering from average space mean speeds (defined as the distance traveled along a road section divided by the time taken to travel it) in the range 15 to 30 mph. This range contrasts with the approximately 55 mph speed possible under the best possible level of service, or free-flow conditions such as those usually found in HOV lanes.

Although time was lost by peak-direction travelers on Honolulu's Moanalua and Boston's I-93 freeways, as it was by reverse-direction travelers on Houston's I-45N (where a contraflow lane was created by reversing a previously off-peak-direction lane), users of the general-traffic lanes on Miami's I-95, Houston's I-45N, Seattle's I-5, and Virginia's I-395 actually saved time after HOV-lane introduction during both a.m. and p.m. peak periods.

Difficulties again exist, however, in making such before-and-after comparisons. Growth in total traffic volumes during the interim must be fully understood if the full benefits or costs of an HOV lane are to be determined. Clearly, if a new lane is added to the highway, whether HOV or not, average traffic speeds will increase immediately. Only by removing the HOV priority from the added lane can the lane's impact be definitely established. In practice this is obviously an unwise approach, and so simulation modeling of the problem must be used, incorporating the potential for route switching or departure-time adjustments, or both, as well as the modal shifting resulting from a reconversion from an HOV lane to a general-traffic lane. Little or no reliable data on any of these potential impacts appear to have been collected to date.

What the data in Table 4 can show is the extent to which non-HOV-lane users' travel speeds and times

TABLE 4 Automobiles Removed, Speeds, and Time Savings on Selected HOV-Lane Freeways

Project	Automobiles Removed Daily (Estimated)	Speeds[a] (mph) Before Priority	After priority: General lanes	After priority: HOV lanes	One-way trip time savings, HOVs vs. general lanes (minutes)
I-10, San Bernardino Fwy. Los Angeles.	3,462	b	b	b	18.0
I-95, Miami.	b	31.5	38.1	52.9	2.0
I-93, Boston.	1,405	29.4	17.0	42.2	4.0
Banfield Fwy. Portland.	414	38.0	37.5	51.5	1.0
I-45N, Houston.[c]	3,372	22-26	29.0	55.0	9.3
I-395, Shirley Hwy. VA.	10,945	b	19-33	46.9	15-20
I-66, northern VA.	2,316	d	d	45.0	12-15[e]
I-5, Seattle.	4,000	30.0	47.6	55.0	1.8

Notes:
a AM peak hour average speeds.

b Data not available.

c Contraflow lane section.

d I-66 has been a dedicated HOV freeway during peak commuting hours since its opening.

e Compared to other parallel routes.

have deteriorated or improved since HOV-lane inception. When a serious worsening in traffic congestion has occurred due to growth in the number of commuters using the corridor, it is natural for some travelers to question the existence of an HOV lane, even if it is actually helping to keep the level of congestion in the corridor down (as is the case for all those lanes with MCUs significantly greater than 1.0). It is therefore worth publicizing information of the sort presented in Table 4 because public opinion, even when misinformed, can be a force in the decision-making process and in the past has caused the delay or abandonment of potentially beneficial HOV-lane projects.

On the basis of these operating speeds, travel-time savings on existing projects range from 1 to 20 min on a one-way commute, with the I-10 (San Bernardino), I-45N (Houston), and Shirley Highway (Virginia) projects proving particularly beneficial to both ridesharers and bus riders. That is, the longest lanes offer the greatest time savings.

Unfortunately, what is missing from the reported data is the percentage of total commute time represented by such savings for the various corridors studied. Because a 7-min savings can have different implications for commuter behavior on, for example, a 20-min commute versus a 40-min commute, it is difficult to judge just how effective HOV-lane projects can be expected to be in inducing a shift to HOV modes. Clearly, a range of commuter travel distances and hence times can be expected along any given urban corridor, and this range as well as the average commute time will affect the overall value of time savings associated with an HOV lane.

An equally important omission in currently collected data on HOV-lane performance is that of the variance in daily traffic speeds on the HOV lane versus that of adjacent general lanes. A benefit of traveling on the HOV lane frequently cited both in the literature and via telephone interview is the reduced variability in journey times that the lane offers. Indeed, anyone who has traveled frequently on any of the previously mentioned highways or along similar corridors elsewhere is familiar with the long delays possible when an accident or breakdown occurs, and fewer vehicles per lane means fewer breakdowns. Whereas travel demand and supply modeling in recent years has brought out the significance of such variability in service levels to transportation facility use, this knowledge has not as yet been applied to an empirical validation of the impact of such variability on the encouragement of HOV-lane use. Nor, therefore, have the potentially very high levels of such variability on some highways been used fully as a publicity tool to encourage the use of HOV modes.

A further note of caution is also offered when data such as those reported in Table 4 are used. Such speed data, as with the traffic volume data reported earlier, are usually obtained by monitoring traffic on only a small number of weekdays (sometimes a single day) at a limited number of points along the HOV-lane section and for specific time intervals within the peak hour or period. Also, as shown by the authors for Shirley Highway in April 1985 (1), traffic speeds can vary quite substantially at different times within the peak (and thereby complicate slightly the calculation of journey-time variability). Also reported are the significant differences in average speeds that are possible during the most congested operating times as a result of including or ignoring the delays caused to all traffic, including to a large extent HOVs, at lane-entry and (in particular) lane-exit points.

TABLE 5 Growth of Ridesharing During HOV-Lane Projects

Project[a]	Number of RS Vehicles			Vehicle Occupancy		
	Before	After	%Change	Before	After	%Change
San Bernardino, L.A. (1976-1985)	670	2,166	323%	1.20	1.35	12.5%
I-95, Miami. (1976-1984)	2,185	2,714	24%	1.23	1.28	4.1%
I-45N, Houston. (1979-1982)	70	267	281%	11.00	12.30	11.8%
Shirley Hwy., VA. (1974-1982)	272	5,007	1,740%	1.35	4.42	227.4%
Shirley Hwy., VA. (1974-1985)	272	3,723	1,269%	1.35	4.96	267.4%
I-93, Boston. (1974-1980)	315	1,224	289%	1.35	1.48	9.6%
Banfield Fwy, Portland. (1975-1977)	106	518	389%	1.22	1.26	3.2%
Moanalua Fwy. Honolulu. (1974-77)	600	1,341	124%	1.70	1.95	14.7%
I-5, Seattle (1983-1985)	1,350	1,720	27%	1.42	1.53	7.7%

a Results refer to a.m. peak period.

IMPACTS ON THE GROWTH OF RIDESHARING

Table 5 contains the reported number and resulting percent change in rideshare vehicle use and associated highway vehicle occupancies for those projects reporting such figures and for which at least 6 months of HOV-lane use had elapsed before collection of the "after" figures. Only on I-95 in Miami (with its 50 percent violation rate) does the percent increase in HOVs fail to reach well into three figures. Between 1973, the year before carpools were first allowed on the Shirley Highway HOV lanes, and 1981, HOV-lane ridership (RS plus bus) increased by 221 percent from approximately 13,500 to 43,320 HOV-lane users. Since that time a significant drop in the HOV ridership on Shirley Highway has been observed, attributable largely to the opening of the I-66 lanes in 1984 and to the changes in some express bus routes and schedules associated with bus-to-Metro rail connections. Currently some 33,500 riders occupy the lanes, a growth of 148 percent in ridership since 1974.

Again, however, caution must be urged in taking such results on face value. Problems of evaluation arise for the following reasons: (a) difficulties in separating HOV-lane impacts from other supportive HOV facility use in the corridor, (b) possible changes in the underlying demand for ridesharing, and (c) selection of an appropriate preproject comparison date.

HOV-Lane Impacts Versus Other HOV Use in Corridor

In the case of the Los Angeles and Seattle projects, where extensive use is made of ramp metering and bypasses for HOVs, it is difficult to separate the benefits of HOV lanes from those of pure bypass and metering. For Seattle's I-5 flow system, for example, it is estimated that some 3 to 8 min travel-time savings resulted from the ramp metering and bypass lanes that they have been using for more than 2 years, whereas the subsequent introduction of the median HOV lanes saved only an additional 1.0 to 1.8 min.

Also contributing to the success of most HOV projects has been the introduction of express bus services and of park-and-ride lots. However, the only recent reliable published evidence that could be found on the separate impacts of HOV-lane introduction versus (subsequent) improvements in express bus service (tied to openings of park-and-ride lots) comes from the I-45N study of Houston's contraflow-lane operation. On the basis of close monitoring of bus ridership over the period August 1979 to May 1982 (the first 33 months of lane operation) by Houston METRO, it was possible to observe sharp growth in bus patronage coinciding with such openings of new park-and-ride lots and expansions of bus service capacity. On the basis of this empirical evidence it was concluded that the contraflow lane per se led to bus ridership increases in the range 45.9 to 132.3 percent during a 33-month period. It was also estimated that 56.9 percent of those riding the bus would not have done so without the presence of the contraflow lane, whereas 35.4 percent of contraflow-lane users required the improved express bus and park-and-ride lot service in order to use the lane. Whatever the actual figures, the evidence indicates a true synergistic effect among lane prioritization, provision of remote parking, and express bus service.

Underlying Demand for Ridesharing

For example, in the case of Houston's I-45N corridor the previously described growth in HOV use took place in the context of a rapidly growing demand for commuter transportation, both in the corridor and regionwide. In such cases it is not known with certainty just how much additional ridesharing would have resulted had no HOV lane been implemented.

One way to define a suitable basis for comparison is to look at other congested corridors in the same urban area or at the comparative growth of ridesharing regionwide versus that along a priority lane corridor. This is necessarily a somewhat biased comparison, given the expectation that the most appropriate corridors for HOV treatment would have been selected in the first place.

For example, although the number of vanpools in the I-45N corridor of Houston had increased by 281 percent from HOV-lane inception in August 1979 to May 1982 (a ridership increase of 326 percent), a similar growth in vanpooling had taken place throughout the Houston region during this period. Complicating this evaluation, however, is the apparent competition between bus and vanpool services along the I-45N corridor, where express bus has been a major success. A clearer picture is presented by the carpool listings compiled by the Seattle/King County Commuter Pool. These figures indicate that the I-5 north Seattle HOV-lane project increased that corridor's share of regional listings from 20 to 26 percent after 3 months of bus- and carpool-lane operation.

Preproject Comparison Date

A third difficulty with measuring the impacts of HOV-lane use on ridesharing adoption results from the inception of the majority of these projects as a result of the energy crises of the 1970s. Hence, for example, it was estimated that only 106 carpools used the Banfield Freeway daily in April 1975, but there was a rapid upsurge in use before HOV-lane introduction in December 1976. It is therefore difficult, given such statistics, to determine just how much the HOV lane actually contributed to carpool use and how much was due to fear of a fuel shortage.

With the foregoing difficulties in mind, it may still be concluded that seven of the eight HOV-lane projects shown in Table 5 made significant impacts on bus and rideshare adoption for the journey to work and that the maintenance of consistently high levels of pooling right up to the low-fuel-price days of the mid-1980s may be seen as evidence of an HOV-lane project's continued benefit.

RELATIONSHIP BETWEEN RIDESHARING AND BUS PATRONAGE

As to the issue of shifts within HOV modes as a result of HOV-lane operations, it is important to recognize the concern of transit authorities, who fear a significant loss of bus ridership as a result of improved conditions for carpools and vanpools (or for privately operated buspools).

In the case of Houston's I-45N corridor some competition between the two modes clearly has been taking place, but with a favorable result for express bus use. Although such bus patronage has risen 435 percent in the corridor from 1979 to 1982, the growth in vanpooling, which is significant, may well have done little more in the first 33 months of operation than keep pace with vanpooling growth across the region as a whole: vanpooling adoption rates appeared to decrease and increase, respectively, following the introduction of remote park-and-ride lots and the determination that more parking spaces were needed at such lots.

There may be more concern when carpools as well as vanpools are prioritized modes. Of those carpoolers surveyed and riding on the San Bernardino Freeway in May 1978, 32 percent had previously used the bus compared with 39 percent who had previously driven alone.

Well-patronized private bus companies significantly increase the throughput on a number of the lanes. In the case of Boston's I-93, these private bus lines experienced a 17 percent increase in patronage in the period 1974 to 1978 followed by a 55 percent increase from 1978 to 1980. During the same two periods the Massachusetts Bay Transportation Authority buses experienced 19.2 and 25.1 percent ridership increases, respectively. From 1974 to 1980 carpools on the 1.4-mi I-93 HOV lane increased only 4.8 percent (from 580 to 608 vehicles). As in the case of Houston's I-45N lane, buses have managed to outperform the carpool and vanpool modes in terms of lane use.

The foregoing evidence along with that for the 1970s indicates that properly planned express bus service using appropriately located park-and-ride lots can compete effectively with ridesharing modes after lane prioritization, even when both of these HOV modes share the same HOV lane, and that from the viewpoint of providing the commuter with the widest choice of travel, both modes should be made available where (a) sufficiently high and growing demand for travel exists within the corridor and (b) currently high levels of traffic congestion require significant shifts from the drive-alone mode.

IMPACTS ON ENERGY CONSUMPTION

Only three projects were found to report estimated HOV-lane savings in energy consumption for their respective combined a.m. and p.m. peak periods (1): I-45N Houston contraflow lane, 1,121,000 gal/year (8.5 percent reduction claimed); Seattle's I-5 ramp-metering-plus-HOV lane, 190,400 gal/year; and Portland's Banfield Freeway (bus service excluded), 178,184 gal/year.

In all cases these estimates are as derived and reported in the project-specific literature and are based on the then-current government-provided (U.S. Department of Energy and Environmental Protection Agency) average estimates of fuel use. Consistency across projects cannot be assumed, and in all cases the figures can be taken as rough approximations only. In particular, none of these fuel consumption studies looked in any detail at the effects of HOV-lane introduction on traffic route diversion to other highways within a given corridor or at the effects of lane operation on changes in commuter departure times nor were particularly detailed vehicle-type breakdowns used in making the estimates of fuel consumed.

The data in Table 2 on person throughput and vehicle occupancies are used to estimate the number of vehicles removed from the highway daily through carpool and vanpool use given in Table 4. Without regional data on the average amount of fuel used or on the distribution of commute lengths within a corridor, it was not possible to compute accurate fuel savings. However, if, on the basis of the Census Bureau estimates of average urban area commutes, a 22-mi daily round trip, a 230-working-day year, and an average commuter fuel consumption of 15 mpg are used, fuel savings in the range of 40,000 to 340,000 gal of gasoline per constructed HOV-lane mile are obtained (1). Attempts to estimate the additional fuel saved by such projects before versus after HOV-lane speed changes require more detailed information. In particular, such estimates require information on the differences (sometimes significant) between the a.m. and p.m. peak-period conditions as well as data on the nature of traffic flow interruptions during the peak hours.

Attempts to use FHWA's highway lane volume and capacity versus speed relationships resulted in most cases in too large a discrepancy between the reported travel speeds given in Table 4 and the hypothetical values based on the traffic volume data contained in Table 2, indicating that a better understanding of local highway conditions is required before the appropriate formula adjustments can be made.

Evidence is also required on the nature and volumes of route diversions or departure-time shifts or both brought about by HOV-lane implementation. This is one further reason why the appropriate approach to effectively estimating fuel saved from HOV-lane projects should be a combination of corridorwide network simulation modeling and local knowledge of how to adjust the generic formulas typically applied in traffic-flow studies.

REASONS FOR REJECTION OF HOV-LANE ALTERNATIVES

On the basis of a review of some 40 or so published reports, including a number of engineering feasibility studies and environmental impact studies provided by the interviewees, the following major reasons have been given for rejecting or abandoning HOV-lane projects along specific freeways:

1. There is insufficient projected future corridor traffic to warrant putting any new capacity into HOV-only use.
2. Alternative HOV modes of transport, such as rail rapid transit, are currently or are soon to be supported in the same corridor.
3. HOV bypass lanes at metered freeway ramps are considered sufficiently attractive to encourage ridesharing and much less costly to construct.
4. Because of highway geometrics or other physical characteristics of the highway, HOV-lane operation may be unadvisable. The following four situations were most commonly cited: (a) the existing shoulder lane is too narrow and there is no room for road widening or there are too many bridge stanchions taking away part of the shoulder lane at frequent intervals; (b) absence of road space for frequent pull-over spots makes both enforcement and accident or breakdown clearance too difficult and costly; (c) excessive weaving in traffic by HOVs trying to reach or to exit from a not physically separated median HOV lane is a likely safety hazard; and (d) where reverse commuting is heavy, a nonseparated contraflow lane may prove a safety hazard.

SUMMARY AND CONCLUSIONS: POTENTIAL FOR MORE HOV LANES

As reported elsewhere (1) and shown in Table 6, in addition to the 123.5 mi of existing HOV lanes, another 129 mi or so is currently planned to begin operation by the end of 1988. Quite clearly, the major potential for such lanes exists along the growing radial corridors of the already large sunbelt cites of the South and West along with the cities of Seattle and Washington, D.C. Of particular interest are the truly regional HOV-lane plans proposed by the cities of Houston (more than 50 mi in four HOV corridors) and Seattle (some 60 mi on five highways), both currently in their early stages of operation and development.

In other areas of the nation, notably the older, northeastern cities, room to add a lane of any kind may be constrained in many land-locked urban corridors, whereas this survey indicates that too small

TABLE 6 HOV Lanes Reportedly Planned To Begin Operation by 1989

Project[a]	Lane miles	Proposed HOV modes	Lane Type	Proposed Opening Date
1. HWY.12/I-394, Minneapolis-St.Paul.	11.0	Bus,CP	median	1985
2. Katy Transitway Extension, Houston.	6.5	Bus,+4CP	median (separated)	1985-87
3. I-45N Transitway, Houston.	17.6	Bus,VP	median (separated)	1985-87
4. I-45 Gulf Transitway, Houston.	15.5	Bus,VP	median (separated)	Oct.1985-Aug.1986
5. East Street Expressway, Pittsburgh.	5.0	Bus,+3CP	median	1987
6. Bridge No.2, New Orleans.	2.0(x2)	Bus,+7VP	median	1987
7. I-80/I-95, Newark.	1.8	Bus,+3CP	median	1987
8. I-84, Hartford.	11.0	Bus,CP	median	Dec.1987
9. R.L.Thornton FWY., Dallas.	6.5	Bus,VP	median CF lane	1987
10. I-95 Virginia Widening and Extension (to Shirley HWY.)	19.0	Bus,+4CP	median	July 1986
11. I-4, Orlando.	31.0	Bus,CP	median	1985-88

a Planned as reported April-June 1985: does not guarantee that lane will become HOV by 1989. These are considered by the authors to be the most likely projects to be implemented, based upon evidence at that time.

a projected shift to ridesharing modes is a common reason for rejecting the HOV-lane alternative along the busiest corridors leading to medium to large urban centers. An alternative solution here, as currently used in some 240 different locations in the Los Angeles region, may be the use of short HOV bypass lanes associated with ramp-metered freeway operations.

ACKNOWLEDGMENTS

The authors wish to thank Patrick Sutton, Office of Transportation Systems at the U.S. Department of Energy, for sponsoring this work.

REFERENCE

1. F. Southworth and F. Westbrook. Study of HOV Lane Operations: Performance and Prospects. Oak Ridge National Laboratory, Oak Ridge, Tenn., Nov. 1985.

Publication of this paper sponsored by Committee on Energy Conservation and Transportation Demand.

Transportation System Management: A Practitioner's Experience

CYNTHIA V. FONDRIEST

ABSTRACT

The experience and evaluation of the RideShare Department of the Southeast Michigan Council of Governments are presented. From the practitioner's experience, it is concluded that ridesharing programs, because they provide a more economical and less stressful means of commuting to work, can be marketed by major employers as an employee personnel benefit. The use of designated employee transportation coordinators for ridesharing by such employers has established good, solid programs. Marketing ridesharing to the general public enhances the objectives of transportation system management (TSM) by coordinating commuters with existing major businesses and business districts. This evaluation will enable the regional planning agency to reassess its goals in order to satisfy the existing TSM objectives through ridesharing.

It has been almost 10 years since the concept of transportation system management (TSM) was introduced in the planning regulations of FHWA and UMTA. It appears that there has been a considerable shift in the past few years from capital-intensive long-range transportation planning activities to short-range TSM courses of action.

What is TSM? One way to define it is to quote from the federal regulation [40 Federal Register 42976-42984(1975)]:

> Automobiles, public transportation, taxis, pedestrians, and bicycles should be considered as elements of one single urban transportation system. The objective of urban transportation system management is to coordinate these individual elements through operating, regulatory and service policies so as to achieve maximum efficiency and productivity for the system as a whole.

As seen from this definition, striving to achieve the maximum efficiency of the existing highway and transit facilities can be regarded as one of the TSM objectives. Ridesharing is an element in this objective.

BACKGROUND

As part of the trend for regional planning and local operating agencies to cooperate in making more productive use of existing transportation facilities, the federal government instituted TSM in 1975. To the transportation practitioner this translated into planning on the basis of how well the existing facilities operated and how to maintain these facilities to the optimum. A consideration in achieving TSM objectives was the institution of ridesharing on a national basis.

On a regional level, ridesharing becomes integrated into the transportation air-quality analyses of TSM in the Southeast Michigan Council of Governments (SEMCOG) region under the Transportation Planning Guidelines of the Environmental Protection Agency. When implemented, ridesharing activities result in reduced energy consumption and abatement of the air and noise pollution associated with the urban transportation system. In recognition of UMTA's high priority on paratransit planning, vanpooling became the initial task. Ridesharing became part of the regional short-range plan because of the TSM emphasis that all facets of transportation be integrated into one system rather than several separate systems.

SEMCOG RideShare, as it is now identified, took 8 years to develop. Staffing now includes six full-time employees--one manager, three ridesharing planners, one ridesharing research assistant (data processing), and one administrative assistant-secretary. The program services the seven-county region in southeast Michigan as the ridesharing agency of record. For those involved in paratransit planning, the development of this program and its goals and achievements has been a valid learning experience.

RIDESHARING AS A METROPOLITAN PLANNING ORGANIZATION FUNCTION

The regional ridesharing vehicle-pooling program became part of the work program of the metropolitan planning organization (MPO), SEMCOG, in FY 1977-1978. The initial objective was to utilize COG resources in the start-up, coordination, and monitoring of ridesharing activities. The method was to refine the geocoding file of the urbanized portion of the tricounty area. The council used the geocoding as input to one of several vanpool vehicle-pooling software packages. During the following year the council selected, acquired, and made operational the package that best served the needs of southeast Michigan. The planning of this task was coordinated with the Southeast Michigan Transit Authority (SEMTA) and the Detroit Department of Transportation (DDOT). Production completion included selected packages made operational on the council's data processing hardware. The budget for this task allowed one person to develop the program within a time frame of 16 weeks.

It is important to note that also during this

Southeast Michigan Council of Governments, 1249 Washington Boulevard, Detroit, Mich. 48226. Current affiliation: Office of Transit Services, City of Alexandria, 301 King Street, Alexandria, Va. 22314.

fiscal year, President Jimmy Carter mandated ridesharing as a federal regulation, stating that federal government agencies would appoint transportation coordinators for each federal facility. The objectives of the federal program were to conserve fuel, reduce traffic congestion, improve air quality, provide an economical way for federal employees to commute to and from work, and reduce the need for parking at federal facilities.

During its second year the ridesharing program at SEMCOG employed one staff member half time whose major task was to identify the role that SEMCOG would play in assisting the implementation of vanpools in southeast Michigan. The staff met with companies interested in forming vanpools for their employees or those who already were conducting a working vanpooling program. Two private-sector corporations, Chrysler and Detroit Edison, conducted surveys of vanpoolers in the seven-county region in southeast Michigan. These surveys determined travel characteristics before and after vanpooling. The information gathered from this survey was then coordinated with the Michigan Energy Administration. The result was a documentation of socioeconomic, travel, and attitudinal data from vanpool participants in the SEMCOG region. It gave RideShare an idea of who the target audience was and what their travel preferences were. This survey provided staff with information they could use in handling employer-based vanpool programs.

During the same fiscal year, SEMCOG developed its own regional TSM plan, with ridesharing as one of the elements. In the TSM description, ridesharing efforts in the seven-county region in southeast Michigan were defined. Included in this were descriptions of formal and informal pooling, vanpooling, and carpooling and general obstacles to the expansion of the program. It was stated that at that time (December 1979) "existing ridesharing efforts were not considered to a great degree; there was an absence of an overall ridesharing program promotion effort. This represented the most serious ridesharing deficiency in this region." Also, with the exception of some basic vehicle occupancy data, there was very little information regarding carpooling in the region. It was indicated that the Michigan Department of Transportation had begun to provide parking facilities within highway rights-of-way. Vanpools were identified only through existing programs with regional employers.

There was a great amount of work to be done in order to get the ridesharing program on the road. The computer service was in place and park-and-ride lots were available. SEMCOG needed to promote its software service to the major employers of the seven-county region and promote ridesharing by changing employees' commuting habits. RideShare had its challenge set.

The objective of the FY 1979-1980 ridesharing work program was to focus on employer-based vanpool programs. These programs promoted both carpooling and vanpooling within the SEMCOG region. First existing ridesharing programs in comparable markets were reviewed. The program best suited to meet RideShare's needs was incorporated into SEMCOG's computer system and used as the basis for the free computer information system (CIS) system, which helped employees with the same work hours and home and work locations contact one another for the purpose of carpooling or vanpooling for their daily commute. One staff person was assigned to the task for a 40-week period. During this time, the computer matching program was documented.

FY 1980-1981 gave RideShare the opportunity for promotion to the region's employers and their staffs. Regional local governments and the public and private sectors cooperated in this task. Promotional materials were developed and disseminated. The basis for this promotional effort was the free use of SEMCOG's CIS.

At this time, SEMCOG RideShare engaged in the promotion of the third-party vanpool program with the Michigan Department of Transportation. The third party was Van Pool Services, Inc. (VPSI), a subsidiary of Chrysler Corporation. The service was called Michivan. SEMCOG RideShare provided the free matching service, which helped identify those individuals who were interested in driving a van daily to and from their work location. RideShare helped find enough passengers to fill either a 12- or a 15-passenger vehicle, explained to them how the program worked, and then referred them to VPSI. The work for this program was coordinated with both SEMTA and Ann Arbor Transportation Authority (AATA).

This planning effort enhanced the TSM program and continued to satisfy its goals of reducing air pollutants and energy consumption. The plan produced the first application and accompaniments in the form of support graphics, documentation of employers contacted, and ridesharing match lists. Staffing included a program coordinator, three RideShare planners, and one computer programmer.

In FY 1981-1982 the objectives, methodology, planning, and production of the previous year were replicated. In addition, for the first time, the program was documented on paper.

RIDESHARE--A MARKETABLE SERVICE

There were marked changes in the strategies of the program in FY 1982-1983. Marketing specialists were sought and the staff was increased to seven, including one fleet management specialist, one half-time bicycle transportation specialist, and one half-time communications specialist. The marketing specialists developed a plan for the calendar year to produce materials for dissemination in the region describing the ridesharing services. This plan included an escalated media awareness campaign. The media promotions, on radio and television, served double duty as in-kind services matching.

One of the goals of the marketing plan (discussed later) was to implement self-supporting transportation programs for large employers. RideShare continued to market the VPSI-Michivan third-party vanpool program. Expanding the existing data base to include medium-sized and small employers became another goal. The concept of flextime (staggered work schedules) was incorporated into these promotional endeavors.

In addition, two new areas of ridesharing were researched. The first was the development of a ridesharing contingency plan, an action to be taken during transportation disruptions to aid employers in making sure that their employees have transportation to and from work. This plan was threefold in its purpose: to educate the general public and employers on what ridesharing services could be provided during a transportation emergency, to detail a plan describing the implementation of these services, and to provide a short-range program identifying steps that SEMCOG takes as part of its normal work program. The method in this contingency plan was to identify staff members for emergency ridesharing. Implementation time and costs for seeking transportation alternatives in transportation emergency situations were also included.

The second area of ridesharing researched was general public marketing and matching. Until this time ridesharing had been promoted only to employers in the region. The promotion for the general public included a telephone number and widespread advertising and distribution of applications. The unique thing about this promotion was that applications could be taken over the telephone as well as through the mail. This, of course, expedited the process of matching through the computer system. The process took 1 week once the application had been received at the agency. Mail applications sometimes took longer, depending on the speed of the mail service. Taking applications over the telephone enabled RideShare to satisfy the customer in a shorter period of time.

As an addendum to the promotional process, locations for new carpool parking lots in addition to those that were currently in operation through the Michigan Department of Transportation were sought. The emphasis was on the rural parts of the region.

FY 1983-1984 as well as FY 1984-1985 were devoted to expansion of the program plans set in place for FY 1982-1983 with an emphasis on general public matching. Using the existing employer-based programs as a model, RideShare staff became involved in intense marketing in the forms of media planning, on-site promotions, and overnight batch processing for applicants.

STATISTICS

After 8 years of planning and development, SEMCOG RideShare has contacted 6,800 individuals and 1,974 employers in the seven-county region in southeast Michigan and has conducted 303 employer programs and distributed 328,906 applications to employees and the general public. This effort has contributed to the distribution of 22,298 match lists.

Thus far, 78 vanpools have been formed that transport 928 individuals to and from work daily. Through the matching service an estimated 4,019 carpools have been formed with an average 2.9 passengers per vehicle. This is a total of 11,655 persons carpooling to their place of employment on a daily basis.

Some cumulative annual statistics are as follows:

- VMT reduction: 79,289,406
- Gallons of gasoline conserved: 5,321,436
- Tons of pollution (HC/CO) reduced: 309/3,017
- Accidents prevented: 470
- Injuries prevented: 156

PROGRAM EVALUATION

By studying the products in the comparative charting for 1982-1984 (Figures 1-4), RideShare has learned that the implementation of the marketing plan has given the program the exposure in the region that was lacking in 1979. Ridesharing has been marketed well enough so that returns are higher with less time allocated to marketing. The program is selling itself. RideShare can target its expertise toward other areas, including marketing the Michivan vanpooling program more extensively, seeking new employer clients, and developing ridership counts in carpools formed throughout the region.

RideShare staff is constantly learning new ways to better serve the region through marketing. The use of highway signs--"RideShare Info 963-RIDE"--has doubled applications to the program. In telephone applications, RideShare planners communicate first hand with applicants, learn what their needs are, and match them with other applicants more expeditiously.

Personalizing applications and support materials for clients, such as incorporating company logos into these materials, gives employees more confidence in the RideShare services because they know that their employer is supporting the program. Many of the employer-based clients offer incentives to these employees in conjunction with the ridesharing program. The most popular incentives are premium parking, reduction in monthly parking fees, or subsidized parking facilities.

In marketing for federal government facilities, RideShare has learned to work with the federal Executive Order, first mandated in 1979 and again in 1985, requiring each federal agency to have a transportation coordinator and a workable ridesharing program [41 CFR § 101-106(1984)]. The order has helped to increase the data base.

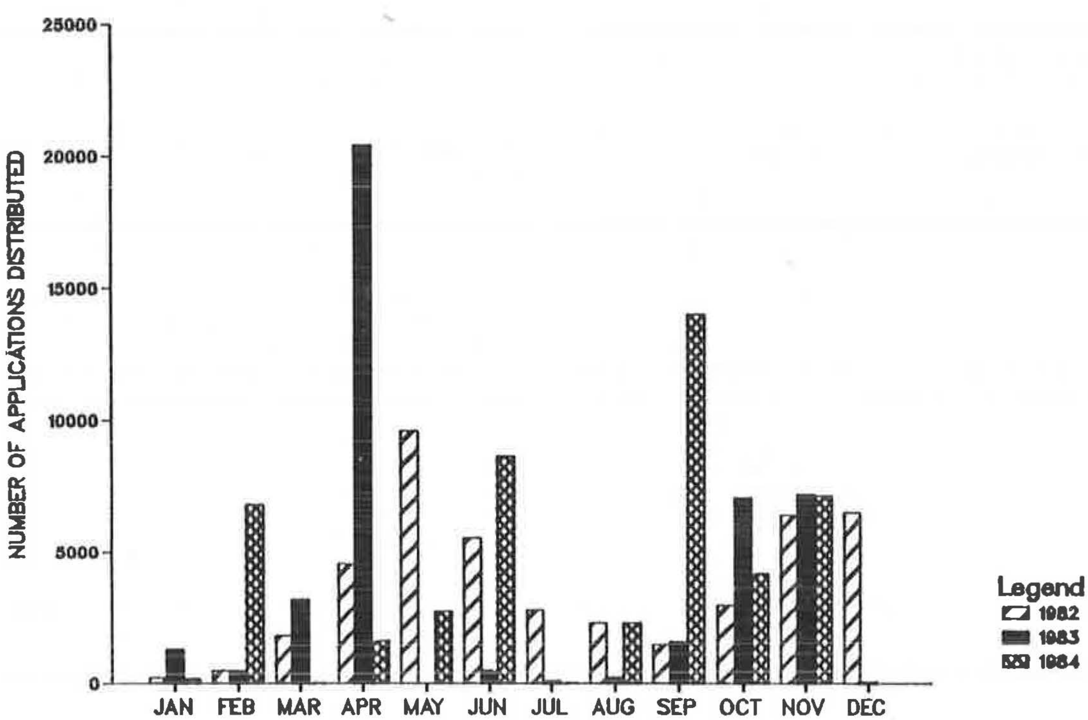

FIGURE 1 Rideshare applications distributed by month and year, 1982-1984.

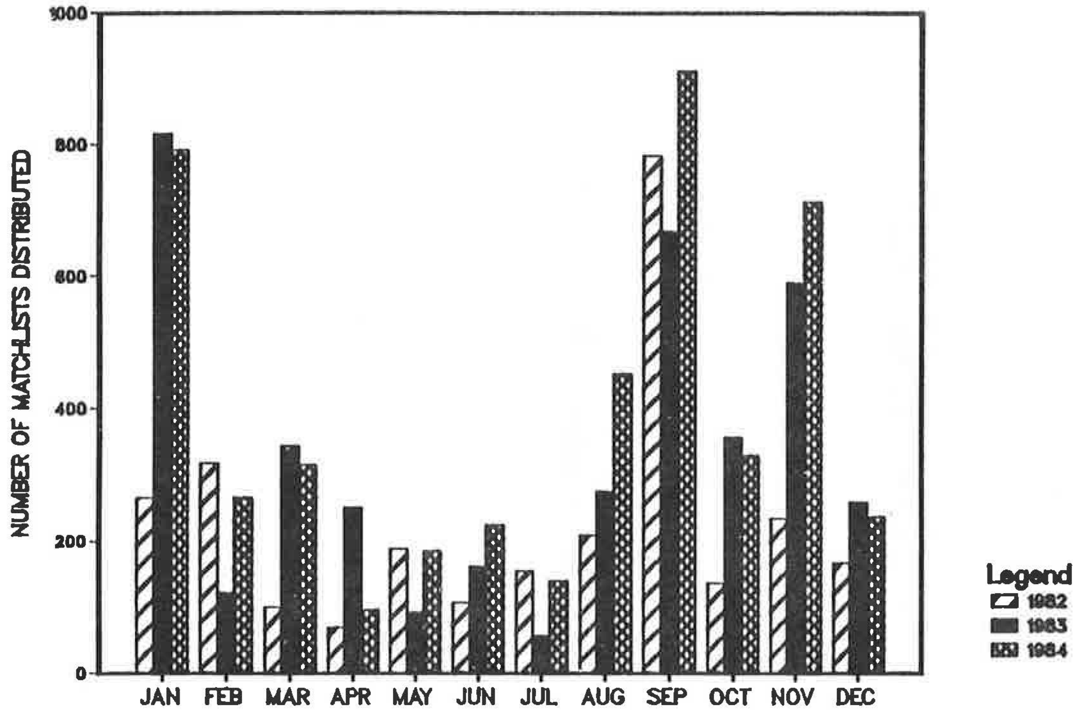

FIGURE 2 Rideshare match lists distributed by month and year, 1982-1984.

Working with major banks in the region has educated staff on how to serve employers who have more than one branch office. Many of the major banks in the central business district are relocating. RideShare's services have been called on to aid in ensuring that each employee has transportation to the new work site. One bank's rideshare program has earned an award from the National Employee Services and Recreation Association for outstanding program promotion based on an employer kit that RideShare staff produced for them. The same employer program has also received recognition from the Michigan Department of Commerce and the U.S. Department of Commerce for energy innovation through an award program.

SEMCOG is confident that RideShare has developed excellent employer-based programs through implementation of the marketing plan. However, RideShare staff has learned that there are also areas that need improving. One concern is follow-up. There is no established procedure to follow up on applicants to the program to determine what mode of transportation they are using in ridesharing. The second con-

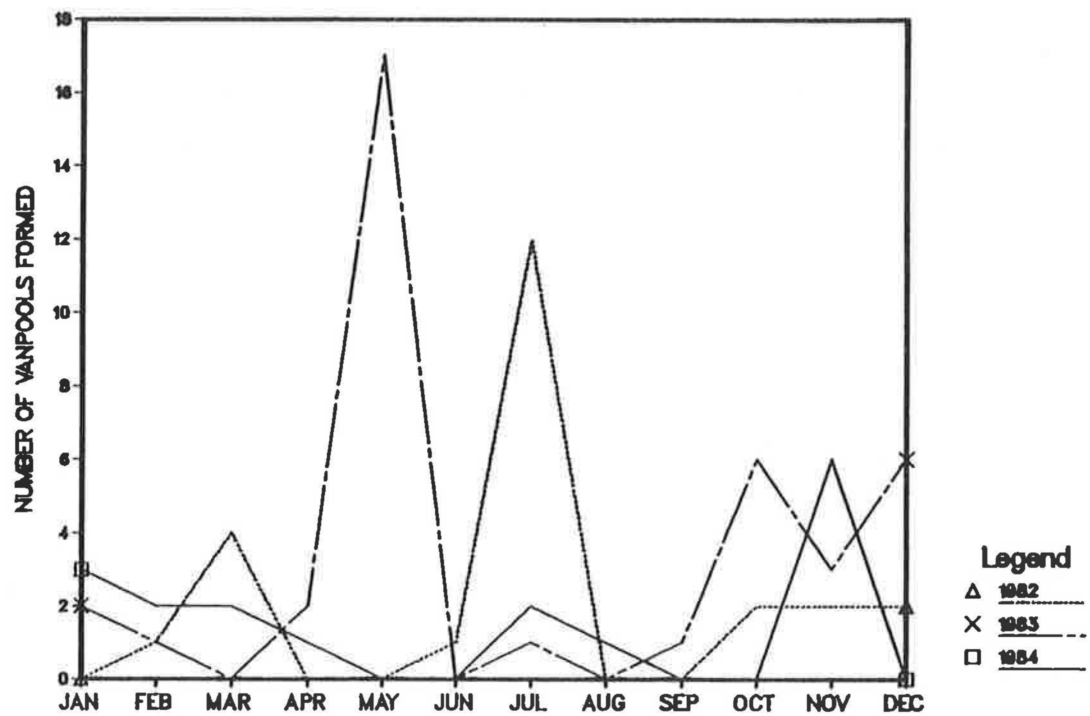

FIGURE 3 Number of Michivan vanpools formed by month and year, 1982-1984.

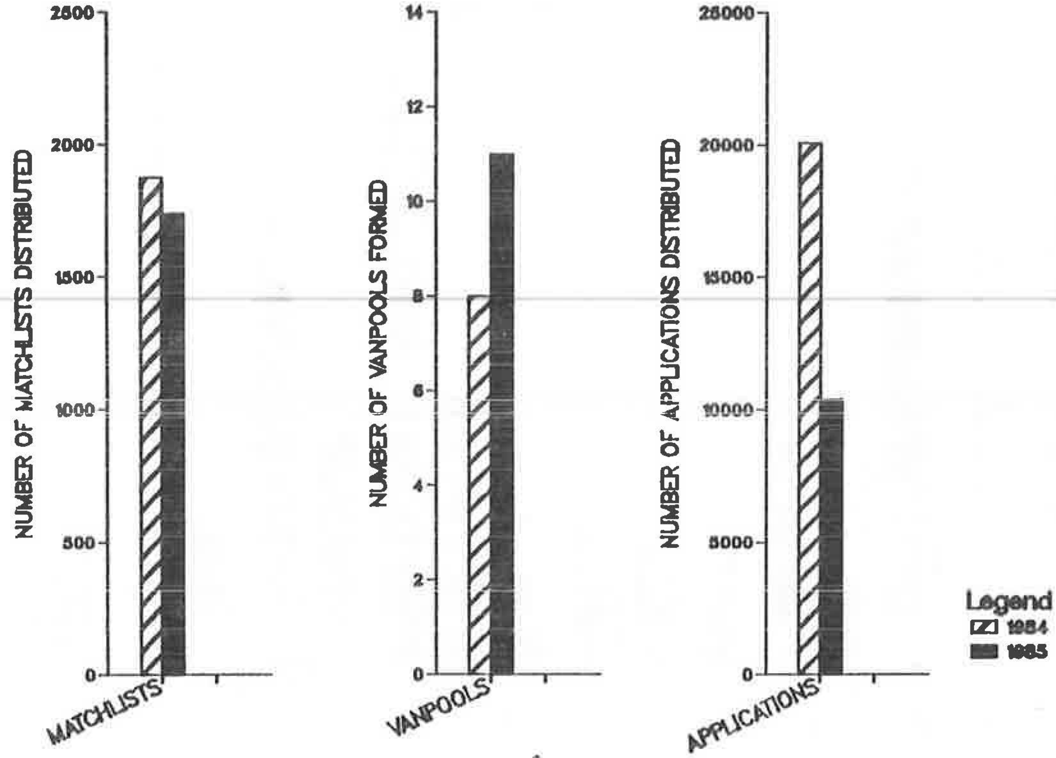

FIGURE 4 Rideshare Program, January through June 1984 compared with 1985.

cern for development of SEMCOG's ridesharing program is how to market and implement a carpool registration program.

The prime recommendation for creating a workable ridesharing program as part of the TSM objective is to look at ridesharing as a marketable service. The SEMCOG RideShare program differs from others throughout the country in that ridesharing is treated as a saleable service. SEMCOG has tried to convince commuters that the RideShare program is a dependable service that helps people save money. By establishing a client-agency relationship and marketing ridesharing as a consumer product, RideShare has established a unique blend to attain their goal--making ridesharing a part of the personnel services of businesses in the seven-county region. The program has also made the general public aware that the service is available, sound, and an institution in its own right.

MARKETING PLAN

Promotion

Employer Kits

Although the RideShare program encompasses matching for the general public, the main thrust will continue to be employer programs. It has been the experience of the majority of rideshare organizations nationwide that the rate of participation is highest when participants are enrolled through their employer. This is mainly because a given company's employees meet two of the major criteria for successful ridesharing: common work destination and work hours.

RideShare staff enhance employer contacts with the employer ridesharing kit, which provides a range of program resource materials, specifically, the items detailed in the following paragraphs.

Employer Brochure

The employer brochure explains how the RideShare program can benefit the company, describes the services the staff can provide, and details the steps required to implement a successful ridesharing program.

To reach employers, specific employer benefits are emphasized, such as reduced parking requirements, employee benefit at no cost to the company, expanded labor market, easier relocation, reduced traffic congestion, and positive community image.

Sample Memo

A memo sent from top management to employees before implementation of the company's ridesharing program explains the program and the company's commitment to it and discusses the benefits of carpooling or vanpooling and program activities that will be conducted.

Providing employees with a sample helps ensure that (a) top management is perceived as endorsing the program and encouraging employees to participate and (b) pertinent information is disseminated to all company personnel before the program begins.

Sample Match List

The match list helps the client understand RideShare's services by showing the final product that employees will receive and the factors RideShare uses to determine suitable matches. It illustrates the computer system capabilities as well.

Site Coordinator Brochure

The site ridesharing coordinator, who is selected by management to work with RideShare staff, or, if applicable, the employee transportation coordinator is the target of this brochure. Because this role is vital to successful implementation, the RideShare program, as well as procedural requirements of the coordinator, must be fully explained.

Sample Newsletter Article and Graphics

The site coordinator submits an article about the RideShare program to the company newsletter before the start of the program. Supporting graphics may also be supplied.

Program Folder

All-purpose program folders hold all materials appropriate for a given audience and feature the program name and company logo.

General Program Brochure

The general program brochure gives reasons for ridesharing, explains how the program works, and provides a chart for estimating actual annual commuting costs based on daily round-trip mileage and transportation mode.

Posters

Colorful posters with catchy copy are a key marketing item. RideShare develops one general program poster and later several are targeted to more specific interests or employers.

Surveys

Surveys to determine ridesharing needs before a program is promoted are essential to the success of the effort.

Highway Signs

Highway signs are considered a highly successful promotional tool nationwide because once in place, they become a permanent and repetitive message. Therefore, signs reading "RideShare Info 963-RIDE" have been placed on major routes into Detroit's central business district, Troy's Big Beaver corridor, and the Southfield Civic Center area because of the high concentration of commuters and large employers.

Ridesharing Display

A display may be used in conjunction with either employer programs or general public promotions to supplement RideShare presentations or act as a substitute for RideShare personnel when they cannot be present to give out information but want a more in-depth presentation than a brochure or poster alone can provide.

Public Service Announcements

Because of limited financial resources and the seemingly limitless ways to spend those resources, the general public campaign relies heavily on air time donated by local radio stations to publicize rideshare programs via public service announcements (PSAs).

Because this method has been proven second only to highway signs in successfully recruiting new pooling participants and entails no significant financial expenditure, it warrants substantial staff time and effort in the creation and presentation of professional-sounding PSAs. To increase the likelihood that the PSAs will be used during peak commuting hours (not, incidentally, the most valuable air time) and, in some cases, will be used at all, contact by program staff with the public service director or appropriate personnel is vital.

Talk Shows

In conjunction with the PSA campaign, when the stations receptive to the ridesharing message are selected, local stations with programs that feature brief highlights of a topic (e.g., 90-sec vignettes on WOMC's "Sunday in Detroit," which runs from 11:30 a.m. to 12:30 p.m.) can be targeted. The best strategy appears to be to gain experience in brief radio spotlight forms and then to try to get on higher-exposure radio and TV programs.

Press Releases

Press releases are used to announce and publicize a wide variety of program events and happenings, for example, a new vanpool formed, a successful employer program, a ridesharing week, and are targeted to the appropriate audiences. Press releases are written and produced in house and can be as specific or general in nature as desired.

Ridesharing Week

As the campaign aimed at the general public gets under way, a promotional Rideshare Week can be the capstone of the fall drive. For maximum effectiveness it should be held in late September or early October when interest in ridesharing peaks. PSAs and press releases can be targeted toward this event, which, in concert with the billboard displays, will terminate the general-public campaign.

Possible events include displays in malls and downtown stores, recognition of companies strongly supportive of ridesharing (via press releases, paid ads, or plaques and certificates), van demonstrations, endorsements by elected officials, contests (recruit new poolers and win a prize), and people riding together for one day.

The impact of this event would be heightened by association with city celebrities (e.g., a group of the Detroit Tigers riding to "work" at the ballpark).

Billboards

A mass media public awareness campaign composed of a blitz of billboard advertising, PSAs, and press releases appears to be the most effective route for reaching a maximum portion of the target audience at a minimum cost.

There are several reasons for allotting a substantial portion of the budget to outdoor advertising:

1. Audience: The target audience is people who drive to and from work alone and commuters who travel the major highways where the billboards are located and see them every work day. In addition, research shows that billboards are the most effective method

of advertising with upscale adults and working women, two prime target groups for ridesharing.

2. Control: RideShare creates the message the audience will receive and selects the billboard locations and the start date. A choice can be made to use boards only on the highway routes into the downtown area or along known heavy suburb-to-downtown routes.

3. Visibility: Billboards are a day-in, day-out reminder; they cannot be turned off or ignored; the message is presented with minimum clutter; they offer creative flexibility; and they provide far more exposure for the advertising dollar than newspapers, radio, or TV.

Premiums

Premiums, or giveaways, are effective because most items are useful and reinforce the service and message each time they are used, especially if they are distinctive novelties. In addition, although people may be reluctant to accept a brochure or flyer, thinking that it entails some commitment on their part, everyone likes to get "something for nothing."

1. Litter bags are excellent because they are related to driving and vehicles, in keeping with the ridesharing program. They can be handed out separately or they make a handy carrier for other materials such as those that RideShare likes to distribute--brochure, Michivan fact sheet, notepad, van cutout, balloon, and bumper sticker.

2. RideShare has found balloons to be an excellent way to attract attention and present opportunities to discuss the program. One unique use of balloons by another ridesharing organization has been to reward someone already ridesharing with a balloon bouquet at their office, which not only helps reinforce the commitment of those already ridesharing, but stimulates the interest of others in the workplace. A picture of the event can be used in the company's newsletter and could possibly receive more coverage if the picture and story are sent to local media.

3. Notepads with the ridesharing organization's name and phone number are inexpensive, useful, and reinforce the message each time a new sheet is used.

4. Van cutouts work because they are unusual and evoke some amusement on the part of the recipient, which helps reinforce the message.

5. Key tags ("Ridesharing--Your Key to Savings") also fit the program transportation theme, are useful, and would remind the user of the program.

6. Tent cards, used in cafeterias or lunchrooms, and payroll stuffers (for example, "A lot more of this paycheck would stay in you pocket if you shared the ride") are other ways to reach prospective poolers and create interest among employees.

7. Bumper stickers are a novelty item, are related to the transportation theme, and can advertise ridesharing.

Holiday Mall Promotions

Ridesharing promotions can be held for mall employees at major malls before December in an effort to alleviate the severe parking congestion typical of the holidays. RideShare contacts mall merchant associations about developing carpooling programs for their employees during the Christmas season in order to increase customer parking spaces.

Targeted Area Promotions

If it is ascertained that specific areas would benefit from a concentrated promotional effort, information can be disseminated by notices, posters, displays, brochure distribution, ads in local papers, press releases, and so on. Organizations to cover include chambers of commerce, welcome wagons, schools, stores, libraries, real estate offices, and other appropriate outlets. Presentations can be given at neighborhood meetings or for community groups.

Implementation

Coordinator Kit

The coordinator kit contains the same information as the employer kit, but also includes worksheets of program steps that need to be completed by the coordinator and that are designed specifically for that organization by the staff program coordinator.

Vanpool Driver-Coordinator Kit

A prospective vanpool driver or organizer can be educated about the program so that he can identify potential passengers and sell them on vanpooling. Development of the following items for this kit better equips drivers to help in forming pools, which eliminates much of the time RideShare staff currently devotes to assisting drivers in finding passengers.

1. Introductory letter: The step-by-step process by which a vanpool is formed is explained.

2. Vehicle brochure: Furnished by VPSI, this brochure shows potential passengers that the vans are comfortable and well-equipped.

3. Recruiting ("Riders Wanted") posters: These posters are displayed on bulletin boards at work sites and at the home end and indicate the work hours, route and destination, and contact person for the potential vanpool.

4. Michivan fact sheet: Distributed to each potential passenger by the driver-coordinator, it summarizes the major features of the program and reinforces the credibility of the program and driver.

5. Driver information packet: Furnished by the Michigan Department of Transportation, this booklet gives details of the program from the driver's perspective.

6. Publicity sheet: This gives tips on how to publicize a potential vanpool.

Maintenance

Pooling Pointers Brochure

Research reveals that the major factor in the breakup of carpools is usually failure by carpool members to establish operating rules and understandings before starting. To avoid misunderstandings and frustrations from the beginning, a brochure offering guidelines on issues that need to be addressed is helpful to poolers. This information will likely improve the extent of operation and the success of the carpools and vanpools that rideshare program staff works hard to organize.

RideShare Newsletter

The continued bimonthly publication and distribution of a newsletter will help maintain the drivers' and passengers' commitment to and enthusiasm for vanpooling by providing articles on the benefits of ridesharing, its status in other cities and states, activities and innovations of the program, and so on.

Pooler's Packet

Supplying new carpoolers and vanpoolers with materials that promote ridesharing is an effective method for encouraging them to continue to rideshare and reinforces the message that pooling is a rewarding experience. Materials might include premiums (bumper sticker, litter bag, notepad), a letter congratulating them for joining a pool and reiterating the benefits of sharing the ride, a copy of the rideshare newsletter, a pooling pointers brochure, a general program brochure to give to a friend, a map of park-and-ride lot locations, and the business card of a program staff member for future reference and assistance.

ACKNOWLEDGMENT

Preparation of this paper was financed in part through grants from FHWA and UMTA.

Publication of this paper sponsored by Committee on Transportation System Management.

A Level-of-Service Framework for Evaluating Transportation System Management Alternatives

ABISHAI POLUS and ANDREJ B. TOMECKI

ABSTRACT

The complexity involved in evaluating a transportation system, as reflected in the large number of, and often conflicting, goals and objectives postulated by various groups affected by the system, is discussed. Desired improvements can encompass, for example, a reduction in person hours of travel, vehicle delay, traffic volume, or energy consumption as well as an increase in the number of transit passengers. Alternative strategies may result in different changes in each of the variables. Existing evaluation procedures, like goal-achievement analysis or cost-effectiveness analysis, are shown to have various disadvantages, the main one being an inability to compare the different magnitudes of improvement caused by different variables. A benefit-cost analysis can address this problem only if the variables evaluated can all be reduced to monetary terms, which is seldom possible. An evaluation procedure is proposed in which a panel of decision makers representing the various interests affected by the transportation system allocates weighting factors to the selected variables. The utility analysis can be used, thus allowing conflicting views to be presented in an open discussion and a consensus to be reached. The weighted worth of all variables is then summed to give the level of service of the transportation system (LTS), which allows the comparison of one strategy with another, enabling decision makers to select the most suitable alternative.

The elements of any typical transportation system, though rather complex, are interrelated. Private vehicles, public vehicles (e.g., buses, taxis, rapid transit trains), streets and parking facilities, pedestrians, and installations for pedestrian use should all be considered elements of a single urban transportation system. In recent years, there has been a shift in engineering philosophy toward better, more efficient use of existing transport systems. Whereas the standard solution to growing demand in the past was the provision of additional capacity, planners and engineers now seek the best possible use of existing systems with, perhaps, minimal cost adjustment.

In the present economic climate, characterized by the shortage of funds for transportation facilities and services, it is natural to expect the capital used for transportation purposes to be scrutinized carefully in respect to the efficiency and produc-

A. Polus, Department of Civil Engineering and Transportation Research Institute, Technion-Israel Institute of Technology, Haifa 32000, Israel. A.B. Tomecki, National Institute for Transport and Road Research, Council for Scientific and Industrial Research, Pretoria 0001, South Africa.

tivity of the investment. The former emphasis on a high-cost urban transportation infrastructure and subsidized public transport operations has given way to the efficient management of existing facilities and services. Once it has been recognized that a transportation system encompasses a loose cluster of elements--public transport, arterial streets, paratransit, traffic signals, and so on--the need arises to manage them as a system. Tools must be developed for defining the objectives of the system, measuring its effectiveness, and evaluating its performance. Hence, the concept of transportation system management (TSM) was developed.

In the original FHWA definition of TSM [40 Federal Register 42976-42984 (1975)], the stated objective was to coordinate the individual elements through operating, regulatory, and service policies in order to achieve maximum efficiency and productivity for the system. This definition is dependent on an understanding of the concept of a system. Mackey (1) suggested a broad understanding and used the following definitions:

- A system is a set of elements with relationships between the elements and between their attributes.
- Efficiency is determined by comparing the consumption of the resources of a system with an agreed standard for a unit of output.
- Productivity is determined by comparing the actualities (demand) of the system and its capabilities (supply).

On the basis of these definitions, four observations emerged:

1. Pricing policies are essential for managing a transportation system.
2. In order to maximize the efficiency and productivity of a system, alternatives based on capital investment must not be excluded from consideration.
3. The elements of a transportation system can be broadly defined as transportation modes, transportation infrastructure, and land and its use (the FHWA document lists only transportation modes as elements of a system).
4. A change in any of the system's elements affects the attributes of the other elements. These effects may be beneficial or detrimental. Constant monitoring of the performance of the system is essential to assess the influence of changes on the system as a whole.

As a result of these definitions and observations, a modified TSM concept emerged: Urban transportation system management is a process of coordinating the individual elements of a system through operating, regulatory, pricing, service, and investment policies so as to achieve maximum efficiency and productivity for the system as a whole. Monitoring is an essential part of the process and is discussed at length by Meyer (2).

Two terms emphasize the essence of the TSM philosophy: coordination of the elements of the system (rather than changing individual elements) and maximization of the efficiency and productivity of the system. The idea of quality of service has not been included in the definition, but in this paper it will be treated as an inherent part of the TSM process.

The TSM process consists of the following components:

- Definition of the problem,
- Generation of alternative feasible solutions,
- Evaluation of these solutions,
- Selection of the most appropriate solution,
- Implementation of this solution, and
- Monitoring of the system.

The adoption of TSM as a short-term planning and implementation approach has a considerable effect on the planning process as a whole. For example, traditional long-range urban transportation planning processes, which involve massive data collection and development of long-range prediction models, do not always apply. Furthermore, although one can expect tangible benefits from TSM to be achieved relatively soon after its introduction, it is important to understand that TSM should be looked at as a continuous process, composed of interrelated marginal modifications, not a one-time improvement.

There is ample literature on some of the TSM process components. Prominent publications include Transportation Research Board Special Reports 172 and 190 (3,4) and a management overview on alternatives for improving urban transportation by Rowan et al. (5). Some studies concentrate on a more specific problem, such as the FHWA handbook on freeway management (6), NCHRP Report 241 (7), or a study by May (8) on models used to predict impacts resulting from traffic management strategies applied to freeway corridors, arterial networks, or rural highways.

The emphasis in this paper will be on the selection and evaluation of the solution to be implemented, because it is believed that these are the most vulnerable components of the process and the least covered aspects in the literature.

GOALS AND MEASURES OF EFFECTIVENESS

In the TSM process, the definition of the problem consists of the formulation of objectives, the selection of strategies and tactics leading to the achievement of the objectives, and the selection of the relevant measures of effectiveness (MOEs). The traditional approach, based on a single objective and a small number of strategies and MOEs, is no longer workable. The objectives must satisfy many, often conflicting, requirements--authorities demand economic efficiency, public transport users want quality of service, automobile users are concerned about the availability of road space and parking, and nonusers of transport request the protection of their environment. In order to illustrate the complexity of the problem, the work of Abrams and Direnzo (9) and Abrams et al. (10) can be cited. They postulate five TSM goals:

- To maintain or improve the quality of transportation services,
- To increase the efficiency of the existing system,
- To minimize the cost of the improvements,
- To minimize undesirable environmental impacts, and
- To promote desirable and reduce undesirable social and economic impacts.

These goals lead to 20 objectives as diverse as "minimize travel time," "maximize public transport use," "maximize capacity," "maximize automobile use," "maximize equity," and so on. The objectives, in turn, are assessed in terms of 70 different MOEs. In such a situation, no project can be unequivocally evaluated. Therefore, the foregoing studies finally recommend what are termed the 12 most essential MOEs for TSM planning:

- Person hours of travel
- Point-to-point travel time
- Vehicle delay
- Vehicle hours of travel
- Number of vehicles by occupancy

- Person miles of travel
- Traffic volumes
- Vehicle miles of travel
- Transit passenger miles of travel
- Number of transit passengers
- Energy consumption
- Emissions

Even with this reduced number of MOEs, a comparison of alternative solutions remains difficult.

The issue of the overall evaluation of various TSM strategies attains its full significance when some strategies are composed of contradictory impacts and the available knowledge about the relative effectiveness of the various actions is limited. For example, improvement in priority treatment for public transit may be adversely related to network supply of parking for passenger vehicles. The simultaneous judgment and evaluation of impacts, consequently, are of prime importance for a TSM project before its implementation. As a starting point, one has to hypothesize tentatively how a given strategy may affect the range of MOEs of a system. For this analysis, it may be necessary to use both historical and existing field data and, perhaps, some simulation techniques. The most promising strategy, or combination of strategies, may thus be identified by evaluating its expected effectiveness and impact.

MOEs must be formulated to be applicable to analyses of different scales; for example, a corridor of one arterial and several local streets is to be examined differently from an area of several satellite towns adjacent to a large city. In the first instance, one may want to look at measures that describe in detail local traffic flow characteristics on the highway concerned and on the adjacent streets to which traffic may be diverted. In the second case, it may be more appropriate to look at overall MOEs, such as general measures of the amount of travel or modal-choice characteristics. Lockwood and Wagner (11) suggested that, as a general rule, the larger the area of application of a TSM strategy, the less detailed the MOEs should be.

Several potential MOEs are presented in Table 1. These suggested measures are categorized according to area of TSM application and subdivided into preliminary and final measures. They are presented as an example only; one could, of course, change or replace several of them, both among groups and in general, depending on the strategy adopted and the type of study. However, it should be recognized that MOEs must be responsive to the most complete range possible of relevant impacts. Preferably, they should also be quantifiable and measurable either directly by conventional traffic, safety, and environmental variables or indirectly by being represented by common monetary worth.

In evaluating a TSM project, further consideration must be given to the data collection and analysis capabilities of the local implementing agency. Therefore, practicality, directness, and ease of data collection are relevant criteria for selecting appropriate measures. For example, travel time, speed, number of stops, and delays are more simple, direct measures than are overall parking demand, energy consumption, and central business district (CBD) vitality. This is the reason that at certain times, such as when evaluation resources are limited, it is desirable to apply small-area measures to a regionwide or citywide evaluation scheme. Finally, one should also try to avoid using redundant MOEs, thereby measuring and evaluating similar impacts; for example, because average speed and travel time may measure the same effect, they should preferably not be used together in the same evaluation scheme.

TABLE 1 Potential MOEs by Area of TSM Application

	Area of TSM Application	
Type of MOE	Small Area or Longitudinal Transportation Corridor	Regionwide or Citywide
Preliminary and readily available	Change in average speed or travel time	Impact on delay at preselected priority and signalized intersections
	Change in peak and off-peak vehicle volumes	Impact on modal choice
	Change in vehicle occupancy	Impact on environmental variables, such as air-pollution or noise levels
	Change in bus ridership or seat availability	Impact on overall energy consumption
	Change in traffic composition, particularly heavy-vehicle percentages	Impact on parking demand
Final general and extended	Change in link reliability	Impact on system reliability
	Change in link and adjacent street level of service	Change in vehicle travel
	Change in accident risk and accident rates	Change in system modal choice
	Change in public transport level of service	Impact on overall operating costs
	Change in sidewalk pedestrian flow level of service	Impact on CBD vitality through office space availability, rental rate change, residential floor area variability, or retail tax paid, or all of these
	Change in pedestrian risk exposure	Impact on residential neighborhood, such as change in through-traffic percentage, change in truck use of local streets, or change in noise levels
		Impact on overall pedestrian and vehicle safety

EXISTING EVALUATION METHODS

The evaluation methods currently used cannot give more than a general indication of the worth of a solution. A short discussion of the three most common evaluation methods follows.

Goal-Achievement Analysis

This method is used for a subjective assessment of the extent to which the goals of a TSM project are attained. Its main disadvantages are

- Limited number of MOEs,
- Difficulty in comparing the worth of the different magnitudes of improvement of different MOEs, and
- Lack of consideration of project costs.

The advantage of this kind of analysis is that it enables the magnitude and incidence of individual impacts to be predicted. A decision is taken according to a weighted array of results based on predicted changes in the MOEs as shown in the following simplified example:

	Percent Change	
MOE	Alternative A	Alternative B
Vehicle delay	-5	-10
Traffic volume	-3	+1
Energy consumption	-1	0

Cost-Effectiveness Analysis

The basic process of cost-effectiveness analysis compares the costs of gaining an objective with the degree to which each alternative in a series of schemes approaches the goal or objective. The individual results are divided by the costs required to achieve them. Different factors cannot be combined; separate comparisons must be made for each MOE individually assessed. An advantage of the method is that it takes economic efficiency into account; however, a single comparison taking all important measures into account cannot be made. A decision is made on the basis of the individual results, as shown in the following example:

	Percent Change/Cost of Project	
MOE	Alternative A	Alternative B
Vehicle delay	-5/50 = -0.10	-10/40 = -0.25
Traffic volume	-3/50 = -0.06	+1/40 = +0.03
Energy consumption	-1/50 = -0.02	+0/40 = 0

Benefit-Cost Analysis

All benefits resulting from a project are reduced to monetary terms and then compared with the costs of the project. The outcome is a single ratio of benefits to costs. The serious weakness of this method, however, is that many MOEs cannot be expressed in economic terms; therefore, they must either be excluded from the analysis or have an arbitrary value ascribed to them.

In sum, existing evaluation schemes are inadequate for TSM projects because (a) they assess alternatives in terms of a limited number of MOEs that are readily convertible to monetary terms and (b) they lack sensitivity to the magnitude of the capital involved.

These weaknesses explain in part why the concept of TSM is widely accepted but seldom implemented to its full significance. Because the evaluation results are open to criticism, it is difficult to convince a broad spectrum of interested parties that their objectives are being met satisfactorily. Clear, explicit evaluation methods would greatly encourage practical interest in a TSM project.

EVALUATION AND WORTH TO SOCIETY

The evaluation method proposed in this paper attempts to eliminate some of the drawbacks of the existing methods. It is based on several assumptions:

1. The size of the system is immaterial: TSM may be applied, at one extreme, to a single operational environment (e.g., an outlying commercial center or residential suburb) or, at the other extreme, to a large conurbation containing many operational environments. It is assumed that the system, large or small, contains three elements: modes, infrastructure, and land use; that these elements have different characteristics and that different influences act on them; and that linkages between the elements exist and are variable. If the system is small, the interface with the outside must be considered an integral part of the study.
2. There is a group of involved but objective individuals, transport specialists, and others able to define the problem and assess the relative importance of the objectives.

TSM strategies should receive the full attention of local and state authorities, as well as of the public, because these strategies may have significant effects on traffic, the environment, and the economy. It is important, therefore, to assess the full range of impacts, both short-term and long-term, and to find out whether they may counteract one another. In a survey of parking management strategies by Ellis (12), for example, reducing parking-space supply and increasing parking costs in the CBD area were considered. Although this strategy may initially create a mode-choice shift toward further use of public transport, it may eventually lead to a deterioration in the residential and economic vitality and prosperity of the CBD by stimulating a change in land use.

Another problem associated with the evaluation of TSM strategies is that low capital improvements may at times have the highest payoff in improved efficiency. Among these, one may count such tactics as the restriction of parking near intersections to allow for turning lanes, the installation of parapets to separate pedestrians from heavy traffic flows, and stricter enforcement of traffic regulations. Nevertheless, any policy considered must evaluate the full range of potential improvements, regardless of their initial capital costs.

An alternative approach that is proposed in this paper for the evaluation of TSM projects consists of comparing the costs of a series of alternatives with system efficiency as measured by its level of service.

The hypothetical relationship between capital investment and a change in vertical level of service may assume the general shape shown in Figure 1. At Point I, low-cost projects are introduced, such as pedestrian barriers, road-lane marking, or improved signing, and some slight change in vehicle level of service may be expected. At Point II, more capital investment is made, perhaps for improving road lighting, resurfacing deteriorated roads, or improving drainage at certain locations, as well as for implementing parking-control strategies, and a further upgrading of the level of service is achieved. TSM projects represented at Point III, such as the improvement of the signal system (by coordination or vehicle actuation techniques) or the diversion of truck traffic to special truck routes, may reduce delay and the number of stops and increase average speed.

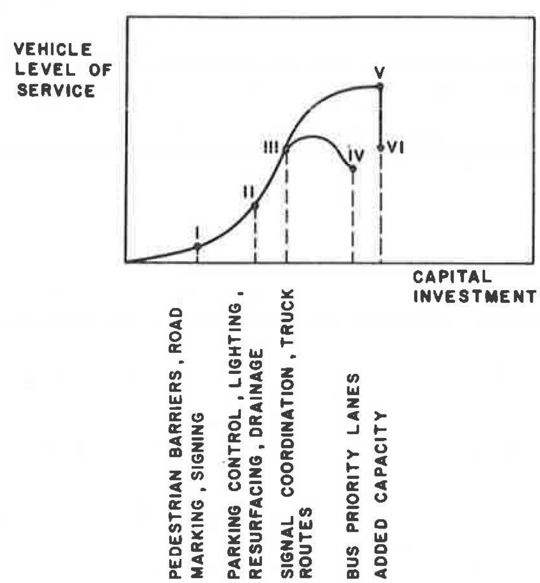

FIGURE 1 Potential change in level of service as related to capital investment.

A deterioration in vehicle level of service may be experienced at Point IV, where the capacity of the system is partly reduced by the construction of bus priority lanes; on the whole, however, the public will probably benefit because of the expected improvement in transit level of service. On the other hand, a major project, such as expanding the network capacity, may further improve the level of service (note Point V) if it can be assumed, of course, that travel demand will remain constant. Because this assumption is not valid in many instances, one may expect some shift in the travel function toward higher demand. Some future deterioration in the level of service is then to be expected (note Point VI) until equilibrium between network supply and travel demand is achieved.

The question arises of what level or range of capital investment a public agency involved in TSM may want to consider or, more specifically, the recommended limit of capital investment sought for a TSM strategy. It is now necessary to ascertain what acceptable range of strategies or capital-investment limits will still provide the best benefits to the community. For this, consider the two curves shown in Figure 2. The first is the capital-investment curve, which is of the same logistic type as the curve shown in Figure 1. The capital-investment curve shows that for high and low levels of service, the investment needed to create a constant amount of change is higher than that needed for an intermediate level of service. Similarly, if the monetary worth to society is considered, the opposite trend may be observed: an improvement in a higher level-of-service situation provides lower monetary benefits and that in a lower level-of-service situation may yield a higher monetary worth.

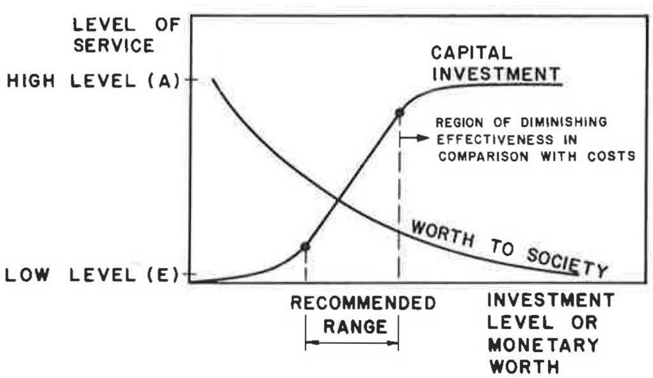

FIGURE 2 Recommended range of capital investment for TSM strategies as related to capital investment and monetary worth to society.

A similar approach was discussed recently by Brinkman and Smith (13) in their analysis of two-lane rural highway safety. They showed the diminishing returns for additional investments on present worth of benefits over a next-20-years curve. They also demonstrated the rapid reduction on safety and operational cost-benefit-ratio curves: the ratios are shown to be very high at a low-expenditure level and to decrease rapidly as the expenditure level increases.

Thomas and Schofer (14) suggested earlier that because of the nature of transportation decisions, some basic requirements have to be satisfied, such as knowledge of all feasible solutions and their consequences and a precise definition of optimality. These requirements, however, cannot always be met.

It is suggested, therefore, that the recommended range of capital investment for TSM projects be established at the middle level, as shown in Figure 2. The exact amount allocated for each project has to be determined on the basis of its individual merits and in accordance with decision policies determined by the authorities concerned. Expansion investments are not always recommended for TSM projects because of the diminishing returns for high level-of-service situations and also because of elasticities of demand, which in turn may further reduce the final level of service.

It should be noted that when the concepts of worth and capital investment are discussed in this paper, it is assumed that the investment capital is designated by society for TSM projects only.

LEVEL OF SERVICE OF THE TRANSPORTATION SYSTEM

The traditional measurement of the level of service, such as a load factor for isolated intersections or an operating speed for highways, cannot be applied to TSM projects, in which a large number of diverse variables have to be included. It is therefore proposed that the level of service of the transportation system (LTS) be introduced to represent the performance of the system. The LTS must be capable of incorporating both tangible and intangible MOEs. For different projects, the number of MOEs may vary, but for a single project the number of MOEs for various alternatives must remain constant. In each case, a single LTS value will result.

The LTS is constructed as a function of several MOEs:

$$LTS = f(x_1, x_2, x_3, \ldots, x_k) \qquad (1)$$

where x_i is the independent MOE and i is the index of MOE ($i = 1 \div k$).

In considering a broad spectrum of independent variables, such as those presented in Table 1 or those in the discussion of existing methods of evaluation (e.g., vehicle speed, vehicle delay, traffic volume, or energy consumption), a common denominator has to be found. The independent variables are thus allocated relative values (a_i; $i = 1 \div k$) of weighting factors established by utility analysis, and the system level of service is expressed as

$$LTS = a_1x_1 + a_2x_2 + \ldots + a_kx_k \qquad (2)$$

Utility theory defines utility functions for different attributes of a system, such as aesthetic comfort, the amount of emissions, automobile travel time, bus waiting time, or traffic volumes. Although the MOEs produce tangible figures, allocating comparable values to such diverse variables as emissions, aesthetics of transportation facilities, or traffic volumes requires the assessment of intangibles. The utility analysis described by Roebuck (15) is therefore recommended for the determination of the LTS function. Utility analysis is a semiquantitative approach for "trading off" the possible effects of implementing any given scheme, and as such is a guide to decision making. The procedure calls for the establishment of a utility analysis panel of decision makers, in accordance with the spirit of TSM, which emphasizes coordination of elements. The members of the panel should represent the three elements of the system:

- Land use: town planners, residents, and local businessmen;
- Infrastructure: traffic or highway engineers and traffic police; and

• Transportation modes: public transport planners and operators.

The size of the panel and its composition will vary from project to project; in each case, however, it must reflect the more important or relevant elements of the system. The panel may undergo some changes during the lifetime of a project as additional elements, ignored initially, are introduced or, conversely, as the initially envisaged elements are dropped as matters progress. The role of the panel is to define the problem (guided by the experts initiating the project), set out the objectives, and determine the relative importance of these objectives, and thus to allocate weighting factors, based on utility curves, to the independent MOEs in their system level-of-service function.

The main advantages of utility analysis, then, are that

• A comprehensive range of effects can be considered;
• A multidimensional goal system can readily be handled;
• A minimum level of service or maximum tolerable disbenefit can be introduced;
• The views and values of interested or affected parties, rather than arbitrary values, are taken into account; and
• During the discussion, each individual on the panel is exposed to other points of view.

As a result of the panel discussion, every variable is unequivocally rated against others. It remains for the project management to calculate the values of the LTS for various proposed alternatives. The selection of the most suitable alternative is performed with the use of a graph of the kind shown in Figure 3. The vertical axis shows the LTS values associated with the proposed alternatives and the horizontal axis, the expenditure level. The four curves indicate the overall efficiency (or productivity, depending on the MOE selected) of each of the four assumed alternatives. The project selected would show the highest efficiency (highest LTS) within the financial constraints. If two alternatives give similar results, the utility analysis panel should be consulted again to approve a final decision.

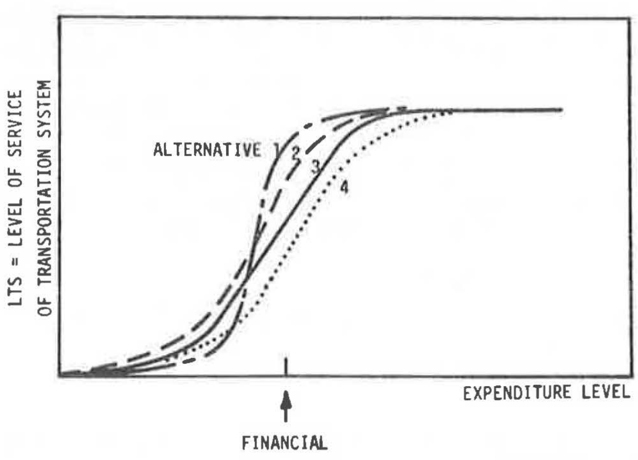

FIGURE 3 LTS of four alternatives as related to expenditure level.

APPLICATION OF THE LTS FUNCTION

A TSM study is being conducted for the city of Springs, South Africa. The study is run by a professional team representing the provincial, metropolitan, and local authorities and the Department of Transport. Public participation is secured by the involvement of elected and appointed representatives, local transport companies, and the general public, organized into three groups: decision makers, those involved in transportation, and those affected by transportation. The purpose of the groups is the identification of transportation problems in the area and the selection of the objectives, constraints, and MOEs of the study.

In the Springs study, the following were identified as the major problems:

• Delays to vehicular traffic at some intersections on main routes leading to the central business district (CBD),
• Delays to traffic caused by school buses, and
• Inadequate parking facilities at the railway station.

The main constraint appeared to be the availability of funds, which are not sufficient to attend to all the existing problems. Three alternative solutions were proposed by the professional team:

1. Geometric and signalization improvement of critical intersections;
2. Signalization improvement at critical intersections, relocation of the bus stop at one of three affected schools, and development of a parking area for 50 vehicles in the vicinity of the railroad station; and
3. Relocation of the bus stops at three schools.

The selected MOEs were vehicular delay, fuel consumption, commuters' delay while walking to the station, and students' delay. A panel consisting of the professionals and the group representatives allocated the following weighting factors to the selected MOEs:

MOE	Weighting
Vehicular delay (vehicle-minutes)	$a_1 = 2$
Fuel consumption (liters)	$a_2 = 10$
Pedestrian delay (person-minutes)	$a_3 = 4$
Students' delay (person-minutes)	$a_4 = 2$

The computer and manual analyses indicated that the following benefits can be achieved during a morning peak hour:

• Alternative 1--1,000 vehicles would save 60 sec and 100 mL each;
• Alternative 2--1,000 vehicles would save 30 sec and 50 mL each, 200 vehicles would save 15 sec and 20 mL each, 400 students would save 15 sec each, and 75 people would save 3 min each in walking time; and
• Alternative 3--600 vehicles would save 15 sec sec and 20 mL each, and 1,200 students would save 15 sec each. The LTS function was calculated as

$$LTS_j = \sum_{i=1}^{k} a_i x_{ij}$$

where i = 1, ... 4 is the index of MOE and j = 1, 2, 3 are the alternative solutions.

The calculation results are shown in Table 2. The decision was made to base the selection of the alternative for implementation on the maximum value of the LTS function. Alternative 1 yielded the highest

TABLE 2 Evaluation Process Using LTS Function

Improvement	MOE	x_{ij}	$x_{ij}a_i$	LTS
Alternative 1 (j = 1): geometric and signalization improvements at intersections	Vehicle delay	1,000 x 60/60	$1{,}000a_1$	3,000
	Fuel consumption	1,000 x 100/1,000	$100a_2$	
Alternative 2 (j = 2)				2,740
Signalization improvements	Vehicle delay	1,000 x 30/60	$500a_1$	
	Fuel consumption	1,000/50/1,000	$50a_2$	
Bus stop relocation	Vehicle delay	200 x 15/60	$50a_1$	
	Fuel consumption	200 x 20/1,000	$4a_2$	
	Students' delay	400 x 15/60	$100a_4$	
Parking facility	Pedestrians' delay	75 x 3	$225a_3$	
Alternative 3 (j = 3): bus stop relocation	Vehicle delay	600 x 15/60	$150a_1$	1,020
	Fuel consumption	600 x 20/1,000	$12a_2$	
	Students' delay	1,200 x 15/60	$300a_4$	

value of LTS and therefore was recommended for implementation.

CONCLUSIONS

Five major conclusions may be drawn from the foregoing discussion of evaluating TSM projects:

1. The essence of the TSM approach is the coordination of the elements of the system in order to maximize its efficiency and productivity.
2. Various transportation management strategies require a capital input that is not necessarily proportional to the resulting change in the level of service.
3. The assessment of a transportation system by the conventional level-of-service measure (i.e., based on one variable, such as speed) cannot be done because of the multiplicity of the system users' expectations. Therefore, the use of the LTS based on a combination of variables is proposed.
4. In order to include a broad spectrum of sometimes conflicting objectives in the evaluation procedure, a panel of decision makers should be consulted to allocate weighting factors to the relevant variables, such as speed, fuel consumption, or traffic volumes.
5. The LTS may be calculated for each alternative proposed on the basis of the magnitude of changes in each variable multiplied by the relevant weighting factors. The selection of the alternative to be implemented is based on its efficiency (or productivity) within the capital-investment constraints.

ACKNOWLEDGMENT

The support of S.H. Kuhn of the National Institute for Transport and Road Research is gratefully acknowledged.

REFERENCES

1. T.C. Mackey. Course Notes on Transportation System Management. DOT/NITRR Committee on TSM courses in South Africa, Pretoria, South Africa, April 1983.
2. M.D. Meyer. Monitoring System Performance: A Foundation for TSM Planning. In Transportation System Management in 1980: State of the Art and Future Directions, Special Report 190, TRB, National Research Council, Washington, D.C., 1980.
3. Transportation System Management. Special Report 172. TRB, National Research Council, Washington, D.C., 1977.
4. Transportation System Management in 1980: State of the Art and Future Directions. Special Report 190. TRB, National Research Council, Washington, D.C., 1980.
5. N.J. Rowan, D.L. Woods, and V.G. Storer. Alternatives for Improving Urban Transportation--A Management Overview. Technology Sharing Report 77-215. U.S. Department of Transportation, Oct. 1977.
6. R. Sumner et al. A Freeway Management Handbook, 4 vol. FHWA, U.S. Department of Transportation, May 1983.
7. M.R. Misch, J.B. Margolin, D.A. Curry, L.J. Glazer, and G. Shearin. Guidelines for Using Vanpools and Carpools as a TSM Technique. NCHRP Report 241. TRB, National Research Council, Washington, D.C., 1981.
8. A.D. May. Demand-Supply Modeling for Transportation System Management. Research Report. University of California, Berkeley, July 1980.
9. C.M. Abrams and J.F. Direnzo. Measures of Effectiveness for Multi-Modal Urban Traffic Management, Vol. 2: Development and Evaluation of TSM Strategies. Report FHWA-RD-79-113. FHWA, U.S. Department of Transportation, 1979.
10. C.M. Abrams et al. Measures of Effectiveness for TSM Strategies. Report FHWA-RD-81-177. FHWA, U.S. Department of Transportation, 1981.
11. S.C. Lockwood and F.A. Wagner. Methodological Framework for the TSM Planning Process. In Transportation System Management, Special Report 172, TRB, National Research Council, Washington, D.C., 1977, pp. 100-117.
12. R.H. Ellis. Parking Management Strategies. In Transportation System Management, Special Report 172, TRB, National Research Council, Washington, D.C., 1977, pp. 54-67.
13. C.P. Brinkman and S.A. Smith. Two-Lane Rural Highway Safety. Public Roads, Vol. 48, No. 2, 1984, pp. 48-53.
14. E.N. Thomas and J.L. Schofer. Strategies for the Evaluation of Alternative Transportation Plans. NCHRP Report 96. TRB, National Research Council, Washington, D.C., 1970.
15. C.S. Roebuck. An Overview of Utility Analysis and Its Application to Evaluation of Transport Alternatives. NITRR Technical Note TT/8/77. National Institute for Transport and Road Research, Pretoria, South Africa, 1977.

Publication of this paper sponsored by Committee on Transportation System Management

A Planning Process To Develop Traffic Management Plans During Highway Reconstruction

A. J. NEVEU and L. MAYNUS

ABSTRACT

As the emphasis by transportation agencies shifts away from new construction and toward the repairing and maintenance of existing facilities, the problem of how to maintain traffic through and around the reconstruction becomes an important issue facing agency officials. The New York State Department of Transportation formed a task force to develop a document to guide the regional offices in the preparation of traffic management plans that may include transportation system management (TSM) actions. A planning process was presented for the regions to follow to determine whether TSM actions were necessary to maintain traffic and a list of possible TSM actions to implement was provided, which was drawn from previous experience in Pittsburgh, Syracuse, and Boston reconstruction projects and reported on the specific application, costs, and effectiveness of the TSM action.

From the 1950s to the early 1970s the major focus of the nation's highway program was on construction of new and better facilities to carry increasing traffic volumes at high speeds. The freeway systems now present in many urban areas were planned and constructed during this period. As those highways begin to reach their design service life, the emphasis of the state transportation agency is shifting away from building new facilities to rebuilding the older, deteriorating systems. Concern over the condition of the transportation infrastructure has grown rapidly in the past few years. In New York State, for example, voters in 1983 approved a $1.25 billion bond issue devoted entirely to a 5-year program to rebuild the state's transportation infrastructure.

As this reconstruction continues to grow in importance, a problem comes to the forefront that was not a concern in the construction of new facilities. During the reconstruction of a highway section, the designer has to be concerned with the existing traffic on the facility. In most cases, traffic volumes are low enough to be adequately handled within the project site by traditional strategies for the maintenance and protection of traffic, which may include lane closures, lane constrictions, crossovers, and off-site detours onto alternative routes. However, many urban highway systems support such high levels of traffic that these strategies will not be enough to permit reasonable traffic flows during the reconstruction period. A concerted effort involving every level of government, labor, and business must be used to alleviate traffic disruptions due to reconstruction on these high-volume roadways.

Recent reconstruction projects in Pittsburgh and Syracuse have demonstrated the use of transportation system management (TSM) actions to reduce traffic congestion by offering alternative travel options. Although the use of TSM actions is not remarkable in itself, their use in a reconstruction context was an important milestone. It marked a change in the way that transportation agencies plan for traffic management during reconstruction. Whereas previously almost all of the planning was confined to the project site, now strategies that were, in some cases, far removed from the project site were being considered to help reduce congestion and maintain mobility. At the same time, FHWA began to allow construction funds to be used for these off-site actions. These factors have combined to spur greater interest in these innovative traffic management plans.

Because of this increased concern for traffic management planning during reconstruction, it became necessary to collect information from recent experiences and provide this to other potential users.

The New York State Department of Transportation (NYSDOT) undertook the development of a manual to provide some guidance to their regional offices for the preparation of traffic management plans, which may use TSM strategies (1). This manual is composed of two sections. The first develops a procedure by which reconstruction projects that may need TSM actions to maintain traffic flows at an acceptable level can be easily identified and addressed. This procedure outlines steps to follow by which the project manager can determine whether the project may need TSM actions and the major points to consider in the development, implementation, and monitoring of the traffic management plan.

The second portion of the manual is devoted to specific TSM actions that have been or may be used in traffic management efforts. This section draws heavily on experience with TSM strategies in reconstruction projects in Pittsburgh, Syracuse, and Boston. Information is presented on location of the action, a description of the specific program that was developed, estimates of its effectiveness and cost, and general comments on its applicability, special circumstances, or possible improvements. In addition, sample contracts or arrangements between major parties involved in the implementation of specific TSM actions are included where possible. With this manual, the highway planner can begin identifying reconstruction projects that may need special attention to the traffic management plans and can select which types of actions may be applicable for these projects.

The manual focuses only on use of TSM actions for

New York State Department of Transportation, State Office Campus, Building 4, Room 104, Albany, N.Y. 12232.

traffic management during reconstruction. The more basic and traditional plans for maintenance and protection of traffic are not addressed. These have been addressed for many years by highway designers and should continue to be given high priority. The foundation of a good traffic management plan will always begin with aggressive, on-site strategies to maintain flow and protect the work crews. Only in special cases do TSM actions need to be implemented, monitored, and evaluated. New and more effective on-site techniques are being introduced, and older ones are being reemphasized or redefined. The highway designer must be ready to use these new procedures as they are introduced.

The purpose of this paper is to present the planning process developed during the study. The planning process is based on the experiences from previous reconstruction projects on which TSM strategies were used to alleviate traffic disruptions (2,3). These steps were designed to conform to the current NYSDOT design process and responsibilities, but the general concepts could be easily adopted by other states.

PLANNING PROCESS TO FORMULATE A TSM PLAN

Background

As the nontraditional types of traffic management strategies become more widely known and applied, it is necessary to define where their evaluation and implementation fall in the current process for developing traffic maintenance and protection plans. This is especially important at this time when the concepts are still very new and no guidance on how to best utilize them is generally available.

A general planning process is presented that outlines the steps to follow to initiate and implement a traffic management plan. This procedure does not change the way highway designers develop "traditional" traffic maintenance and protection plans; it does demonstrate where the new concerns regarding the selection and implementation of TSM strategies should appear in the process.

The basic philosophy behind the TSM planning process is to do only the traffic management activity that is necessary to maintain a reasonable level of service through and around the reconstruction site. For a majority of the projects the traditional traffic maintenance and protection schemes that have been developed and implemented by the highway designer for many years will be adequate. However, there will be cases in which the project will be sufficiently complex or traffic volume will be sufficiently large to warrant additional traffic management strategies. In addition, a group of projects in the same general region may also require TSM action for traffic management, even though any one of them is not large enough to merit such consideration. These procedures facilitate identification of these projects and outline a process to develop traffic management plans to fit those extraordinary circumstances.

The procedures fit into the current NYSDOT design process with little difficulty. They do not change the existing process but rather add several steps if traffic management actions are needed. If these actions are not needed, the process is not different from the existing one.

This procedure is intended to provide some guidance to project designers in determining whether TSM actions will be necessary. It is not intended to be the exact process to be followed for each project. Differences between projects and areas are too great to allow this. Each project must be addressed differently, and this procedure should be viewed as one way of approaching the analysis questions.

This expanded planning process is shown as a flow chart in Figure 1. Each of the boxes is briefly described in the following sections.

Step-By-Step Process

1. Examine Areawide Construction Schedule: The magnitude and nature of construction within an area determine to a large extent what types of traffic maintenance actions can be applied and how effective they will be. Problems could arise if some of the alternative routes for a reconstruction project are being worked on at the same time. This would include not only state projects, but also county, city, and utility company (telephone, power, water) projects as well. If there are conflicts between projects, consideration should be given to altering the construction schedule if other constraints (e.g., funding deadline) allow.

2. Commit to Highway Reconstruction: Once the areawide construction schedule has been examined and possible conflicts minimized, the reconstruction project or projects can be programmed. The planner should be aware of activities, such as upcoming bond issues, that may accelerate the programming of related projects. The construction schedule must be flexible enough to accommodate such changes without interference with projects that have been previously programmed.

3. Develop Maintenance and Protection of Traffic Plan: Maintaining and protecting the traffic flow is an integral and traditional part of highway reconstruction. This has been part of the design phase for many years, and no changes are envisioned here. A comprehensive traffic maintenance plan can eliminate or reduce many traffic problems without resorting to TSM actions. Development of the plan for maintenance and protection of traffic should begin early enough in the design phase to indicate how traffic will be handled in the construction zone, to allow assessment of the capacity loss, and to develop an adequate TSM plan, if necessary. This is especially important if related projects are accelerated. Anticipating such project acceleration may prevent the TSM plans from breaking down. Because the traffic maintenance plan is affected by the highway design, and vice versa, interactions between two activities should be continued and increased. The traffic maintenance plan should explicitly consider commuter and through traffic separately, because their needs are different and strategies to assist one may negatively affect the other.

Contract provisions that accelerate reconstruction progress or minimize traffic disruption should also be considered. These would include incentives for early completion, late penalties, specific deadlines for the various tasks, strict enforcement of the schedule, nighttime work allowances, use of new materials or techniques that may speed completion, visual screening of work areas, or readily available emergency vehicles to handle accidents quickly.

A good public information program is a vital part of the traffic maintenance plan. This is also a TSM action, but should not be limited to that use alone. Frequently employed public information actions include the distribution of construction maps of the area, advance publicity about the upcoming work, and frequent appearances by department staff to explain the project, its duration, and its benefits.

With such a comprehensive traffic maintenance and protection plan, many traffic disruptions can be eliminated or at least reduced to an acceptable level.

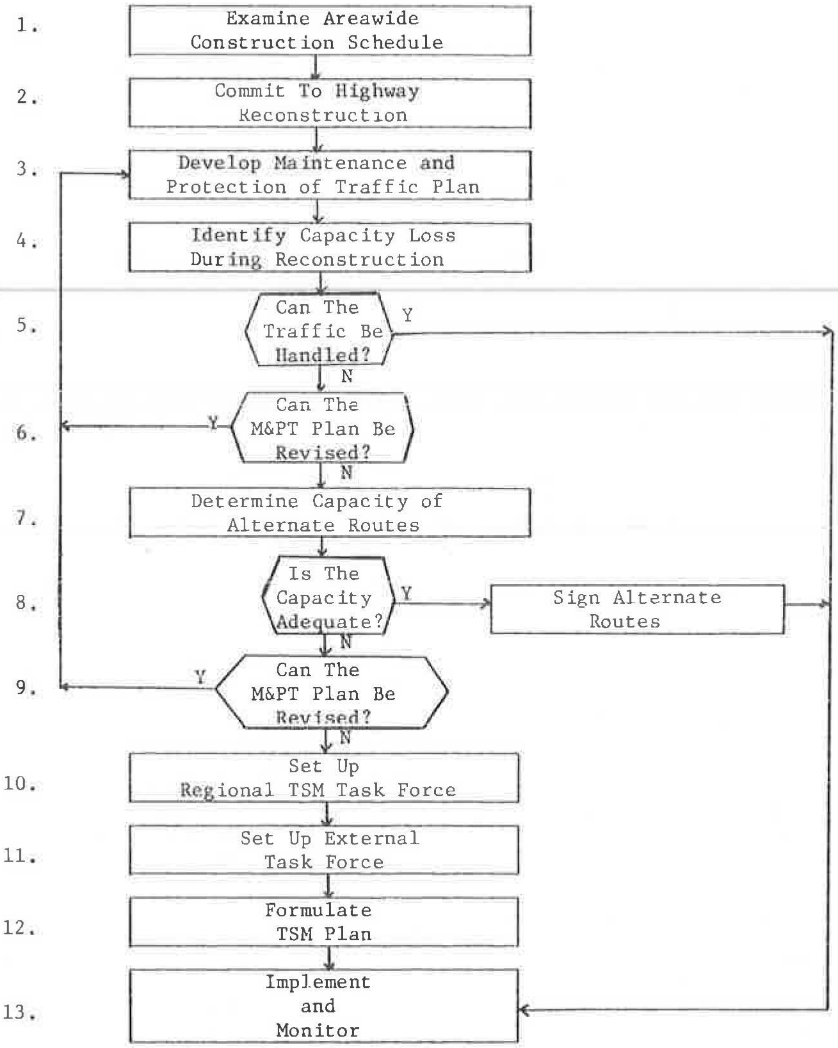

FIGURE 1 Planning process to formulate a TSM plan.

4. Identify Capacity Loss During Reconstruction: Reconstruction activities and the traffic maintenance and protection plan frequently result in a loss of capacity on the highway section under reconstruction. Lane closures, lane constrictions, protective barriers, and reduced speed limits are examples of capacity-reducing activities. It is necessary to estimate the loss of capacity and compare it with the traffic flow before reconstruction begins to determine whether the existing traffic can be handled or if diversions from this route will become necessary, especially during the peak hours.

5. Can the Traffic Be Handled? If the traffic maintenance and protection plan can accommodate the existing traffic with minimum disruptions or delay, an extensive TSM plan will not be necessary, although some TSM strategies may still be desirable. If the traffic cannot be handled, other actions to alleviate the disruptions, including an extensive TSM program, should be examined. The actual criteria to be used in this assessment should be a function of the existing conditions. It is impossible to set an arbitrary acceptable level.

6. Can the Traffic Maintenance and Protection Plan Be Revised? If the traffic plan can be revised, return to Step 3 to make alterations, then continue along the process again. If the traffic maintenance plan cannot be satisfactorily improved, other solutions must be developed.

7. Determine Capacity of Alternative Routes: The first item to consider is the use of alternative routings within or around the corridor. This should include routings for both commuter and through trips. These routes would be beyond the typical off-site detour and could encompass several possible routings. Computerized traffic simulation techniques may be helpful in defining alternative routes and their ability to handle increases in traffic. The areawide construction schedule should be examined to determine whether any work is planned on the alternative routes that would affect their usefulness for the project under construction.

8. Is the Capacity Adequate? If the alternative routes have adequate capacity, put signs in place informing the motorist of the options and the alternative routes. If adequate capacity is not available, reevaluate the traffic maintenance and protection plan to determine whether additional capacity can be gained.

9. Can the Traffic Maintenance and Protection Plan Be Revised? If revisions are possible, repeat the process from Step 3. If no revisions are possible, it will be necessary to develop TSM strategies to add to the traffic maintenance and protection plan.

10. Set Up Regional TSM Task Force: The first step in developing a TSM supplement to a traffic maintenance and protection plan is the creation of a

local departmental study group or task force composed of all involved department functions. This should include design, construction, planning, traffic and safety, and program planning as a minimum. It is this group that will provide the guidance and expertise for the development and implementation of the TSM plan. Through this group the general definition of the traffic problems should be developed, and some idea of the solutions should be formulated. It is imperative that a clearly defined leadership role be provided and supported by all the involved parties.

11. Set Up External Task Force: Once the internal task force has been organized and the problem scope with potential solutions identified, it is necessary to bring in other interested parties to advance the development and implementation of a TSM plan. These groups may include the metropolitan planning organization, city police and fire officials, mayor's office, transit operators, town and county governments, business and civic organizations, and the media. It is through these groups that most of the TSM actions will be developed and implemented. Many of the potential TSM actions become the responsibility of these organizations, so their interest and cooperation is of the utmost importance.

12. Formulate TSM Plan: Using experiences from previous projects, a TSM plan is developed by the implementing agency with involvement of the external task force. The internal task force provides technical support and serves a review function as well. The TSM plan can include whatever actions are considered necessary or reasonable by the task force, using whatever resources are available to them. Both commuter and through traffic need consideration. The second section of the NYSDOT manual provides a selection of possible TSM actions along with the anticipated costs, effectiveness, procedural guidelines, and other helpful information.

13. Implement and Monitor: The TSM plan is implemented along with the traffic maintenance and protection plan to minimize construction-related traffic disruptions. Traffic flows should be monitored to uncover problems with the plans; revisions should be made as necessary to maintain smooth movement through the corridor. Flexibility, in terms of deleting or adding TSM actions to the traffic management plan, is essential to the plan's success.

The process presented here is to provide general guidance in identifying reconstruction projects that may require special treatment and in determining applicable TSM strategies to implement. This procedure can be used for a single project or for an areawide problem with equal ease. As more experience is gained in this area, this procedure will be refined.

TSM ACTIONS

The following pages present an example of the TSM actions given in the NYSDOT manual. These TSM actions have been or could be used to maintain traffic during reconstruction. A description of the action, the location in which it was used, the specific program implemented at that area, an estimate of its effectiveness, any cost information available, and a set of general comments covering special circumstances, possible improvements, and relationship to other actions are given (1):

Action: EXPRESS BUS SERVICE

Location: Syracuse, I-81, 1984

Description: Working with park-and-ride lots as designated bus stops, the area's transit authority, Central New York Regional Transportation Authority, and a private transit carrier, S&O Motor Lines, Inc. provided 12 trips into the city during the morning peak period and 10 trips out of the city during the evening peak period. These trips were operating at 15 minute intervals to provide convenience to the commuters. In order to develop the market once the service began no fares were charged during the first week.

The bus services were set up such that after the activities began they would be adjusted, eliminated, or expanded to fit the actual response of the commuters.

The operators were responsible for the advertising and other media related activities concerning the bus services. They provided a multicolor pamphlet, "THREE WAYS TO BEAT THE MAZE," explaining the TSM package and the need for it, car-pool posters and sign-up sheets, and newspaper and radio advertising.

The users of the buses were surveyed just after the services began. This was done to help evaluate the effectiveness of the system and to learn where to adjust it for increased effectiveness. See the comments section for some results of the survey.

Costs: Final analysis of the costs is not presently available. NYSDOT and FHWA subsidized the costs of these services such that the bus lines would not lose money.

Comments: Of the people responding to the survey (197), 40 percent drove alone before the service. About 14 percent had previously ridden with someone else. Almost 82 percent of those responding indicated that they used it continually (4-5 days per week) and 82 percent had found out about the service through the media efforts provided by the bus companies.

These actions are presented as separate entities in the manual but a general traffic management plan would incorporate several TSM strategies. The effectiveness of the package of actions is not explicitly considered in this manual. Some actions reinforce each other, some directly compete, and some have no impact on other actions. Extreme care should be taken to recognize any possible synergistic effect on any implemented TSM package.

This manual is not to be considered a static tool. Numerous revisions and additions to the manual are anticipated as these TSM strategies are applied and evaluated in various situations across the nation. It is therefore imperative that a good evaluation of each use of these TSM strategies be part of any traffic management plan so that other highway planners and designers may learn from each experience.

SUMMARY

The planning process developed by NYSDOT is aimed at providing the regional offices with guidance for the identification of highway projects that may need TSM strategies for traffic management and suggestions on the development and implementation of such plans. To date, this procedure has not been applied in its entirety. It is based, however, on the steps followed in previous TSM traffic management plans. It is intended to serve as a starting point for the consideration of which projects may need TSM strategies to maintain acceptable traffic flows. The characteristics of the individual project would determine the specific sequence of activities and steps to follow in the development of a traffic maintenance plan. It is hoped that as more projects are subjected to this procedure, the experience gained through them can be incorporated into the planning steps.

REFERENCES

1. How to Manage Traffic During Highway Reconstruction. New York State Department of Transportation, Albany, June 1985.
2. R.B. Anderson et al. Study of Alternative Transportation Strategies During Reconstruction. Pennsylvania Department of Transportation; FHWA, U.S. Department of Transportation, March 1983.
3. M.D. Meyer. Reconstructing Major Transportation Facilities: The Case of Boston's Southeast Expressway. In Transportation Research Record 1021, TRB, National Research Council, Washington, D.C., 1985, pp. 1-9.

Publication of this paper sponsored by Committee on Transportation System Management.

Traffic Signal Timing as a Transportation System Management Measure: The California Experience

ELIZABETH A. DEAKIN, ALEXANDER SKABARDONIS, and ADOLF D. MAY

ABSTRACT

Traffic signal retiming has long been suggested as a means of improving traffic operations and reducing fuel consumption and emissions. However, few local agencies have been able to muster the resources to systematically retime their signals. In California, a statewide program--the Fuel Efficient Traffic Signal Management (FETSIM) Program--was established to address this need. The FETSIM Program provides funds, training, and technical assistance to local agencies to retime their signal systems for greater operating efficiency. To date, 62 local jurisdictions have participated in the program, receiving grants totaling $4 million (1983-1985). In 1986 and 1987 an additional $2 million will be available for grants. The objectives, design, and results of the FETSIM Program's first three funding cycles are described. The program was intended both to produce immediate transportation benefits and to develop within local agencies the skills needed to use state-of-the-art methods for longer-term signal systems management. The transportation benefits have been substantial, with average first-year reductions of 16 percent in stops, 15 percent in delays, 7.2 percent in travel times, and 8.6 percent in fuel use in the retimed systems. Training benefits to local agency personnel also have been positive. However, the program has not had a major influence on local priorities; basic problems in funding and staffing for local transportation activities, including signal work, remain. These problems appear likely to work against long-term maintenance of efficient signal-timing plans unless state funding continues to be made available.

Traffic signal retiming has been proposed as a transportation system management (TSM) measure because it can reduce stops and delays and thus increase the operational efficiency of local streets as well as save travel time and cut down on fuel use and emissions. However, relatively few local agencies have been able to muster the resources to systematically retime their signals on their own. Thus, despite advances in techniques for optimizing signals as a system, many traffic engineers only adjust signal timings one at a time when equipment failure or complaint-generating operating problems occur.

California's traffic engineers have been well aware of the need for periodic retiming of their traffic signal systems, but many have also found that tight city budgets and the daily pressure of work make it difficult or impossible for them to undertake the necessary efforts. One result has been higher-than-necessary fuel use. In California, 65 billion vehicle-mi, or one-third of the state's total vehicle miles of travel, occur each year on streets controlled by traffic signals. Fuel consumption on signalized streets accounts for nearly 20 percent of the state's annual petroleum use, and almost 1.5 billion gal of fuel are burned up each year during stops and delays at traffic lights (1). As shown in Figure 1, about one-third of the fuel used in the widely spaced signal systems in suburban California is lost in stop-and-go driving and in idling. In downtowns, where signals are closer together, fully 43 percent of the fuel is consumed in stops and delays (data from California Department of Transportation, May 1984).

Institute of Transportation Studies, University of California, Berkeley, Calif. 94720.

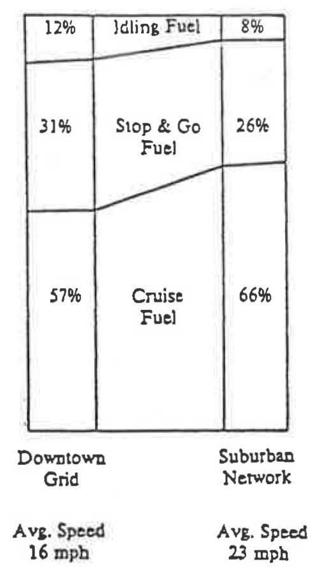

FIGURE 1 Use of fuel on signalized streets in California.

Although many of the stops and delays along signalized streets are necessary or unavoidable, some could be reduced or eliminated by more efficient signal timing. In response to this opportunity, the Fuel Efficient Traffic Signal Management (FETSIM) Program was initiated. Through 1985, 61 cities and one county have participated in this statewide initiative, retiming nearly 3,300 signals. The FETSIM

Program's design and implementation are described and its impacts are discussed. An evaluation of the program is made and signal timing's potential as a TSM measure is considered.

PROGRAM OBJECTIVES AND DESIGN

The FETSIM Program's primary objective is to reduce stops, delays, and fuel consumption through the implementation of more effective signal-timing plans. The program thus provides California cities and counties with both the financial resources and the technical assistance necessary to retime their signals. A second objective of the program is to enhance the capability of the state's traffic engineers to continue to manage their traffic signals effectively; consequently, the program provides training in signal-timing techniques and strategies.

The FETSIM Program is funded through petroleum account monies via the California Energy Resources Conservation and Development Commission; it currently is administered by the California Department of Transportation (Caltrans). Grants have been made available to cities or counties through annual program cycles. To be eligible for a grant, the local jurisdiction was required to have 10 or more signals in a coordinated system capable of multiple timing plans. Beginning in 1986, somewhat less restrictive eligibility criteria were applied. Local agencies are permitted to participate in more than one program cycle if they have additional eligible signal systems. Expenditures have been allowed for all aspects of signal-timing optimization: data collection, data processing, time-plan development, implementation, and field evaluation; grantees also have been permitted to pay in-house staff salaries under the program or to elect to contract with consultants. In the 1983-1985 programs, however, grant funds were not authorized for purchasing signal equipment or control system software or for conducting studies of the potential benefits of coordinating or upgrading signal systems. In 1986, a program testing the cost-effectiveness of funding signal equipment upgrades was initiated.

Each program cycle is of 12 months' duration, during which grantees are given training and technical assistance in the design and implementation of improved timing plans for their signal systems.

THE TRAINING PROGRAM

Training activities for the program have the dual objective of enabling participating traffic engineers and their consultants to use state-of-the-art signal system timing techniques and encouraging longer-term local commitments to signal retiming. The training is conducted through a series of workshops covering principles of fuel-efficient traffic signal management, project design and organization, practical use of traffic signal-timing and evaluation tools, and methods for implementing and maintaining improved timing plans. Basic knowledge of traffic signal timing is assumed, but no previous experience in computer use or fuel-efficient traffic management is required.

The Traffic Network Study Tool (TRANSYT) computer model has been used for optimizing signal settings and for analyzing the resulting traffic impacts (2). TRANSYT was selected because it is capable of handling complicated networks, because it has been thoroughly field tested, and because it directly produces estimates of delay, stops, and fuel consumption. The publicly available TRANSYT-7F version of the model (3) has been emphasized in the FETSIM Program.

TRANSYT is a macroscopic (platoon-based), deterministic model that simulates existing conditions in a system of signals and then optimizes the timing plans. Use of TRANSYT requires coding the network into links and nodes, and accurate data on traffic volumes, saturation flows, speeds, and existing signal settings are needed. TRANSYT's traffic model is applied to these inputs to produce estimates of degree of saturation, travel time, delay, stops, and fuel consumption, as well as flow profiles and queueing estimates. These outputs are compared with observed conditions, and input data and model parameters are adjusted until the model reasonably represents actual operations. TRANSYT then generates alternative timing plans for the signal system. The alternative plans are evaluated using stops, delays, and fuel consumption as the measures of effectiveness, and the best plan is implemented in the field. In-place studies of performance then are carried out to make sure the desired results are being obtained; minor adjustments often are necessary.

The TRANSYT model was used in the program to optimize signal timings for minimum fuel consumption. Several studies have shown that along arterials and in networks, the fuel minimization strategy also tends to minimize delays and stops (4,5). In comparison, delay minimization tends to minimize fuel and reduce stops but may not produce good progression, particularly along arterials. Stop minimization may result in unacceptable timings because it tends to produce long delays on low-volume approaches.

It was recognized at the outset that most participants would need considerable training to be able to apply the TRANSYT model. The workshops thus were designed to provide step-by-step guidance through lectures and laboratories in which participants gained hands-on experience in model use. Orientation workshops are held shortly after the awarding of grants, to assist local agencies in the planning and organization of their projects and to familiarize participants with TRANSYT's data collection, coding, simulation, and calibration requirements. Implementation workshops, 5 months later, cover traffic signal optimization techniques, procedures for installing and fine tuning improved timings, and methods for field studies.

At a third workshop, held at the conclusion of each program cycle, the local agencies present their results. An important purpose of this final workshop is to allow participants an opportunity to evaluate the program; this feedback has been used to refine the workshops and grant conditions in subsequent years.

TECHNICAL ASSISTANCE

Technical assistance during project implementation is also a key design feature of the FETSIM Program. Centers established in Berkeley and Los Angeles coordinate these efforts. Assistance has ranged from advice on data collection procedures and evaluation approaches to help in setting up, running, and interpreting computer programs. In addition, local agencies that do not have in-house computing facilities are provided access to computers through the two centers.

Participating agencies are visited at least twice by the center's staff, who examine each project area, answer questions, and assess progress. Ongoing telephone contact is used to assure that the agencies' projects are proceeding on schedule and to discuss any technical problems that may have arisen. In addition, a newsletter, the FETSIM Bulletin, is mailed to all participants as a way to distribute information on the schedule of events and transmit technical advice.

TABLE 1 FETSIM Program: Three Funding Cycles

	1983	1984	1985
No. of grants	41	22	18
No. of signals	1,535	937	700
Avg grants per intersection[a] ($)	1,037	1,025	970
Total grants to cities ($)	1,592,000	862,882	637,251
Costs for technical assistance, training, research, evaluation, and administration ($)	470,000	203,100	190,772
Total expenditures ($)	2,062,000	1,065,982	828,023

[a]Actual costs when available; otherwise grant awards.

LOCAL PARTICIPATION

Summary data are given in Table 1 on participants' projects and budget allocations (along with costs of training, technical assistance, research, and administration). A total of 81 grants were awarded, but only 62 separate jurisdictions are represented; a number of cities participated in two or more program cycles.

Costs per signal were slightly lower in the second and third program cycles than in the first. In part, this reflects the fact that local jurisdictions were strongly urged to participate in program costs in the later cycles. On average, local contributions were 5 percent of grant amounts. It should be noted, in addition, that most participants adhered to the state's guideline of $1,100 per signal rather than budgeting each task in detail.

Consultants were employed in about three-fourths of the FETSIM projects, with assignments ranging from only data collection to the full range of project activities. Only 11 jurisdictions undertook model application in house; these included 5 of the 6 largest participating jurisdictions, plus 4 other jurisdictions whose staff had substantial previous experience with the TRANSYT model. Only two jurisdictions whose staff had not previously used TRANSYT extensively did the modeling aspects of their projects in house.

In each funding cycle to date, the majority of the local agencies were able to complete their projects with little difficulty. However, some local agencies experienced problems. For example, a number of participants in the first funding cycle discovered that their signal equipment was in serious need of repair, which delayed their projects. In subsequent cycles, a field check and problem correction were required before the cities commenced data collection. Also, several first-cycle cities experienced changes in traffic patterns because of construction, which seriously hindered the development of optimal signal timings. This problem has been largely eliminated by restricting grants to those cities that do not expect such changes. In all three cycles, inadequate data collection procedures caused difficulties in the application of the TRANSYT model in a few cities. The technical assistance teams have been increasingly on the alert for such problems and now review data and coding sheets before modeling begins.

PROGRAM RESULTS

Transportation Benefits

Results from the participating jurisdictions show that in nearly every case, the program has produced major transportation benefits (6,7). On the basis of TRANSYT outputs, the retimed signal systems have attained average first-year reductions of 16 percent in stops throughout the day and 15 percent reduction in delays. Travel times through these systems have declined an average of 7.2 percent, and fuel use has dropped 8.6 percent. (Because benefits often are overestimated at intersections when oversaturation occurs, such intersections have been eliminated from this estimate of average improvements. This may result in a slight underestimation of overall program benefits.)

Field measurements of benefits were estimated from data produced by 11 cities that conducted thorough floating car studies in the 1983 cycle. These studies were conducted during the a.m. peak, midday, and p.m. peak for 2 weeks before and 2 weeks after the implementation of the new timing plans along test routes selected to represent the overall flow patterns in the study areas, including turning movements. Travel times, stops, and delays were recorded for each test run. On the basis of these field tests, stops and delays both were reduced by more than 14 percent, and travel time was cut by 6.5 percent; using these results to calculate fuel consumption produced an estimated decline of 6 percent. Comparison of TRANSYT predictions with field measurements showed that TRANSYT generally overestimated benefits by 1 to 4 percent (Table 2).

To provide an additional check on estimates of benefits from TRANSYT and floating car studies, an instrumented vehicle was used in the 1983 cycle to measure actual traffic performance and fuel consumption in the city of Berkeley's grant project area, consisting of 28 signals in a dense central business district (CBD) grid pattern. The instrumented vehicle was driven before and after implementation of the new signal timings on routes selected to reflect the overall pattern of traffic movements in the area (8). The results of the instrumented-vehicle test were within 2 percent of the TRANSYT outputs and verified that significant fuel savings and improvements in the quality of traffic flow were obtained from the optimization of the signal timings.

TABLE 2 Comparison of TRANSYT and Field Results

Control Period	Travel Time		Delay		No. of Stops		Fuel Consumption	
	TR	FLD	TR	FLD	TR	FLD	TR	CALC[a]
A.m. peak	-6.6	-5.4	-14.5	-14.0	-14.9	-9.4	-8.3	-4.2
Midday	-7.5	-6.9	-15.1	-1.47	-11.6	-15.6	-7.7	-6.0
P.m. peak	-8.0	-7.0	-14.7	-12.3	-13.5	-11.9	-7.8	-6.4

Note: Values given are percent changes, averages based on results reported in 11 cities, 1983. TR = TRANSYT results; FLD = field results.

[a]Calculated from the field-measured travel times, delays, and stops.

Field studies were not required by the state in subsequent program cycles, because of the heavy time and resource commitments required to obtain statistically significant results. A number of local jurisdictions have carried out field tests voluntarily, however, and these field tests have consistently found TRANSYT predictions to be within 2 to 4 percent of measured values.

Annual benefits of the FETSIM Program for each funding cycle, based on the TRANSYT model results, are given in Table 3. Benefits have declined somewhat in later cycles, in large part because in the later cycles local jurisdictions entered the program with more recently timed signal systems. Nevertheless, at average fuel costs of $1.10 to $1.15 per gallon, avoided fuel expenditures during the first cycle outweigh program costs by a factor of nearly 6 to 1.

Other transportation benefits of the program include reduced vehicle wear and tear and travel-time savings. On the basis of AASHTO figures (9) for the costs of vehicle wear and tear due to stops and delays, an additional $30.55 million is being saved by motorists each year. AASHTO's method for estimating value of time would produce an annual savings equivalent to another $22.5 million. Other benefits, including air quality and safety improvements, are believed to have been produced by the program but these benefits have not been quantified.

Training Program Benefits

The benefits of the training program were assessed through surveys conducted at the completion of grant activities. Here, significant differences among the participating agencies were observed. In the jurisdictions that carried out most aspects of their projects in house, participating staff generally believed that they would be able to use the TRANSYT model for future signal retiming on their own. It is noteworthy, though, that in at least half of these cases, the assigned staff were already experienced TRANSYT users. In the cities that tended to rely on consultants for most of the project work, most staff members failed to gain enough expertise in the use of the model to apply it independently in the future; nevertheless, a majority of them believed that they were sufficiently well versed in the model application to design future projects and closely supervise consultants. Cities in which the staff lacked background in computer use (and, in many instances, in traffic engineering) did not fare as well. For these participants--about one in five--much of the content of the training program was at too advanced a level for them to assimilate more than the general principles, and most believed that they would continue to be dependent on consultants in project design and management.

Cities' consultants were also encouraged to participate in the training program. Although many of the consultants already had basic knowledge of the TRANSYT program, the training allowed them to develop expertise. City staff, moreover, believed that training for consultants helped assure a high-quality product.

Although the training program was favorably received by all participants, it is important to note that most local jurisdictions did not avail themselves of the opportunity to become model users. Instead, the majority of city personnel utilized the training sessions as an opportunity to become knowledgeable managers of signal-timing projects.

THE FUTURE OF THE PROGRAM

The California energy commission and Caltrans estimate that there are some 20,000 signals in California, more than 90 percent under city or county control. Because only about 15 percent of these signals have been retimed under the FETSIM Program to date, a substantial market for additional program cycles is believed to exist. To assess this market and the level of future interest in the program, telephone interviews were conducted with the traffic engineers in a sample of 101 California cities, including both nonparticipants and those who had received one or more grants (10).

The interviews revealed a number of reasons that nonparticipating cities had not pursued grants from the FETSIM Program. Among the larger cities (populations of 50,000 or more), almost one in five was not aware of the program. (This is in spite of annual program announcements to all city and county traffic engineering departments, plus announcements and presentations at meetings of professional societies such as the Institute of Transportation Engineers and the American Society of Civil Engineers.) About one-third of the nonparticipating cities could not meet the program requirements of 10 or more signals in a coordinated system capable of multiple timing plans; for example, many had single-dial controllers or lacked signal interconnections, or both. Sixteen percent did not apply for a grant because their cities were making major construction changes or were currently conducting transportation studies, and another 16 percent was satisfied with their present timings. Nine percent did not apply for a grant because of staff limitations.

In the smaller nonparticipating cities (population less than 50,000), 60 percent was not aware of the FETSIM Program. For those who were aware of it, one of the most important reasons for nonparticipation was lack of personnel capable of supervising a signal-timing project; in 75 percent of the small cities there is no engineer on the staff and less than 10 percent of consulting engineers' time is denoted to signal work. Inability to meet the program signal system requirements was a second major barrier; in 85 percent of the smaller cities there are fewer than 10 signals in any one system, and most of these cities also lack signal interconnections or multiple timing-plan capabilities, or both.

TABLE 3 FETSIM Program: Annual Benefits

	1983	1984	1985
Signals retimed ($)	1,535	937	700
Savings in fuel costs ($)	12,800,700	6,700,000	4,600,000
Savings in operating costs ($)			
Due to reduced delays	800,000	400,000	250,000
Due to reduced stops	16,300,000	7,700,000	5,100,000
Value of time saved ($)	12,400,000	6,200,000	3,950,000
Total money saved ($)	42,300,000	21,000,000	13,950,000

Note: Benefits are based on TRANSYT model outputs.

On the basis of the interview findings, only about half of the traffic signals in the state appear to be eligible for retiming under the current FETSIM Program criteria. It would take 8 to 10 years to retime all these signals at current funding levels and annual rates of participation. However, the interviews also suggested that modifications to the program would allow additional signals to be retimed. Such modifications are currently under consideration. One restriction that currently limits signal retiming is the requirement of 10 or more signals in a coordinated system. The interviews found that an estimated 1,800 signals, or about 10 percent of the total signals under local control, are in simple systems that include fewer than 10 signals. Although these small systems could be retimed by using the TRANSYT method, simpler techniques (such as PASSER-II) also would be suitable and would be preferred by local officials. Trial programs assessing PASSER-II and TRANSYT for retiming these small, simple signal systems are currently under consideration.

Also, at least 2,500 more signals could be retimed if improvements in signal equipment, including coordination capabilities and multiple-timing plan capabilities, were funded. Costs for signal hardware vary considerably, depending on the existing equipment, the type of new equipment desired, and the system configuration. Increasing the number of timing plans could cost on average $1,200 if the system is already coordinated, whereas costs could be $1,000 to $3,500 per controller for interconnection (10). Replacing controllers requires a larger investment ($4,500 to $9,000 per intersection) but would be essential in some cities. Although funding such hardware improvements would increase the average cost per signal substantially, benefits also might be considerably higher in those systems that would find coordination and multiple-timing plans advantageous. Furthermore, a number of the cities that lack signal hardware report that their signal-timing plans are in serious need of improvement, so that potential gains could exceed those achieved to date. On the other hand, areas with little traffic peaking may not benefit substantially from multiple-timing plans, and areas where signals are widely spaced may gain little from coordination. Because of the uncertainties over cost-effectiveness of hardware investments, more detailed analysis will be carried out before a commitment is made to a full-fledged hardware assistance program.

Table 4 gives cost estimates for three program options currently under consideration for future years.

EVALUATION

Experience with the FETSIM Program provides an opportunity to evaluate the potential of traffic signal timing as a TSM measure. The program has clearly demonstrated that traffic signal-timing improvements are a cost-effective way to reduce stops, delays, and fuel consumption, and thus to increase the operating efficiency of local streets. Benefits outweigh costs by almost six to one, even when 1 year of avoided fuel consumption is taken as the only measure of benefit. Using a broader but widely accepted estimate of benefits, which includes travel-time and vehicle wear and tear savings, a 19:1 first-year benefit-to-cost ratio results. Both the percent improvement attained and the benefit-cost measures compare very favorably with the performance of other TSM strategies.

But the benefits of the program do not appear to be sufficient to induce major shifts in priorities in favor of signal timing. Indeed, surveys of former participants indicate that there has been little or no change in local commitment to signal-timing efforts. In large part this may be due to the lack of visibility of the benefits that accrue. For example, from the perspective of the California motorist who drives 20 mi a week on signalized streets that have been retimed, the annual fuel savings may amount to $5 or so--10 cents a week. This is not an amount that is likely to be noticed, let alone one that is likely to generate citizen support. Although the motorist also benefits from travel-time savings and reduced vehicle wear and tear, the savings for any one individual are similarly small; it is only when aggregated across the many motorists who travel in these signal systems daily that the benefits are found to be substantial.

Ironically, though, commonly used methods of assessing benefits can also make signal retiming appear to be of minor statewide importance. Recalling that about 20 percent of total petroleum use in California is on signalized streets and that about 15 percent of these signals have been retimed to date, the 8.6 percent average decline in fuel use from retiming has reduced the state's fuel bill by only (20 percent) (8.6 percent) (15 percent) = 0.26 percent. Furthermore, the dollar savings accrue to individual motorists, whereas the costs of retiming must be borne by government--whose tax revenues decline as fuel consumption is reduced.

Another problem facing signal timing as a TSM measure is the uncertainty over how long the stream of benefits will continue. The answer obviously will differ from place to place, depending on the rate of change in traffic volumes and patterns. Other studies have suggested that 2 to 3 years of benefits are likely (11). Of course, with regular data collection and model updating, signal timings could be adjusted periodically at minor cost to maintain program benefits indefinitely. However, few participating cities have concrete ideas about how quickly traffic changes might offset the improvements obtained through the program, and even fewer have developed strategies for periodic retiming of their signal systems. Again, this reflects the low level of local resources being devoted to signal timing, which appears not to have been changed by the demonstrated benefits of the program. Thus, the same forces that led to the sizable benefits from state-funded retiming--lack of resources or initiatives at the local level to do the job on their own--may lead to degradation of timings in the future, so that benefits are lost.

Maintenance of efficient timings is further complicated by the fact that few local staff are able to use state-of-the-art signal-timing methods such as TRANSYT. Although the FETSIM Program offered intensive training in TRANSYT to all participants, few city staff members gained enough knowledge to continue the use of the traffic signal-timing method on their own; the majority relied almost entirely on consultants for the signal-timing optimization work. Because most of these local agencies lack the local funds to hire consultants, future opportunities for

TABLE 4 Future FETSIM Program Options, Markets, and Costs

Program Options	No. of Signals[a]	Cost per Signal[b] ($)	Total Costs ($)
Continue current program	6,500	1,375	8.9 million
Retiming plus equipment	2,500	7,500[c]	18.8 million
Small systems	1,800	500	1.8 million

[a]Estimated number of signals eligible for retiming assistance under each program option--excludes signals already retimed (1983-1985).
[b]Includes cost of retiming and cost for training and technical assistance.
[c]Includes an average cost for equipment ($6,000).

signal retiming are likely to be rare unless state funds remain available.

In short, then, the California experience indicates that traffic signal timing is highly cost-effective but does not appear able to generate a strong constituency. Maintenance of signal timing is likely to be hampered by lack of local funding commitments, coupled in many cases with a lack of local staff capable of handling such efforts in house. Continuing state assistance may be the only way to assure long-term signal-timing efficiency.

Other findings of the FETSIM Program also deserve notice. In particular, the program has revealed a need for greater attention to the way in which local agencies select and utilize signal equipment. In each program cycle, it became apparent that a number of cities had purchased highly sophisticated signal control systems but had not used many of the systems' features. In other cities, an assortment of signal equipment had been installed over the years, and the various makes and models were incompatible. Furthermore, a number of cities that lack hardware for coordinated, multiple-timing plans reported that they had been unable to convince their city councils that improved equipment would be worth the cost. Good signal management requires appropriate equipment; providing help in sorting out equipment issues may be a prerequisite to efficient signal timing.

One strategy that has been suggested for maintaining signal timings would be to use the TRANSYT model to evaluate traffic impact and mitigation measures for new developments requiring environmental impact reports (EIRs) (12). Because most large public projects and many private ones require EIRs under California law, a number of cities would be able to at least partially update their timing plans in this way. However, although most of the participants believed that such a practice would be apt, considering that major new developments and projects are a primary factor in traffic changes that render existing timings inadequate, they also thought that their city councils would be reluctant to require such work as part of the development approval process.

A final note on the impact of the program: when the FETSIM Program was initiated, concerns were raised that retiming signal systems might lead to induced travel and mode shifts, which in turn could cancel out the traffic flow, fuel savings, and air quality benefits initially obtained. Examination of the participants' results showed that the aggregate travel-time benefits of the program are large, but from the perspective of the individual traveler they are too modest to be likely to induce additional trips; even in the cities that gained the most from the project, automobile travel times for the typical trip through the network improved by less than a minute. Also, bus travel times generally improved as much as automobile travel times; some cities even used the program as an opportunity to weight signal timings to favor bus routes. Thus, it appears safe to say that the benefits of the program will not be canceled out by program-induced, short-run traffic increases or shifts to automobile. To the extent that cities consider the program benefits as "room for development," however, a return to previous traffic performance may occur.

CONCLUSIONS AND RECOMMENDATIONS

California's FETSIM Program has produced positive results, both in transportation impact and in personnel training. However, experience suggests that refinements may be in order. For example, the current program design emphasizing multiple-timing plan, coordinated signal systems appears to be capable of reaching only 50 percent of the total signals statewide. Program modifications including use of a variety of signal-timing methods or providing funds for signal equipment or both could extend the reach to up to 80 percent of the total signals. But the cost-effectiveness of such modifications will need to be considered carefully, with detailed analyses and demonstration projects preceding full-fledged program offerings.

Although the program was designed to give local agency staff the skills to maintain fuel-efficient signal timings, follow-up surveys indicate that only a few local agencies will be able to act unassisted in the future. Many participants relied on consultants for most of the work, and although some gained enough knowledge to independently design and supervise future projects, others gained relatively little from the training programs. Incentives to encourage more meaningful local involvement deserve consideration, but it must be recognized that some local stall members lack the background needed to meaningfully participate in a program of this complexity. Alternative program designs explicitly recognizing that many local agencies prefer consultants to do the work should be considered.

Lack of resources may be a barrier to the maintenance of efficient timing plans, because the benefits of the program have not had a discernible impact on local funding for signal-timing efforts. It may thus be necessary to develop more explicit strategies for encouraging local long-term maintenance and renewal of signal-timing improvements. Alternatively, it may be necessary for the state to provide repeat assistance to localities wishing to update their signal timings.

Other states considering the development of traffic signal-timing programs are advised to consider the following:

1. The program should be designed for the kinds of traffic signal systems in the state. For example, a state having very few systems of 20 or more signals probably should not base its program solely on TRANSYT. Consideration also should be given to the status of signal equipment. If the California experience is borne out in other states, inadequate equipment may be a major barrier to efficient signal operations.
2. The program should reflect staff capabilities among local jurisdictions. Unless a substantial portion of the target audience for the program is capable of handling the technical aspects of signal timing (and is interested in doing so), a detailed training program may not be justified. An alternative program design might be to establish technical assistance teams to provide services to local agencies, rather than to train local staff and their consultants.
3. Attention should be given to long-term maintenance of efficient signal-timing plans. Possibilities include development of strategies for assuring local updating of timings or establishment of an explicit policy to repeat state-assisted efforts every few years.

ACKNOWLEDGMENTS

Work performed in 1983-1985 in support of the FETSIM Program by the Institute of Transportation Studies, University of California, Berkeley, under contract to the California energy commission is described. In 1984 and 1985 this contract was administered by the California Department of Transportation.

REFERENCES

1. Fuel-Efficient Traffic Signal Management: An Action Plan for California. California Energy Resources Conservation and Development Commission, Sacramento, March 1983.
2. D.I. Robertson. TRANSYT: A Traffic Network Study Tool. TRRL Report LR253. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1969.
3. C.E. Wallace et al. TRANSYT-7F User's Manual. FHWA, U.S. Department of Transportation, Feb. 1983.
4. S.J. Kahng and A.D. May. Energy and Emissions Consequences of Improved Traffic Signal Systems. Research Report UCB-ITS-RR-81-2. Institute of Transportation Studies, University of California, Berkeley, 1981.
5. Fuel Efficient Traffic Signal Operation and Evaluation, Volume III: Garden Grove Demonstration Project Report. California Energy Resources Conservation and Development Commission, Sacramento, April 1982.
6. E.A. Deakin, A. Skabardonis, and A.D. May. The Fuel-Efficient Traffic Signal Management Program: Evaluation of the First-Year Activities. Research Report UCB-ITS-RR-84-12. Institute of Transportation Studies, University of California, Berkeley, Oct. 1984.
7. E.A. Deakin and A. Skabardonis. The Fuel Efficient Traffic Signal Management Program: Evaluation of the Second and Third Funding Cycles. Research Report UCB-ITS-RR-85-14. Institute of Transportation Studies, University of California, Berkeley, Oct. 1985.
8. A Manual on User Benefit Analysis of Highway and Bus Transit Improvements. AASHTO, Washington, D.C., 1977.
9. A. Skabardonis and E.A. Deakin. Guidelines for Conducting Before and After Studies. California Energy Resources Conservation and Development Commission, Sacramento, Sept. 1983.
10. E.A. Deakin, A. Skabardonis, and C.E. Monsen. Market Potential for the Fuel-Efficient Traffic Signal Management Program. Working Paper UCB-ITS-WP-85-6. Institute of Transportation Studies, University of California, Berkeley, June 1985.
11. F.A. Wagner. Energy Impacts of Urban Transportation Improvements. Institute of Transportation Engineers, Washington, D.C., Aug. 1980.
12. E.A. Deakin and A. Skabardonis. Assessing the Traffic Impacts of Transportation and Land Development Scenarios. Transportation Quarterly, Vol. 39, No. 4, Oct. 1985.

The contents of this paper reflect the views of the authors and do not necessarily reflect the views or policies of the California Energy Resources Conservation and Development Commission or the California Department of Transportation.

Publication of this paper sponsored by Committee on Transportation System Management.

Transportation System Management in Connecticut: Attitudes and Actions

HERBERT S. LEVINSON and KONSTANTINOS G. ZOGRAFOS

ABSTRACT

The status of transportation system management (TSM) in Connecticut is given. The attitudes and actions of 13 regional planning agencies and 9 city traffic agencies are identified as obtained from a questionnaire survey and follow-up interviews conducted from 1983 to 1985. Both types of agencies perceived TSM as mainly traffic engineering, and traffic engineering improvements dominated the list of projects implemented. These agencies took a pragmatic approach to TSM, in which selling improvements is more important than studying them, and they cited examples of application as an important need. A continuing effort to broaden the scope of TSM and to emphasize its coordinative and complementary aspects is also stressed.

Transportation System Management (TSM) is in transition today. Once considered a planning process, it is increasingly viewed as an action program. The focus is on identifying problems and finding suitable solutions. Action rather than study is the goal of many agencies (1).

Much has been written on the process-related aspects of TSM, measures of effectiveness, and methods of evaluation. But relatively little information has been made available in recent years on how specific agencies perceive TSM and, in turn, formulate and implement improvement programs.

In response to this need, Connecticut regional planning agencies (RPAs) and city traffic and transportation departments (CTDs) were queried about their TSM activities. The salient findings are described here. They are based on a questionnaire survey and follow-up interviews conducted from 1983 to 1985 with 13 regional planning agencies and 9 city traffic agencies. The attitudes and actions of these agencies are identified, and how they influence decisions concerning specific project implementation is discussed. The status of TSM in Connecticut's communities as of mid-1985 is summarized.

SURVEY DESIGN AND SCOPE

A questionnaire was distributed to 22 planning and operating agencies to obtain their attitudes, perceptions, and practices regarding the application of TSM throughout the state. Some 14 questionnaires were returned, a 64 percent response rate. The distribution by type of agency and percentage of response are as follows:

	RPAs	CTDs	Total
Questionnaires distributed	13	9	22
Questionnaires returned	9	5	14
Percentage of response	69	56	64

Transportation Institute and Civil Engineering Department, University of Connecticut, Storrs, Conn. 06268. Current affiliation: H.S. Levinson, Polytechnic University of New York, 333 Jay Street, Brooklyn, N.Y. 11201. K.G. Zografos, Civil and Architectural Engineering Department, University of Miami, Coral Gables, Fla. 33124.

The completed questionnaires covered the major population and employment centers in Connecticut (see Figure 1). They included responses from city traffic engineers in Hartford, West Hartford, New Haven, Norwalk, and Stamford.

Questionnaire Content

The questionnaire was designed to record the views of local officials about TSM actions, to identify their problems and accomplishments, and to determine their analysis needs. It was structured to permit an evaluation of the TSM programs surveyed (2).

Nine major topics were included:

- Agency's characteristics (Question 1)
- Agency's role in the TSM process (Question 2)
- Agency's perception of TSM (Question 3)
- TSM projects suggested (Question 4)
- Agency's goals related to TSM (Question 5)
- Implemented TSM projects (Questions 6 and 7)
- Unimplemented TSM projects (Question 8)
- Ways to improve TSM planning and implementation in local communities (Question 9)
- Analysis needs (Question 10)

Responsibilities and Roles

The RPAs serve as the metropolitan planning organizations (MPOs). These agencies, by mandate, develop various transportation improvement programs and are involved in coordination of transportation planning and TSM activities. The CTDs, in contrast, are line agencies with direct operating and implementation responsibilities. These responsibilities vary among specific agencies. In Stamford and New Haven they include traffic, parking, and transportation planning for the local transit district.

The responsibilities and roles reported by the 14 agencies that responded are shown in Table 1. Planning is the primary role of all RPAs in the TSM process. Besides planning, five RPAs have funding responsibilities through the transportation improvement plan (TIP) process, three have implementation duties, and two report involvement in the review

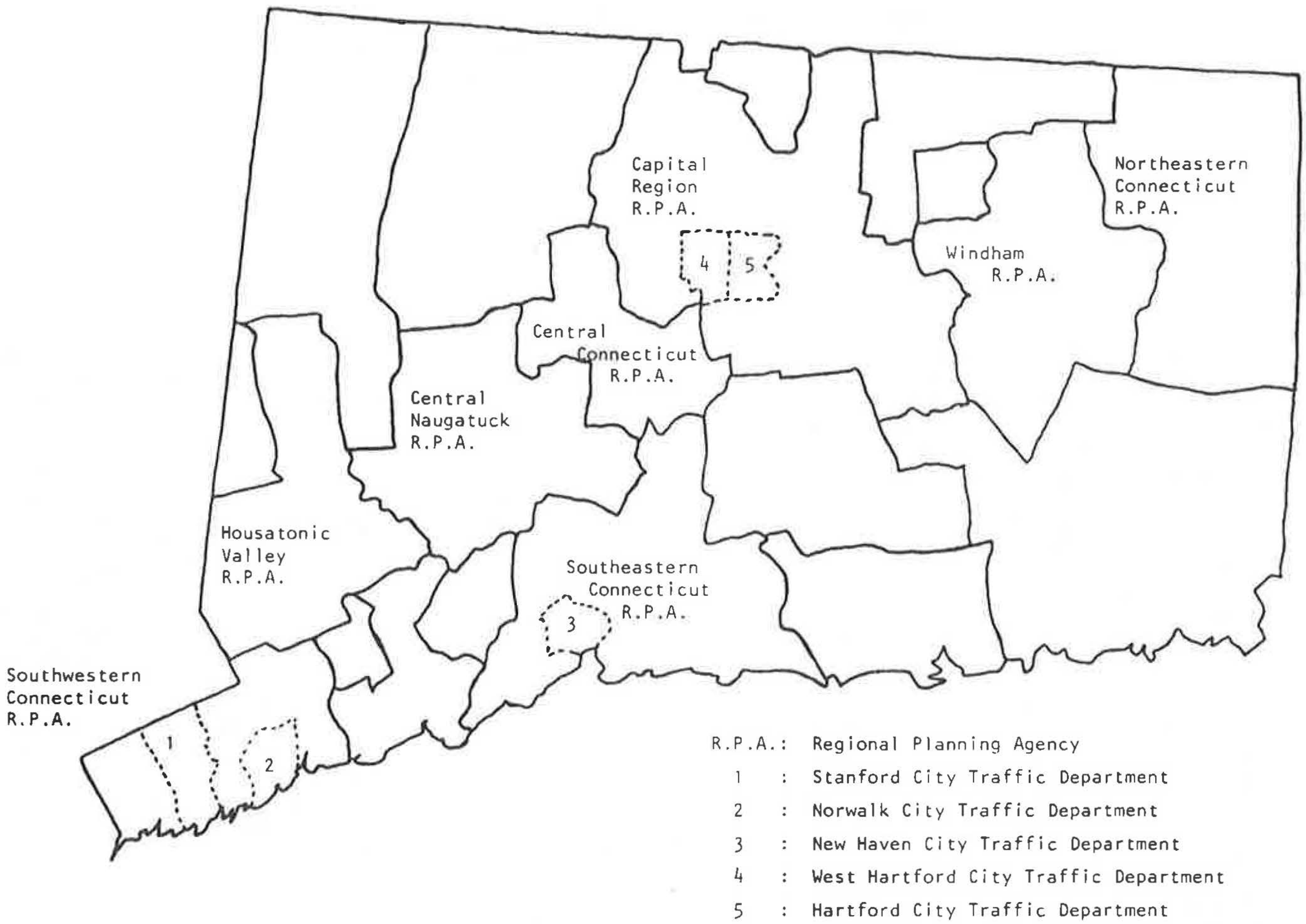

FIGURE 1 RPAs and CTDs surveyed.

TABLE 1 Responsibility and Role of Respondents (Questions 1 and 2)

	RPA Respondent No.									CTD Respondent No.					
Item	1	2	3	4	5	6	7	8	9	1	2	3	4	5	Total
Primary responsibility															
Planning	X	X	X	X	X	X	X	X	X	–	–	–	–	–	9
Operations	–	–	–	–	–	–	–	–	–	X	X	X	X	X	5
Agency's role in TSM															
Planning	X	X	X	X	X	X	X	X	X	X	X	X	X	X	14
Implementation	–	–	–	X	–	X	X	–	–	X	X	X	X	X	8
Review	X	–	–	–	–	X	–	–	–	X	–	X	–	–	4
Funding	X	X	X	–	–	X	X	–	–	X	–	X	–	–	7

Note: Total no. of agencies responding, 14; X = positive response.

process. Other roles reported by specific RPAs were as follows:

- Lobby for funding
- Trigger project implementation through TIP
- Occasional timely political intervention or advocacy

All five CTDs recognized both TSM planning and implementation as their primary roles. Two also reported funding and reviewing responsibilities.

QUESTIONNAIRE ANALYSIS

The 14 survey questionnaires returned were analyzed separately for RPAs and CTDs. Questions involving ranking of preferences (3, 4, 5, 9, and 10) were analyzed in two steps. First, descriptive statistics (means, medians, and frequencies) were computed to identify general patterns pertaining to perceptions, practices, and preferences. Second, statistical tests were used to determine the significant differences among agencies relative to their most important choice. In addition, attitudes and actions of specific agencies were identified.

Perceptions of TSM

Six alternative perceptions of TSM were presented to participants, who were asked to rank them on a scale from 1 to 6, where 1 corresponds to the most important action or perception and 6 to the least important. Table 2 summarizes the median and mean scores of this ranking for RPAs and CTDs.

TABLE 2 Perceptions of TSM: Mean and Median Ranks (Question 3)

	RPAs		CTDs		All Respondents	
Perception	Mean	Median	Mean	Median	Mean	Median
Traffic engineering	1.6	1	1.3	1	1.5	1
Transit improvements	3.3	3	3.0	3	3.2	3
Priority bus or HOV use of streets	5.2	5.5	4.0	3.5	4.7	5.0
Parking	4.2	4.5	3.2	3.0	3.8	4.0
Limiting car use	4.0	4.0	4.5	4.5	4.2	4.5
Coordination of actions	2.4	2.5	3.8	4.0	2.8	3.0

Note: On a scale of 1 to 6, 1 was most important and 6 was least important.

Both groups of respondents perceived traffic engineering as the most important action. RPAs viewed coordination as next in importance followed by transit improvements. CTDs, however, ranked transit improvements and parking measures higher than coordination. High-occupancy-vehicle lanes and car use restraints were considered to be the least important (or least relevant) TSM actions. Activities considered part of TSM but ranked low in importance also included goods movement and incorporating traffic criteria and standards into the local zoning ordinances.

General perceptions of TSM reported by specific agencies were as follows:

- Cost-effective system improvements.
- Best use of existing facilities. Our emphasis is on streets, because of low development density and public interest.
- More efficient use of the transportation system.
- Identification of the most appropriate and lowest-cost solution.
- Mainly traffic engineering--then transit, parking, and coordination.

Projects Selected

Five general types of TSM projects were ranked by survey participants in order of importance: traffic engineering, transit, ridesharing, parking, and work schedule changes. The median and mean scores of this ranking, classified by the type of the agency, are given in Table 3.

Traffic engineering projects predominated among both RPAs and CTDs. This is consistent with the low population and employment densities throughout most parts of the state. Except for downtown Hartford, employment is less than 25,000 in other city centers.

Transit projects were ranked second by both types of agencies and parking projects third.

Project Goals

Six general categories of goals were ranked in order of importance: reduce congestion, improve air quality, conserve energy, expand mobility, reduce operating costs, and encourage development. The ranking was on a scale from 1 to 6 where 1 corresponds to the most important goal and 6 to the least important goal. The median and the mean scores of this ranking are given in Table 4.

The most important project goal of all agencies was to reduce congestion--the underlying rationale for most traffic improvements. The Southwestern Regional Planning Agency, for example, indicated relative to improving Route 7 that "of prime importance was reduced congestion and improved safety."

Expanded mobility was ranked second by both types of agencies. RPAs ranked reduced operating cost third. Goals such as improving air quality, conserving energy, and encouraging land development received the lowest ranking from both RPAs and CTDs.

There was, however, considerable variation in the rankings among agencies. This reflects (a) the site-specific nature of problems and the projects designed to alleviate them, (b) the type of operating environment, and (c) community attitudes and perceptions of need and institutional arrangements.

Implemented Projects

The types of projects actually implemented covered a somewhat narrower spectrum than the projects that were suggested. Once again, traffic engineering improvements dominated. In this sense, they were compatible with the Connecticut urban and suburban environment.

Implemented traffic engineering improvements included

- Routes 58 and 35 intersection improvement, Fairfield;
- Route 7 TSM improvements, Norwalk;
- Widening of Trumbull Street exit from I-91 to provide an additional lane, New Haven;
- Rush-hour parking restrictions along arterial streets, Hartford;
- Bedford summer one-way system, Stamford;
- Traffic signal removal program, New Haven;
- Elimination of exclusive pedestrian phases, Stamford; and
- Traffic signal upgrading, West Hartford.

Parking improvements implemented include

TABLE 3 Types of Projects Suggested: Mean and Median Ranks (Question 4)

	RPAs		CTDs		All Respondents	
Project Type	Mean	Median	Mean	Median	Mean	Median
Traffic engineering	1.4	1	1.0	1	1.3	1
Transit	2.2	2	2.3	2	2.2	2
Parking	2.8	3	2.8	3	2.8	3
Ridesharing	3.0	3	4.0	4	3.2	4
Work schedule changes	4.0	5	5.0	5	4.2	5

Note: On a scale of 1 to 6, 1 was most important and 6 was least important.

TABLE 4 Agency's Goals: Mean and Median Ranks (Question 5)

	RPAs		CTDs		All Respondents	
Goal	Mean	Median	Mean	Median	Mean	Median
Reduce congestion	2.1	1.5	1.5	1.0	1.9	1.0
Improve air quality	4.3	5.0	4.3	4.0	4.3	5.0
Conserve energy	4.1	4.0	3.7	4.0	4.2	4.0
Expand mobility	2.7	2.5	1.7	2.0	2.3	2.0
Reduce operating costs	2.9	3.0	4.0	4.0	2.9	4.0
Encourage development	4.0	4.0	4.7	6.0	4.2	4.0

Note: On a scale of 1 to 6, 1 was most important and 6 was least important.

- 2,400-space Air Rights garage, New Haven;
- Union Station Transportation Center and garage, New Haven;
- 4,000-space town center garage, Stamford;
- Transportation center and garage, Stamford;
- Parking meter revenue security control system, Norwalk; and
- Route 135-15 park-and-ride lot, Stamford.

Transit improvements implemented include

- Transit marketing program, central Connecticut;
- Ridesharing brokerage, northwest Connecticut;
- Regional transit system, Windham;
- Regional ridesharing program, south central Connecticut; and
- Bus shelter programs, Hartford and West Hartford.

It is significant to note that the city traffic engineers in New Haven and Stamford viewed major road and garage construction as TSM. This contrasts with the established concept of TSM that calls for making use of existing facilities rather than building new ones.

The Route 7 TSM projects in Norwalk, according to the RPA, were implemented to correct the "intolerable conditions experienced by the general public along a corridor, and the concern of public officials and private corporations. All demanded that something be done. Support [for improvements] and lobbying led to state action to implement recommendations as well as unified action along the corridor." The problem origin of this action is apparent.

Reported obstacles encountered in implementing projects were

- Communication;
- "Lukewarm" attitude;
- Technical coordination;
- Lack of population density, making it difficult to form vanpools;
- Lack of reliable data;
- Initial town apprehensions on financial liability;
- Red tape; and
- Long design review and approval process.

The agencies did not provide any specific measures of the benefits resulting from the TSM projects implemented. About 40 percent did not judge the resulting benefits, 30 percent cited benefits in general terms only, and 15 percent gave a relative ranking of benefits (e.g., Project A had more benefits than Project B). Only 15 percent identified specific benefits of their projects.

Projects Not Implemented

Relatively little information was received on projects that were proposed but not implemented. Projects that never became a reality generally did not reflect public perceptions of problems or need, receive necessary support of merchants or transit operators, or obtain needed funding. Examples of such projects were

- A regional bicycle plan in central Connecticut (funding not obtained),
- A bus marketing program in the central Naugatuck Valley (bus company not interested), and
- One-way street system in Willimantic (opposed by merchants).

Ways To Improve TSM

Most agencies believed that the TSM process would be improved if better ways of selling and implementing projects were available. Better analysis tools, although desirable, were given the lowest priority by most agencies.

A more detailed ranking of the various ways to improve TSM is summarized in Table 5. RPAs identified a strong need for better interagency cooperation and better funding mechanisms. CTDs desired better examples of successful applications.

Some specific responses were as follows:

- [Obtain] "clear directions from elected officials and administrators to 'do something.'"

TABLE 5 Ways To Improve TSM: Mean and Median Ranks (Question 9b)

	RPAs		CTDs		All Respondents	
Detailed Ranking	Mean	Median	Mean	Median	Mean	Median
Better interagency cooperation	1.9	2.0	3.0	3.0	2.3	2.0
Better funding mechanisms and additional funding	2.2	1.5	3.0	3.0	2.5	2.0
Greater community participation	3.8	3.0	3.3	3.0	3.6	3.0
Better examples of successful applications	3.0	3.0	2.3	1.0	2.8	2.5
Better analysis methods for assessing feasibility and impacts	3.7	4.0	2.3	2.0	3.2	3.0

Note: On a scale of 1 to 6, 1 was most important and 6 was least important.

• [Provide] "attractive easy-to-read summaries for use by political leaders." [There is a need] "to follow through from report to implementation [of] how [best] to deal with Conn. DOT first, then the legislature." Benefit analysis, per se, is not crucial.

• "Bring together parties involved to address a perceived problem. The problem has to be perceived by many to get action. Meetings need to involve public and private officials, then the general public and the press."

• "Consolidation of, or more interchangeability among categorical funding programs."

• "Selling projects is the key."

In sum, agencies were found to be looking for better ways to sell and implement projects. Examples of successful applications elsewhere were viewed as the means by which specific projects might be sold to top officials and the general public.

Primary Analysis Needs

Five "analysis need" items were ranked: examples of application, examples of benefits and costs, case studies of successes and failures elsewhere, "look-up" tables and charts, and improved models. The mean and median scores of the ranking are given in Table 6.

All agencies considered examples of application as the most important tool. Next in order of importance were examples of benefits and costs, for the RPAs, and case studies of successes and failures elsewhere, for the CTDs. Improved models were considered to be the least important analysis need by both planning and operating agencies.

One RPA indicated a need for microcomputer software to facilitate analysis of capacity and signal timing. In general, however, agencies took a pragmatic approach to TSM analysis requirements.

General Remarks

The agency interviews and questionnaires provided important guidelines regarding making TSM a reality. The ingredients needed to accomplish TSM projects, according to one agency, were (a) a problem perceived by many; (b) a call to action by many, including the general public and public officials; (c) development of a plan of action, feasible projects that will provide relief; (d) acceptance of the plan by all parties involved; (e) lobbying support to obtain funding; and (f) pressure on the "implementors" to prevent slippage from the plan of action.

In a related sense, another agency stated that lack of accomplishments reflects (a) absence of clear, continuing, and concerted directions from elected officials and high-level administrators and (b) an inability to define both relevant actors and to jointly gain a consensus and a commitment to followup actions.

Statistical Analysis

A nonparametric test, the Friedman test, was used to determine the statistical significance of the "first choice" ranking for both the RPAs and CTDs. The null hypothesis tested was that there are no significant differences among agencies in their ranking. Where differences are statistically significant (say, at the .05 level), it is clear that agencies agree (or are consistent) in their view of the most important items.

In this test, the responding officials are asked to rank k objects (the alternative TSM choices such as actions, goals, and projects) in order of preference. The objective is to find if the n judges agree with respect to their order of preference and if there are any significant differences among them.

The test statistic Q is computed by the following formula:

$$Q = [12/nk(k + 1)]\ (R_1^2 + R_2^2 + \ldots + R_k^2)\ 3n(k + 1)$$

where

k = number of alternatives included in the question,
n = number of agencies surveyed, and
R = sum of the ranks of the proposed alternatives.

The hypothesis (H_0 that there are no differences among the proposed k alternatives) is rejected if the calculated value of Q exceeds the tabulated value of chi-square (χ^2) with k − 1 degrees of freedom at a chosen significance level. Tables 7 and 8 summarize the results of the Friedman test for the RPAs and CTDs, respectively. The key findings are as follows:

• Both RPAs and CTDs perceive traffic engineering as the most important component of TSM. Similarly, traffic engineering emerges as the most important type of TSM project suggested.

• Both types of agencies perceive examples of application as their primary analysis need.

• Both types of agencies show more variation regarding their improvement goals and the best way to improve TSM. The variabilities reflect, in part, the physical and political environments in which the various agencies operate.

Although the average rankings of the individual items vary between planning and operating departments, the general perceptions of important items appear similar.

TABLE 6 Primary Analysis Needs: Mean and Median Ranks (Question 10)

	RPAs		CTDs		All Respondents	
Primary Analysis Need	Mean	Median	Mean	Median	Mean	Median
Examples of application	2.0	1.5	1.0	1.0	1.7	1.0
Examples of benefits and costs	2.0	2.0	2.7	3.0	2.2	2.0
Case studies of successes and failures elsewhere	3.5	3.0	2.3	2.0	2.8	2.5
"Look-up" tables and charts	3.6	4.0	4.0	4.0	3.1	4.0
Improved models	4.0	5.0	5.0	5.0	3.3	5.0

Note: On a scale of 1 to 5, 1 was most important and 5 was least important.

TABLE 7 Friedman's Test Summary for RPAs Surveyed

Question	Question Title	Q-score	Tabulated $\chi^2_{df,a}$	H_0^a	Most Important Alternative
3	Perceptions of TSM	14.52	$\chi^2_{5,.05} = 11.10$	Rejected	Traffic engineering
4	TSM projects suggested	11.84	$\chi^2_{4,.05} = 9.99$	Rejected	Traffic engineering
5	Agency's goals	6.76	$\chi^2_{5,.05} = 11.10$	Accepted	All statistically equally ranked
9	Ways to improve TSM	7.60	$\chi^2_{4,.05} = 9.49$	Accepted	All statistically equally ranked
10	Primary analysis needs	10.43	$\chi^2_{4,.05} = 9.49$	Rejected	Examples of application

Note: Where Q is greater than the tabulated χ^2-score, the differences are significant and the null hypothesis is rejected; df = degrees of freedom; a = level of significance.

[a]Null hypothesis: There are no significant differences among the proposed alternatives.

TABLE 8 Friedman's Test Summary for CTDs Surveyed

Question	Question Title	Q-score	Tabluated $\chi^2_{df,a}$	H_0^a	Most Important Alternative
3	Perceptions of TSM	10.57	$\chi^2_{5,.10} = 9.24$	Rejected	Traffic engineering
4	TSM projects suggested	37.90	$\chi^2_{4,.05} = 9.49$	Rejected	Traffic engineering
5	Agency's goals	6.14	$\chi^2_{5,.05} = 11.1$	Accepted	All statistically equally ranked
9	Ways to improve TSM	1.87	$\chi^2_{4,.05} = 9.49$	Accepted	All statistically equally ranked
10	Primary analysis needs	11.46	$\chi^2_{4,.05} = 9.49$	Rejected	Examples of application

Note: Where Q is greater than the tabulated χ^2-score, the differences are significant and the null hypothesis is rejected.

[a]Null hypothesis: There are no significant differences among the proposed alternatives.

CONCLUSIONS AND DIRECTIONS

The attitudes and actions of local and regional transportation agencies in Connecticut provide a basis for expanded TSM activities throughout the state, although Connecticut Department of Transportation personnel might have given somewhat differing responses. They also provide guidelines for TSM activities in other urban areas. Key findings and implications follow.

1. RPAs and CTDs perceive TSM mainly as traffic engineering. Some operating agencies do not differentiate between TSM and major new construction.
2. Coordination of complementary actions--a major aspect of TSM--is given relatively little attention, and better "traffic management of land development" is not clearly identified.
3. None of the agencies report an integrated program of TSM actions. "Program packages" of improvements are not indicated. Most projects proposed and implemented were keyed to a specific type of action.
4. Traffic engineering actions are considered the most important type of project, followed by transit and parking improvements. Probably because the state operates the major transit systems and an extensive park-and-ride program, transit route and service changes, carpools, and fringe parking receive comparatively little attention.
5. Projects proposed and implemented reflect the objectives specified by the various agencies. However, specific project goals vary.
6. Projects implemented reflect actual or perceived need. The clearest example is the Route 7 TSM improvement in Norwalk.
7. Benefits of implemented projects are not clearly quantified or assessed. Because of this, cost-effectiveness comparisons of proposals are not possible.
8. Planning and operating agencies have taken a pragmatic approach to TSM. They appear more concerned with selling than studying, with results rather than theory, and with examples of application rather than analytic models. Most agencies clearly indicate that examples of successful applications elsewhere, including benefits and costs, will help them deal with their local officials. This approach is consistent with experiences elsewhere and is a step in the right direction.

These findings suggest a continuing effort to broaden the scope of TSM and to emphasize its coordinative and complementary aspects. Toward these objectives, two actions appear appropriate:

1. A statewide TSM coordinating committee should be established in Connecticut. This committee should meet quarterly to exchange information; improve state, local, and regional coordination; and formulate programs.
2. A fact book on TSM experiences in Connecticut, updated on an annual basis, should be prepared. Such a fact book would provide a logical complement to similar activities on the national level.

These Connecticut-specific guidelines may have transferability to other states. However, in developing statewide TSM program guidance, care must be exercised to reflect the state's size, geography, and urbanization.

ACKNOWLEDGMENTS

This research was sponsored by the Joint Highway Research Advisory Council of the University of Connecticut and the Connecticut Department of Transportation. The help of Charles Dougan and John Drake of the Connecticut Department of Transportation is appreciated.

REFERENCES

1. J. Batchelder, M. Golenberg, J. Howard, and H.S. Levinson. Simplified Procedures for Evaluating Low-Cost TSM Projects: User's Manual. NCHRP Report 263. TRB, National Research Council, Washington, D.C., Oct. 1983.
2. H.S. Levinson and K.G. Zografos. Transportation System Management in Connecticut. Technical Report 82-1. Civil Engineering Department, University of Connecticut, Storrs, 1982.

Publication of this paper sponsored by Committee on Transportation System Management.

Developing Transport Management Improvements for the Tri-State Region: An Overview

HERBERT S. LEVINSON

ABSTRACT

A framework for transportation system management (TSM) in the Tri-State Region of New York City is developed. TSM strategies are classified, it is shown how they relate to various parts of the region, their effectiveness is quantified, and guidelines for emphasizing TSM as an early-action program are suggested. Conditions of applicability are defined for principal types of strategies: each type of improvement is allowed to be used in a reasonable way and a means of screening inappropriate activities is provided. These conditions vary by specified action; employment and population density, dependence on public transport, and many action-specific factors are considered. Measures that involve restraining or reducing motor vehicle use are limited mainly to the Manhattan business district. Measures that involve priorities for buses are applicable in radial corridors within New York City, with selective application in outlying business centers. Ridesharing programs, in contrast, apply best in inner and outer suburbs. Traffic engineering improvements are appropriate throughout the study area. The anticipated effectiveness of selected TSM actions provides a useful planning guide. Although many actions have major impacts over a localized area, making it hard to derive areawide impacts from their application, site-specific impacts can be readily quantified. In TSM emphasis should be placed on immediate action improvements in a multimodal context; TSM should be viewed as an action program rather than a planning process. Improvements should be viewed from a far broader perspective than merely the reduction of VMT, especially when the localized nature of many actions and the conjectural aspects associated with anticipating areawide VMT changes are considered.

Modest growth expectations, limited financial and natural resources, and increased environmental concerns have shifted the focus of regional transportation improvements during the last decade. Transportation system management (TSM) emerged as a means of improving the efficiency of the existing transport system. TSM actions are low-capital operational improvements that emphasize management rather than expansion.

Department of Civil Engineering, Storrs, Conn. 06268. Current affiliation: Polytechnic University of New York, 333 Jay Street, Brooklyn, N.Y. 11201.

A planning framework for TSM in the Tri-State Region of New York City is developed. Actions are identified and classified and it is shown how they relate to various parts of the region. Definitions of measures of effectiveness are given and the anticipated effectiveness of various actions in achieving goals such as improved accessibility, greater safety, fuel conservation, and cleaner air is quantified. Finally, general guidelines for developing and assessing TSM programs are set forth.

This paper is based on a study of TSM conducted in the New York State part of the Tri-State New York City metropolitan area in 1980 (1). At the time of the study most TSM activities involved making shopping lists of improvements, establishing performance measures, and evaluating traffic reduction techniques. In this paper these activities are brought into clearer focus; many of these suggested directions have reinforced TSM research and practice over the last 5 years (2).

OBJECTIVES AND APPROACH

A framework for TSM planning in Greater New York City is set forth. Its analyses are designed to provide answers to questions such as the following:

- Where are automobile-restraint measures most applicable?
- What are the ranges in impacts and benefits associated with various traffic engineering and transit improvements?
- How much time can be saved by a computerized traffic signal system in selected areas of New York City and along Westchester Avenue in White Plains?
- How many people might a paratransit system in Orange or Suffolk County serve? How many would be automobile drivers?
- What are the ranges in benefits associated with bus priority measures?
- What are the impacts of a traffic restraint program on regional or hub-bound vehicle miles of travel (VMT)?
- What are the patronage impacts of expanding bus service in Nassau County?
- How would VMT be affected by an intensive areawide ridesharing program?

To achieve the objectives expressed by these questions, a thorough review was made of the U.S. and Tri-State experience with TSM improvements and measures of effectiveness. Available measurements of before-and-after conditions were obtained, and results of models and traffic simulation studies were summarized. Effectiveness ranges then were developed for actual conditions in the various geographic sectors within the New York metropolitan area.

The general approach suggested is shown in Figure 1.

1. Candidate actions should be screened as they relate to conditions of applicability drawn from evaluations of past experience and professional judgment;
2. Simple, straightforward measures should be used in evaluating effectiveness of improvements;
3. Cost-effectiveness should be determined by

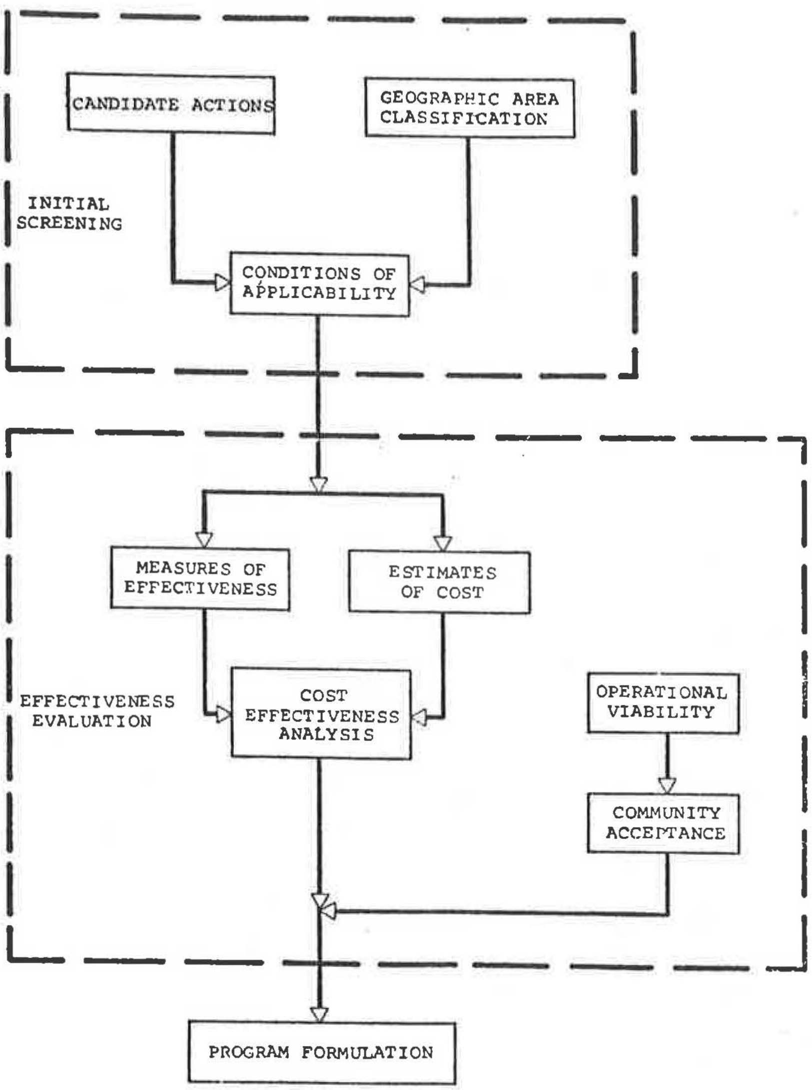

FIGURE 1 TSM approach.

TABLE 1 Comparison of Six TSM Classifications *(3-6)*

RACMs	Federal TSM Regulations	Tri-State TSM Actions	Lockwood and Wagner	JHK/PMM *(6)*	Recommended for Tri-State Region
Inspection and maintenance Vapor recovery Retrofit—heavy duty Cold start Extended idling Improved public transit Long-range transit Exclusive bus and carpool lanes Extended carpool programs On-street parking controls Park-and-ride/fringe lots Pedestrian malls Employer programs Bicycle lanes and storage Staggered work hours Road pricing Traffic flow/improvements Private car restrictions	Efficient use of road space Traffic operations improvements Preferential transit and HOVs Pedestrian and bicycle Parking management and control Work schedules, fare structure, and tolls Reduction of vehicle use Improvement of transit Improved transit management efficiency	Internal transit management efficiency Managing travel demand Improved transit service Better use of road space	Mandatory use controls User information/assistance Pricing Transit operating modification Supply augmentation Demand modification	Traffic operations Traffic signalization Pedestrian and bicycle Roadway assignment Route diversion Parking management Transit operations Transit management Intermodal coordination Commercial vehicles Work schedule Pricing Paratransit	Transportation demand Employer actions Pricing actions Regulation Parking management Other Street system efficiency Freeway operations and control Traffic operations and control Preferential treatment for HOVs and transit Pedestrians and bicycle Commercial vehicles Other Transit service Passenger service Terminal improvements System performance New and expanded service Vehicles and equipment Maintenance Internal transit management efficiency System maintenance Security Cost accounting Other management improvements Vehicle equipment improvements Private automobile Bus transit Commercial vehicles

Note: RACMs = reasonably available control measures to conform with Clean Air Act *(3)*; HOV = high-occupancy vehicle.

comparing the benefits of a given action with the estimated costs to implement, operate, and maintain the improvement; and

4. Operational workability and community acceptance should be considered in formulating programs and establishing priorities.

Classifying Actions

There is no single, generally accepted classification of TSM actions, because each TSM research project generally develops its own taxonomy. In Table 1 several of the more common classifications that have been suggested are compared with the one used for the Tri-State Region. Federal regulations, for example, identify four basic classes: efficient use of road space, reduction of vehicle use, improvement of transit, and improved internal transit management efficiency (4). Lockwood and Wagner proposed a classification consisting of 6 TSM concepts, 24 categories, and numerous action elements (S.C. Lockwood and F.A. Wagner, unpublished data). An FHWA research project has proposed 13 strategies and 59 tactics (6, pp. 5 and 6).

The classification used in the Tri-State study (1) includes five main categories: transportation demand management, street system efficiency, transit service improvements, internal transit management efficiency, and vehicle and equipment improvements. (The vehicle and equipment improvements were included to reflect the many concerns within the Tri-State Region for improving air quality, although they are not normally part of TSM programs.) Parking management actions, such as rate changes, supply constraints, and residential parking permits, form part of demand management, whereas other parking actions relate to improved street system efficiency. However, an alternative classification scheme that treats parking as a separate category has merit and should be used wherever possible.

Defining the Study Area

The 12-county study area contained nearly 12 million people and more than 5 million jobs in 1976 (Table 2). Its counties ranged from densely developed New York (Manhattan) to sparsely settled Dutchess, Orange, and Putnam counties.

Two-thirds of the population and three-fourths of the employment were located within New York City. The greatest concentration of employment was found in Manhattan, where nearly 2.2 million people (40 percent of the area's total) worked. Population density ranged from 62,000 persons/mi^2 in Manhattan to less than 500 persons/mi^2 in Dutchess, Orange, and Putnam counties.

The unusually wide range in population and employment densities coupled with major transportation barriers influenced both travel patterns and the opportunities to effectively manage the transport system. Accordingly, the region was divided into subareas based on employment and population density, topography, rail and road patterns, and political jurisdictions. The following classification scheme, summarized in Table 3, was used to group and apply various TSM actions:

1. Each of the 12 counties formed a basic unit. Counties were further grouped according to employment and population density as follows:
   a. Midtown Manhattan (central business district);

TABLE 2 Population and Employment, New York Region, 1976

Area Counties	Population (000s)	Density (persons/mi^2)	Employment (000s)	Housing (000s)
New York City				
Bronx	1,343	33,061	220	479
Kings (Brooklyn)	2,398	34,403	490	880
New York (Manhattan)	1,417	62,132	2,213	719
Queens	1,968	18,182	483	713
Richmond (Staten Island)	328	5,606	50	108
Subtotal	7,454	24,964	3,456	2,899
Outside New York City				
Dutchess	235	288	94	70
Nassau	1,397	4,856	567	418
Orange	248	290	83	84
Putnam	71	300	14	23
Rockland	254	1,427	81	75
Suffolk	1,279	1,349	363	386
Westchester	878	1,985	357	303
Subtotal	4,362	–	1,559	1,368
Total	11,816	–	5,015	4,267

Source: Tri-State Regional Planning Commission.

TABLE 3 Geographic Classification Scheme for TSM Actions

	TSM Subarea Classification			
Geographic Area	Major Center	Radial Transportation Corridor	Circumferential Travel Corridor	Areawide
Midtown Manhattan (CBD)	x	–	–	–
Manhattan	x	–	–	x
Brooklyn, Bronx, Queens	x	x	x	x
Richmond	x	x	–	x
Inner suburbs (Nassau, Westchester)	x	x	x	x
Outer suburbs (Suffolk, Putnam, Dutchess, Rockland, Orange)	x	x	x	x
Major water crossings	–	x	x	–
Special activity centers	x	–	–	–

b. Manhattan;
c. New York City, Bronx, and Brooklyn-Queens;
d. New York City and Richmond (Staten Island);
e. Inner suburbs (Nassau and Westchester counties); and
f. Outer suburbs (Suffolk, Putnam, Dutchess, Rockland, and Orange counties).

2. Within each county, special subdivisions include

a. Major centers,
b. Radial transportation corridors,
c. Circumferential travel corridors, and
d. Areawide considerations.

3. Major water crossings and special activity centers (e.g., Shea Stadium, Jones Beach) formed two additional groups.

Applying the Conditions

Some TSM actions can be applied throughout the area. Others are limited to specific areas. Therefore, it is necessary to derive criteria that would encourage meaningful applications of TSM actions.

Accordingly, generalized conditions of applicability or planning guidelines were developed by drawing on past experience, a literature review, and professional judgment. They enable each TSM action to be used in a reasonable and effective way. Some are obvious, such as a high degree of transit dependence and availability as a prerequisite for automobile restraint measures or the need for suitable parallel streets before a pedestrian mall is built.

Some may be formulated quantitatively, such as the number of buses per hour that should operate on a street to warrant a bus-only lane. Others must be expressed qualitatively or descriptively, for example, functionally obsolete or poorly located garages or inadequate driver comfort facilities at the end of a bus line. Two basic types of guidelines were established:

1. Land use considerations: type and density of development, such as central area employment, the number of employees required before ridesharing programs can be considered, or the nature of adjacent building frontage or land use; and
2. Transportation considerations: degree of transit use, extent of congestion, number of buses on given routes, or volume-to-capacity ratios.

In combination, these factors produced guidelines for reasonably cost-effective application of various TSM actions. Bus priority lanes on freeways, for example, require certain combinations of freeway design, traffic congestion, traffic flow patterns, and bus use. Actions such as staggered work hours and carpool programs work best when large employers are involved. Automobile restraint measures (or disincentives) require high employment density, high transit use, and extensive street congestion.

Figure 2 (7) shows how various TSM actions relate to population and employment densities within the Tri-State Region. In Table 4, in turn, principal land use and transportation requirements for 20 selected TSM actions are summarized and it is shown where each would best apply within the study area.

These relationships generally are transferable to other U.S. urban areas. In a real sense, they show what works where, enabling inappropriate actions to be quickly screened from the TSM planning process.

1. Some strategies--such as traffic engineering improvements and transit service coordination--apply throughout the study area.
2. Measures that require restraining or reducing the number of automobiles or reducing motor vehicle use (e.g., pricing, automobile-free zones) are mainly limited to the Manhattan business district. The underlying requirements include availability of express transit services, existing high dependence on public transport, high development and employment densities, limited street and parking capacity, inability to expand street capacity, and air-quality problems.

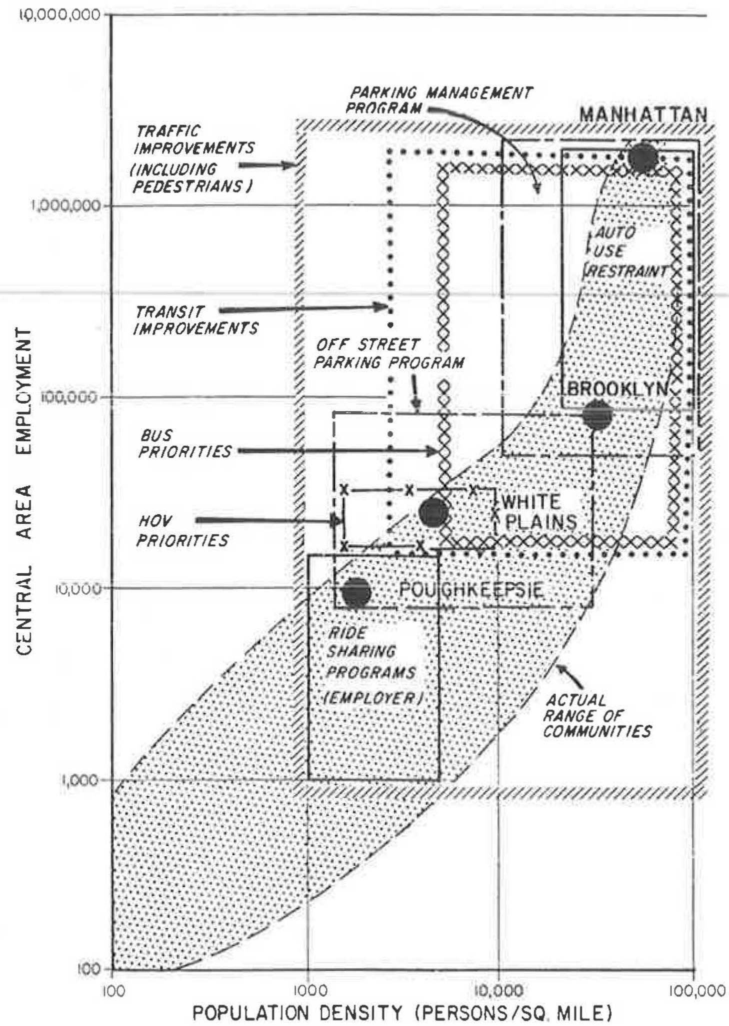

FIGURE 2 Generalized applicability of TSM strategies.

3. Bus priority measures are mainly applicable in New York City where high bus flows are found on arterial streets and express highways. There are also selective applications in inner suburban business districts.

4. Ridesharing or carpool incentives [e.g., high-occupancy-vehicle (HOV) priority lanes and car-pool programs] are most applicable in surburban areas where bus volumes and ridership are limited and where cars are the principal mode for the journey to work.

5. The types of parking improvements vary among areas. Parking restraint is applicable in Manhattan, whereas parking expansion is appropriate in suburban centers, such as White Plains and Poughkeepsie. Park-and-ride improvements are most applicable in suburban areas along regional rail lines and express highways.

Building on this framework, potential TSM measures for midtown and lower Manhattan are identified as follows:

- Staggered work hours
- Bridge and tunnel tolls
- Automobile-free zones
- Automobile-use restrictions
- Stabilized or reduced parking supply
- Limited on-street parking
- Enforced parking regulations
- General traffic engineering improvements
- Upgraded traffic signals
- Express streets
- Bus-taxi streets
- Bus lanes
- Pedestrian malls
- Sky-walk system or concourse system
- Goods: curb loading zones
- Truck route systems
- Taxi cruising regulations
- Increased transit service frequency
- Improved access to stations
- Improved subway security

Those for the rest of New York City, the inner suburbs, and the outer suburbs are shown in Tables 5-7. Measures are shown for major centers, radial transportation corridors, crosstown corridors, and areawide applications within each geographic area.

It is significant that New York City has implemented several actions that are consistent with those suggested in Tables 5-7. Since 1980 the city has put into effect an extensive system of bus lanes in midtown and lower Manhattan, established "red zones" along these bus lanes in which there are $100 parking fines, intensified its towing program, and developed the 49th to 50th Street transit-taxiways. An outbound lane has been added to the Queens Midtown Tunnel during the p.m. rush period by preempting one of the two inbound lanes and limiting inbound traffic

TABLE 4 Generalized Applications of Selected TSM Actions, Tri-State Area

	Principal Considerations		
Action	Land Use and Environment	Transportation	Geographic Area Application
Demand Management			
Staggered work hours	Large employment concentrations	High transit use; overcrowded transit lines	Manhattan CBD
Ridesharing	Large employment concentrations; reduce VMT to improve air quality	Low transit use	Major employment area outside Manhattan CBD
Bridge and tunnel tolls	Existing tolls; major employment concentrations	High peaking congestion; alternative transit service available	Hudson River crossings, also selected crossings of other bodies of water
Area licenses	Large employment concentrations; need to improve air quality	Most trips to area by transit; street congestion; bypass routes available for through traffic	Manhattan CBD
Automobile-free or restricted zones	Major employment and pedestrian concentrations; need to reduce VMT to improve air quality	High transit use	Manhattan CBD
Parking supply constraints	Need to reduce VMT to improve air quality	High transit use; congestion; street capacity constraints	Manhattan CBD
Residential parking permits	Inadequate off-street parking space; high residential density	–	Residential areas in Manhattan, Bronx, Brooklyn, and Queens
Street Use Efficiency			
General traffic improvements	–	Street capacity deficiencies; congestion points	All areas; specific improvements will vary among areas
One-way toll collection	–	Congestion at toll plaza (inadequate reservoir); "escape" routes difficult	Selected East River toll crossings
Freeway ramp controls	–	Freeway congestion; alternative routes available (no entering buses)	Freeways in New York City and inner suburbs
Priority freeway entry for buses	–	Congestion on freeway or ramps; specified number of buses using ramp	Radial freeways, New York City
Park-and-ride lots	Available lane; large employment concentration in CBD; generally, low residential densities	Limited transit in tributary area; radial road capacity constraints; available express transit; minimum competition to established transit system	Principal corridors converging on Manhattan, predominantly in inner suburbs
Priority freeway entry (HOV)	–	Congestion on freeway or ramps; low transit use in corridor	Freeways in inner suburban areas
Bus lanes			
Freeways (bus only or contraflow)	–	Congestion on freeway; specified number of buses; suitable geometry	Radial freeways, New York City
City streets	–	Street congestion; specified number of buses	CBDs in Manhattan, Bronx, Queens, and Brooklyn; major business districts in inner suburbs; arterial streets in New York City
Pedestrian malls (or bus-pedestrian malls)	Pedestrian concentrations; retail frontage	Ability to provide essential services and bypass routes	Central and outlying business districts (no bus malls in outer suburban centers)
Curb loading zones for trucks	Commercial frontage	Curb lanes blocked by parked cars	Business districts; arterial streets in commercial areas of city and some inner suburbs
Transit Service			
Additional express service	Major markets along outlying parts of transit lines	Imbalances between service provided and ridership; track availability; "transportation poor" areas	Bronx subway; Queens, Richmond, Brooklyn, express bus
Service expansion	Areas with growing populations or without transit service	–	Outer Queens and Richmond, inner and outer suburbs
Service coordination	–	Bus-rail services to same or complementary areas	Bronx, Brooklyn, Queens, Richmond, Westchester, Nassau, Suffolk
Paratransit	–	No transit or limited transit in corridor	Inner and outer suburbs

flow. A series of traffic restraint measures on gateways to Manhattan and within the borough is being considered to comply with air-quality standards.

Selecting Measures of Effectiveness

TSM actions should be designed to carry more people in fewer vehicles through an enhanced urban environment and should reinforce developmental goals where possible. Measures of effectiveness provide a means by which various TSM actions can be evaluated within this context. These measures normally reflect the increased efficiency and productivity of the transport system, which, in turn, leads to air-quality and energy impacts. A second type, economic intermeasures, assesses cost-effectiveness, that is, the attainment per dollar or implementation cost (i.e., cost per VMT reduced). A third type includes management-related fiscal measures, such as transit operating costs. Finally, project evaluations should consider qualitative factors, such as general community response or acceptance.

Figure 3 shows how these groups of measures can be used to assess project feasibility, and Figure 4 shows their application in assessing the benefits and impacts of a carpooling program.

Specific measures of effectiveness were derived from a review of available classification schemes. They reflect the specified transportation, economic,

TABLE 5 Potential TSM Actions, New York City: Manhattan, Bronx, Brooklyn, Queens, and Richmond

Major Center[a]	Radial Transportation Corridor	Crosstown Corridor	Areawide
Staggered work hours Bridge tunnel tolls Automobile-free or restricted areas Discourage all-day parking Limit on-street parking Enforce parking regulations Expand parking supply General traffic engineering improvements Turn controls Upgrade signals Bus-taxi streets Curb bus lanes Pedestrian malls Goods: curb loading zones Increase transit service frequency Improve access to stations	Limit on-street parking Enforce parking regulations General traffic engineering improvements Left-turn lanes and prohibitions Upgrade traffic signals Meter freeway ramps Bus bypass of metered freeway ramps (priority entry) Ramp closures Freeway bus lanes (contraflow) Bus "queue bypass" of freeway congestion points Arterial bus lanes (normal flow) Reversible lanes or streets Increase transit service frequency Improve track productivity Expand express service Close low-volume stations Close auxiliary station entrance Coordinate rail-bus service Eliminate duplicate transit service Provide park-and-ride lots (rail, subway, express bus) Expand express bus service	Limit on-street parking Enforce parking regulations General traffic engineering improvements Left-turn lanes and prohibitions Upgrade traffic signals Meter freeway ramps Bus bypass of metered freeway ramps (priority entry) Ramp closures Increase transit service frequency Close auxiliary station entrance Coordinate rail-bus service	Carpooling (outlying special activity centers at LaGuardia and JFK Airports) Residential parking permit program General traffic engineering improvments Truck route systems Bicycle-lane system Bus shelters Improve subway security

[a]Manhattan CBD excluded.

TABLE 6 Potential TSM Actions, Inner Suburbs and Counties

Major Center	Radial Transportation Corridor	Crosstown Corridor	Areawide
Expand parking supply Automobile-free or restricted zones Limit on-street parking Enforce parking regulations General traffic engineering improvements One-way streets Turn controls Upgrade signals Bus-pedestrian streets Curb bus lanes Pedestrian malls Goods Curb loading zones Off-street loading zones Increase transit service frequency	Limit on-street parking in developed areas Left-turn lanes and prohibitions Upgrade traffic signals General traffic engineering improvements Intersection channelization Meter freeway ramps HOV priority entry (HOV bypass-metered freeway ramps) Increase transit service frequency Increase transit coverage Coordinate rail-bus service Provide park-and-ride lots (rail, express bus) Flyovers at key choke points	Limit on-street parking in developed areas Left-turn lanes and prohibitions Upgrade traffic signals General traffic engineering improvements Intersection channelization Meter freeway ramps HOV priority entry (HOV bypass-metered freeway ramps) Flyovers at key choke points	Carpool programs for major employers General traffic engineering improvements Widen intersection radii along bus routes Bicycle lanes or ways Bus shelters Subscription bus service Paratransit service Safety improvements Correct street offsets Selected street extensions (especially bus routes)

TABLE 7 Potential TSM Actions, Outer Counties

Major Center	Radial Transportation Corridor	Crosstown Corridor	Areawide
Expand parking supply Limit on-street parking Enforce parking regulations General traffic engineering improvements Turn controls Upgrade signals Bus pedestrian streets Pedestrian malls Goods Curb loading zones Off-street loading zones Increase transit service frequency	Limit on-street parking in developed areas General traffic engineering improvements Intersection channelization Left-turn lanes and prohibitions Upgraded traffic signals Coordinate rail-bus service Provide park-and-ride lots (rail, express bus) Increase transit coverage	Limit on-street parking in developed areas General traffic engineering improvements Left-turn lanes and prohibitions Upgrade traffic signals	Carpool programs for major employers General traffic engineering improvements Bus shelters Subscription bus service Paratransit service Safety improvements Correct street offsets Selected street extensions (especially for bus routes)

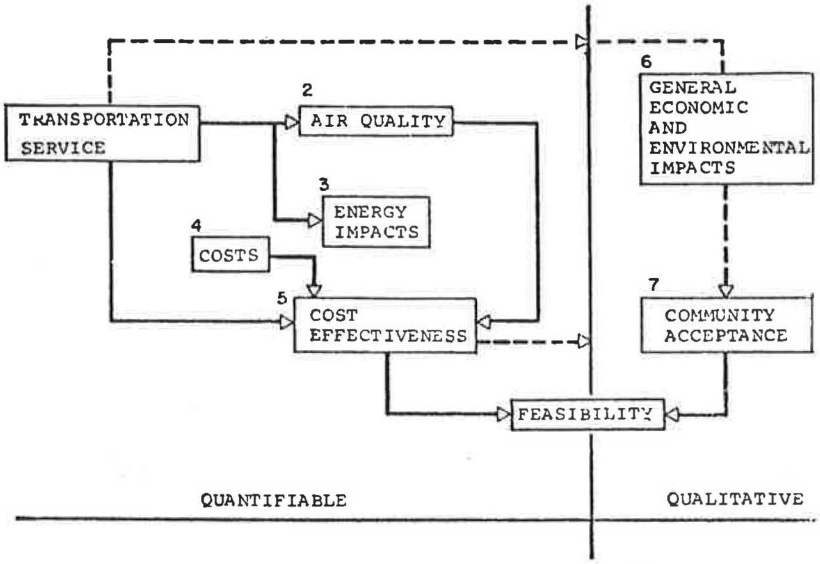

FIGURE 3 Using measures of effectiveness to assess project feasibility.

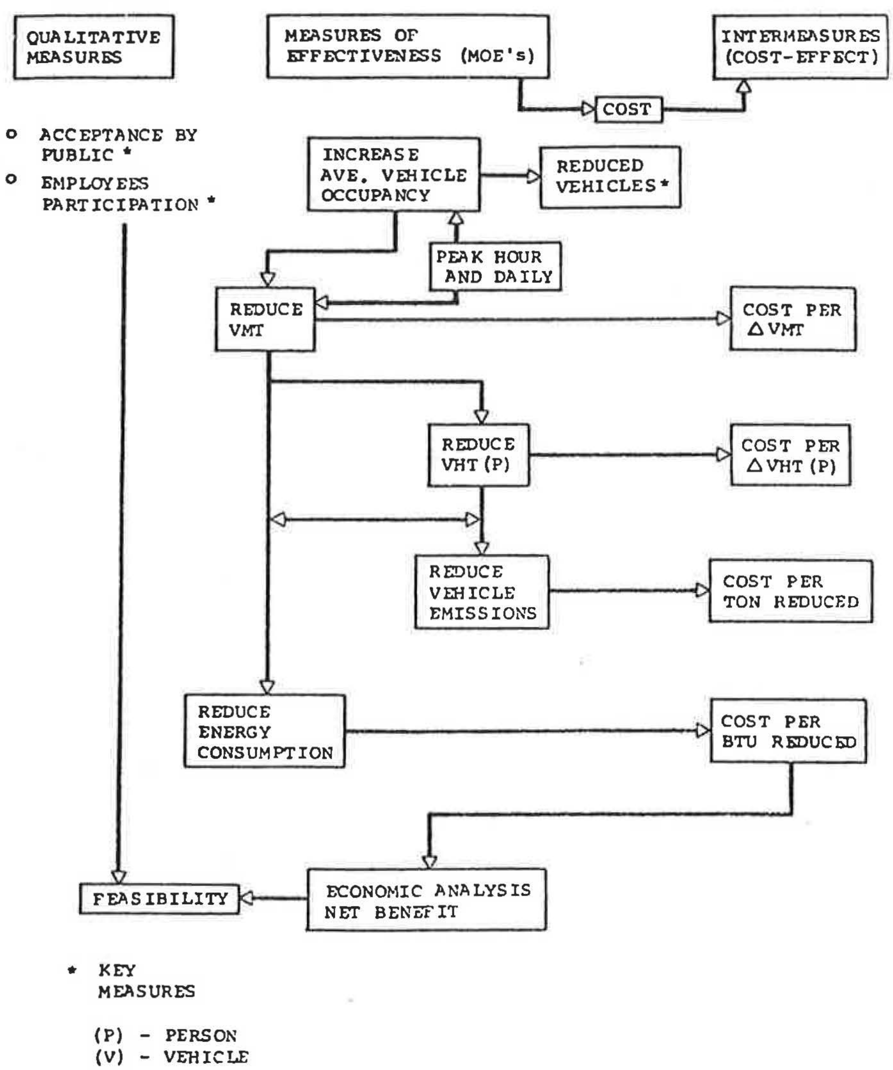

FIGURE 4 Illustrative improvement profile: carpooling programs.

and environmental goals of the region and the capabilities and resources of its planning agencies. Emphasis was placed on selecting a few significant measures that address the salient issues and interrelationships among congestion, mobility, environmental amenity, and costs.

The general measures that are most applicable to TSM strategies include

1. Travel time (minutes per mile, vehicle or person hours of delay or travel time, or average speed),
2. Capacity (persons or vehicles per hour),
3. Safety (number of accidents or accidents per unit of travel),
4. VMT,
5. Average vehicle occupancy (persons per vehicle),
6. Transit ridership,
7. Air quality (tons of carbon monoxide or hydrocarbons emitted), and
8. Energy (BTUs per person or vehicle mile).

The first six measures are basic in that they require data collection or direct estimation. The last two are derived, because they depend on vehicle miles and vehicle hours of travel.

Capital, operating, and maintenance costs also should be considered, both individually and how they relate to changes in system performance, such as annual cost per person-minute saved of VMT reduced. Qualitative factors should complement these parameters in assessing improvement effectiveness.

The preceding measures are easily understood, readily quantified, amenable to statistical analysis, and generally applicable. However, not all are relevant in every case. For example, average vehicle occupancy is not meaningful where traffic signal timing improvements are considered.

Quantifying Improvement Effectiveness

A review of relevant TSM literature found relatively few consistently quantified measures of effectiveness. Some are well documented for selected actions, and others are quantified on the basis of demand or simulation models. Salient observations are as follows:

- Measures dealing with actual performance of the transportation system--capacity, travel time, accidents, vehicle occupancy, and transit ridership--are normally quantified on the basis of actual case studies of before-and-after conditions.
- Changes in VMT are normally inferred or estimated on the basis of changes in transportation measures (car occupancy or transit riders), related factors (carpools formed), or demand models. Few, if any, changes in VMT resulting from TSM actions have been documented in practice. Thus, at the present time assessments of changes in VMT are largely conjectural, and the results have not been verified.
- Air quality and energy consumption are normally calculated from both travel speeds and VMT.

Identifying Complements and Conflicts

Generalized impacts of TSM actions in the Tri-State Region are shown in Table 8. In a broad context, most TSM actions, properly applied, can be complementary. Pricing actions should constrain peak-hour demand, thereby reducing highway congestion and queueing and simultaneously reinforcing transit and reducing emissions. Expanding off-street parking supply should enable on-street parking to be removed, thereby making curb lanes available for buses, commercial vehicles, cars, or property access.

Except where major additions to the road network or off-street parking supply take place, TSM actions generally will not increase VMT. The reasons are ap-

TABLE 8 Generalized Impacts of TSM Actions

Action	Impact: Improved Mobility	Reduced Travel Times or Congestion	Increased Transit Use	Reduced VMT	Improved Amenity
Demand management					
Staggered work hours		X			
Ridesharing				X	
Bridge and tunnel tolls				X	
Area licensing				X	
Automobile-restricted zones				Localized	X
Parking management					
Supply constraints			X	X	
Residential parking permits	X				X
Park-and-ride lots	X			X	
Parking programs	X				
Street use efficiency					
Traffic improvements	X	X			
One-way toll collection		X			
Freeway ramp controls		X			
Priority freeway entry					
Buses			X		
HOV		X		?	
Bus lanes, freeway	X	X	X		
HOV lanes, freeway		X		?	
Bus priorities, city streets		X[a]	X		
Pedestrian or transit malls		X[a]			X
Curb loading zone for trucks		X			
Transit service					
Additional express service	X	X	X	X	
Service expansion	X		X	X	
Service coordination		X	X		
Paratransit	X				

[a]Transit.

parent: (a) development densities and topography largely influence choice of travel mode, (b) major changes in modal use require substantial changes in transit performance or automobile restraints (beyond that readily attainable), and (c) TSM actions generally are localized rather than areawide in their impacts.

The principal conflicts between various TSM actions are focused and obvious. They commonly arise between expanding central area parking supply and increasing transit ridership and between ridesharing and public transport in high-density areas. Such conflicts can be minimized by careful design of TSM program packages.

SUMMARY

Impacts

The anticipated effectiveness of selected TSM actions in the Tri-State Region is summarized by the following impacts:

1. Person and vehicle capacity:
   a. On-street parking controls, 50 to 100 percent;
   b. General traffic improvements (typical), 10 to 20 percent; and
   c. Express transit service, 0 to 20 percent.
2. Travel-time savings:
   a. Bus malls, 2 to 5 min/mi;
   b. Bus lanes on city streets, 1 to 5 min/mi;
   c. On-street parking controls, 0.24 to 2.4 min/mi;
   d. Traffic signal improvements, 0.4 to 1.6 min/mi;
   e. Bus lanes on freeways, 1.2 min/mi;
   f. General traffic improvements, 10 to 20 percent gain in speed;
   g. Bus lane around major queue, 3 to 5 min;
   h. One-way toll collection, 2 to 3 min per car;
   i. HOV-ramp bypass, 1 to 3 min per vehicle;
   j. Transit service coordination, 0 to 10 min per trip; and
   k. Express transit service, 2 to 5 min per trip.
3. VMT reductions (estimates):
   a. Automobile-free zone, up to 20 percent across screenline;
   b. Parking rate adjustments ($1.00 rate increase in Manhattan), 5 percent in Manhattan;
   c. Bridge tunnel tolls, 2 to 5 percent at affected crossing or crossings;
   d. Parking supply reduction, 15 to 3 percent in Manhattan;
   e. Gasoline tax (+$0.10), 2 percent areawide; and
   f. Areawide $0.50 license surcharge, 0.7 to 1.3 percent in Manhattan.
4. Cost-effectiveness:
   a. Carpools, $20 to $51 per pool;
   b. Traffic signals, $0.02 per vehicle hour of travel reduced;
   c. Staggered work periods, $0.25 per vehicle hour of travel reduced (suburbs);
   d. Ramp metering, $1.00 per vehicle hour of travel reduced; and
   e. Park-and-ride lots, $0.02 to $0.035 per VMT reduced.

These impacts were drawn from national experience from 1978 through 1980 and provide useful planning guides. Significant findings are as follows:

- Many actions have major impacts over a very localized area. It is hard to derive areawide impacts from the application of these actions, although site-specific impacts can be readily quantified.
- Traffic engineering improvements will increase capacity up to 100 percent, with 10 to 20 percent gains common. Travel-time reductions of 20 percent can translate into energy and air-quality benefits.
- Demand management measures can achieve regulations in VMT up to 5 percent at specific locations on the basis of theoretical studies of travel elasticities and carpool formation. An effective ridesharing program, for example, would reduce VMT an estimated 0.2 percent in the suburbs and 0.1 percent in New York City; costs would average about $0.02/VMT reduced and about $20 to $50 per capita.
- Bus lanes will save bus passengers 1 to 5 min/mi, and bus (or carpool) priority entry treatments will save 1 to 3 min per ramp depending on the amount of congestion.
- Transit improvements will increase ridership, but at a rate less than the amount of additional service provided. A 2 percent gain in bus mileage would result in a 1 percent gain in riders--of which about one-half might be former motorists. Express transit extensions could increase corridor capacity up to 20 percent and save passengers 2 to 5 min per trip.

These values, although calibrated for the Tri-State Region, may also apply to other urban areas; some adjustments may be required. They are generally consistent with cost-effectiveness analysis developed for a typical urban area of 1 million population as part of an UMTA-sponsored study. The study found the following cost-effectiveness ranges: ridesharing, 1 to 2 cents/VMT reduced, and traffic signal timing optimization, 2 cents/vehicle-hr reduced (8). In the metropolitan New York context, ridesharing would be less effective because of the high reliance on transit for Manhattan-bound trips. In the Tri-State Region, public transport will be more effective in improving mobility and reducing VMT than is suggested by the 40 to 43 cents/VMT reduced.

Attitude studies conducted in the Tri-State Region reported good public support for transit improvements as a transportation control strategy. Public support was also found to be great for rush-hour automobile bans in downtown areas and for pollution-free vehicles. In contrast, public support was found to be low for various pricing mechanisms--such as new bridge tunnel tolls or an areawide surcharge. This implies that pricing mechanisms, despite their theoretical attractiveness, must be selectively applied.

Status in 1986

The city of New York, faced with the mandates of the Clean Air Act, is evaluating a menu of alternatives that will reduce congestion in concert with improved transit services. The candidate proposals, which are under study, were designed to (a) allow imitation or implementation within a short time; (b) bring about a substantial reduction in vehicle entries into Manhattan, vehicles in motion, or VMT or vehicle hours of travel; (c) avoid future traffic increases; and (d) minimize adverse social and economic impacts (9).

The options under study include

1. Banning passenger cars from sections of Manhattan's central business district,
2. Congestion pricing,
3. Restricting single-occupant cars from entering Manhattan,
4. Restricting entries by license plate,

5. Increasing tolls,
6. Providing more transitways,
7. Restricting vehicles that stay in motion,
8. Reducing subsidies for parking, and
9. Banning trucks.

Changing the Perspective

The analysis of TSM opportunities and impacts in the Tri-State Region provides insights into TSM programs in other urban areas as well. It suggests pragmatic approaches to identifying and assessing TSM measures in a large metropolitan area--approaches that also apply in other metropolitan areas. It calls for translating concepts and analyses into meaningful productive improvements and for viewing TSM as an action program, not merely as a planning process.

This approach contrasts with the one set forth in the vast body of literature that appeared in the late 1970s and early 1980s; this literature dealt with the philosophy of TSM, its role in the planning and policy process, and elaborate analytical models designed to detect small differences in travel behavior. Fortunately, some redirection of TSM activities to achieve more of an action emphasis is already taking place. NCHRP Report 263 describes planning procedures for early action improvements that call for finding problems and then keying solutions to them; this research is being supplemented by case studies and user-oriented information (2).

Accordingly, the following TSM guidelines are suggested:

1. TSM improvements should be oriented toward early action. They should focus on management and operation rather than on construction, planning, or evaluation. Consequently, line operating agencies such as the transportation (traffic) department and transit agency should play a key role in developing and implementing improvements. Emphasis should be placed on immediate action improvements within a multimodal context.

2. Programs should be developed on an appropriate geographic scale, preferably on an annual basis. They should be responsive to a broad range of mobility and nontransportation objectives and constraints.

3. The workability of TSM improvements should not be studied in the abstract. Their ability to fit the real-world environment is important. Thus, site-specific analysis is essential.

4. Measures of effectiveness should be clear and relevant. Data collection and analysis requirements should be consistent with the resources and capabilities of planning and operating agencies. As few measures as possible should be used. Because TSM is improvement based rather than data based, data collection and analyses should be kept in scale with overall program objectives and agency resources.

5. Emphasis should be placed on more attainable goals than merely reducing VMT. The localized nature of many TSM actions and the conjectural aspects of anticipated VMT reductions raise questions regarding inferences derived regarding areawide VMT change. Consequently, TSM actions should be viewed from a far broader context. They should emphasize measurable benefits of improved mobility, increased safety, reduced congestion, and increased transit ridership, which collectively produce corollary gains in air quality and energy consumption. This suggests a shift away from the emphasis on reducing VMT: small-scale reductions in VMT may be illusory and statistically insignificant in view of the day-to-day variations in urban travel and actual measurement errors.

6. Differing goals and objectives may call for differing improvement types or priorities. This may require selective trade-offs or compromises. Actions to improve air quality or enhance the environment, for example, may not be the same as those designed to improve mobility. In practice, care should be exercised in implementing measures that adversely affect mobility.

7. Improvements should be coordinated with land use patterns and mobility needs. Their applicability should be keyed to (a) perceived problems and needs, (b) basic transportation plan objectives, and (c) specific physical transportation and land use conditions. The goal is to implement measures that reflect basic goals and that are reasonable to users and the community in terms of benefits, impacts, and costs.

8. The coordination aspect among TSM actions should be given greater emphasis. The related actions that improve multimodal mobility should be given precedence over those that merely bring together ongoing proposals in an unrelated sense (for example, improving transit service and road access to new park-and-ride facilities).

In sum, TSM programs should be real and attainable. They should contain a set of coordinated actions in which the whole is greater than the sum of the individual parts. They should be reasonable in the minds of the traveling public and the affected community.

ACKNOWLEDGMENTS

The author wishes to acknowledge the help of Al Littwornia, Dave Jordan, and Ken Hains, formerly of the Tri-State Regional Planning Commission, and Kevin Tremble of the National Park Service (then employed by Tri-State). Work was initiated while the author was with Wilbur Smith and Associates.

REFERENCES

1. Measures of Effectiveness of Transportation System Management. Final Report. Wilbur Smith & Associates; Tri-State Regional Planning Commission, New York, 1980.
2. J.H. Batchelder, M. Golenberg, J.A. Howard, and H.S. Levinson. Simplified Procedures for Evaluating Low-Cost TSM Projects: User's Manual. NCHRP Report 263. TRB, National Research Council, Washington, D.C., Oct. 1983.
3. Clean Air Act of 1970 (P.L. 9595), 1970.
4. Transportation Improvement Program. Federal Register, Vol. 40, No. 181, Sept. 17, 1975, p. 42979.
5. Maintaining Mobility, 2nd ed. Tri-State Regional Planning Commission, New York, Nov. 1976.
6. JHK and Associates and Peat, Marwick, Mitchell & Company. Measures of Effectiveness for Multimodal Urban Traffic Management. Working Paper 7. FHWA, U.S. Department of Transportation, Nov. 1977.
7. Classify Strategies by Geographical Area. Technical Memorandum 2. Tri-State Regional Planning Commission, New York, June 1979.
8. F.A. Wagner and K. Gilbert. Transportation System Management: An Assessment of Impacts. UMTA, U.S. Department of Transportation, Nov. 1978.
9. R. Sandler. An Approach to Reducing Vehicle Congestion in New York City: A Report to Mayor Koch. New York City Department of Transportation, Sept. 1986.

Publication of this paper sponsored by Committee on Traffic System Management.

Abridgment

Parking Management Through Wheel Clamping

D. MAHALEL and M. LIVNEH

ABSTRACT

The use of wheel clamping for the enforcement of parking prevention policy is described. From the experience gained in Israel and Europe, this device allows more successful execution of an aggressive enforcement policy with relatively restricted means than does any conventional tactic. Where wheel clamping has been employed, the level of traffic regulation compliance has risen and traffic flow has improved. Because of the strictness of this enforcement means, a selected and gradual use is recommended. At first, it should be intended only for serious parking offenses that cause maximum obstruction. The wheel clamp enables effective enforcement of parking prohibition so that traffic management plans can be implemented that authorities hesitated to implement in the past because of low levels of enforcement.

Parking management is part of the general policy of traffic management, and their goals are similar: to define the operational strategy by which the best use can be made of the existing infrastructure. Parking policy determines the allocation of the limited parking places available, and parking tactics deal with the means of carrying out this policy.

The problems that parking policy deal with are the optimal equilibrium between travel lanes and parking lanes, priority for public transport and restriction of the number of parking places, for whom the parking places are intended (i.e., commuters, long-duration visitors, short-duration visitors), and so on.

The common tactics for realizing parking policy are parking tickets, towing, residential parking permits, parking meters, and park-and-ride systems. Implementation of these and other tactics requires the following systems: police, data processing, collection, judicial, and so forth. The strong demand for parking places, on the one hand, and the small supply, on the other, place on the responsible authority the frequent need to enforce parking prohibitions. In light, however, of the large resources that this action requires (in terms of manpower, machinery, and equipment), enforcement is not carried out with the necessary efficiency. As a result, drivers learn that the penalty probability in the case of illegal parking is not high, and the demand for parking is increased once more.

In Israel, in view of the recognition that the accepted tactics for enforcing street parking prohibitions (tickets and towing) were of limited efficiency, the use of wheel clamps was tested. A wheel clamp is a metal clamp that fits over the wheel and prevents the car from moving. The device was tried in Jerusalem and Tel-Aviv to prevent on-street parking. It has been used in London and Amsterdam for more than a year.

The advantages and disadvantages of wheel clamps are evaluated and the experience that has been gained with this means of parking-prohibition enforcement is described.

Transportation Research Institute, Technion-Israel Institute of Technology, 32000 Haifa, Israel.

AN EVALUATION OF WHEEL CLAMPING

The main advantages of wheel clamping compared with other means of enforcement may be summarized as follows:

1. Option to carry out aggressive enforcement with restricted means,
2. High exposure of others to penalty,
3. Stricter penalty for the driver in terms of time, and
4. Feasibility under any condition.

The primary advantage of clamping for the responsible authority (police or municipality) is the ability to execute an aggressive act of enforcement with relatively restricted means. Whereas a towing team, which generally numbers one or two, plus an accompanying traffic warden or policeman can carry out an average of one to two tows an hour, a similar traffic team can carry out 12 to 15 clampings in that time span. The clamping team, moreover, does not need a tow truck, only a regular van. In addition, the fine-collection arrangement is reduced, because there is no need to send out notices for payment, give penalties in case of nonpayment, and so on. The driver whose vehicle has been clamped has to show up himself in order to release the vehicle, and payment of the fine is a condition for its release.

The high exposure of others to the penalty is a direct result of the fact that the device that clamps the wheel is really obvious and the clamped vehicle remains for a number of hours on the spot where it was caught. During this time, curious onlookers clearly see the penalty, other drivers are deterred from parking illegally, and the impact of the clamp is engraved on the memory more than any other means. In contrast, a towed vehicle is simply taken away and has no impact except to free a spot for the next vehicle to park.

Another effect of clamping is the delay in time to which the affected drivers are subjected. Whereas a parking ticket does not delay the driver, clamping does delay a driver for a relatively longer period even than towing. The driver whose vehicle has been clamped is not only required (as in some towing cases) to come to the police vehicle impoundment area and pay the fine. In addition, this driver must return to the vehicle and wait for the wheel clamp to be released. This process can take time, depending on how well the authority is organized. Apparently, this penalty is more painful than a fine.

Still another advantage to clamping is that it permits a continuous row of vehicles to be penalized without having to ensure maneuvering space for them, as is required in towing. This allows the penalty to be employed in cases where the illegal parking is alongside or near a fire hydrant, crosswalk, or bus stop, where towing may not be possible.

Wheel clamping does have some disadvantages as a tactic. One clear disadvantage compared with towing is that the vehicle clamped continues to occupy the space and may obstruct traffic until it is released. Towing, by contrast, removes the vehicle immediately from its spot so that it does not continue to create an obstruction. From the experience with clamping in Jerusalem and Tel-Aviv, it appears that this disadvantage is not as significant as might have been expected. The reasons are as follows:

1. The level of enforcement before the introduction of clamping was so low that there were, in any case, many obstructions to traffic from illegally parked vehicles. In the worst case, then, clamping only returns the situation to what it was previously.
2. The Israeli experience and also that in London point out that clamping enables an aggressive level of enforcement in the wake of which there is a significant improvement in the traffic flow.
3. It is always possible to combine towing and clamping. Towing can be selectively applied to extreme cases of traffic obstruction.

EXPERIENCE WITH WHEEL CLAMPING

The Jerusalem Experience

In the central business district (CBD) of Jerusalem, there are some 5,500 parking places (legal and illegal), of which 58 percent are on street; some 60 percent of this on-street figure are illegal spots. During peak-period traffic, 65 percent of the spots that are forbidden to parking are occupied by a vehicle. These statistics certainly show the surplus demand for parking places.

The use of wheel clamps in Jerusalem is restricted (1) to main arterials in the CBD, spots and junctions where parking creates serious traffic problems, and reserved parking spots, as for the disabled diplomats, police, and so on.

The experiment started with 5 streets containing 230 potential illegal parking spots and was gradually expanded to a larger number of streets. The number of wheel clampings in the first week of the experiment was about 40, and it declined over time. By the 10th week, clamping was 60 percent of what it had been in the first week, and the number of potential illegal parking spots where this enforcement means was carried out was increased by a factor of 2.47 (or from 230 to 570). During the first week, the number of clampings constituted 18 percent of the number of illegal parking spots, whereas during the 10th week it was only 4.6 percent. The number of streets on which this enforcement was carried out was increased from 5 to 16.

No systematic investigation was made of travel speeds in thoroughfares where the enforcement was undertaken, but the personal impression of city engineers was that following the use of wheel clamps, a great easing took place in the traffic flow. Travel speeds increased, and in areas where there had been traffic jams in the past, the traffic now flowed freely.

The municipality estimated that public response was favorable: some citizens called for expansion of the use of wheel clamping to other areas of the city and there were no violent reactions on the part of drivers.

Some 7 months after the start of wheel clamping, its use had been expanded to 30 streets, which have a total of 1,120 potential illegal parking spots. The daily number of wheel clampings stands at 45, or 4 percent of the number of illegal parking places.

In the opinion of city traffic engineers, the experiment has met with success. Wheel clamping enabled the start of an aggressive policy of parking enforcement with relatively limited means, something that the other enforcement means did not permit.

The Tel-Aviv Experience

In Tel-Aviv, the gap between the demand for parking spots and those available is higher than it is in Jerusalem. This situation has caused an excess of traffic offenses: parking on the sidewalk, at bus stops, on crosswalks, and in vehicle travel lanes. Often, there is double and triple parking.

Because of the parking problem, there was a feeling at City Hall that a massive enforcement had to be carried out with wheel clamps. Some 100 vehicles a day were clamped in the first few weeks. Wheel clamping was performed on a large number of streets and for any parking offense. At the same time, however, the enforcement machinery was not set up to deal with releasing the clamped vehicles, with the result that there was a 6- to 7-hr gap between the time when the driver paid the fine and the time when the vehicle was released. Then, too, cars were clamped in the evening; because the drivers could only pay the fine the next day, the penalty of wheel clamping stretched for up to 20 hr.

Public opposition to this punishment was widespread in Tel-Aviv. There were even incidents of violence involving physical damage to the clamps. A citizens organization was set up expressly to cancel this coercive measure. In the wake of these sharp reactions, the municipality changed its enforcement policy after some 4 weeks. Clamping was limited only to the main traffic arterials, and only for the most severe parking offenses: blocking pedestrians' way on a sidewalk, in an intersection, on a crosswalk, and at a bus stop. In light of the change of policy and despite the large number of clampings (120 per day), the driver population of the city came to terms with the measure, and gradually parking lots in the periphery of the CBD began to fill up. Currently, the city plans an expansion of the use of the wheel clamp, but very gradually and selectively.

The lesson of the Tel-Aviv experience was that the public has to be gradually accustomed to obeying parking prohibitions. A drastic means like wheel clamping, therefore, should be employed selectively. At first, it should be limited only to areas where illegally parked vehicles cause serious disruptions to the traffic flow; then after the public has become accustomed to obeying the strictest parking regulations, it can gradually be accustomed to obeying the less serious ones as well.

Experience in London

In London, wheel clamping has been in use since May 1983 for the following parking offenses: on yellow lines (67 percent of all vehicles clamped), in private residential areas (23 percent), and at meters

(10 percent). Clamping is not intended for dangerously or obstructively parked vehicles.

According to Kimber (2), the main change in Londoners' parking behavior was that motorists stayed on yellow lines for shorter periods than before. Although the number of cases of illegal parking did not change appreciably, the average illegal parking time decreased by 40 percent; as a consequence, the density of parked vehicles decreased by 30 percent.

One of the main advantages of this density change was the reduction in journey times for through traffic. The net reduction associated with parking density reductions on yellow lines was estimated at between 8 and 14 percent. Kimber emphasizes that "these consequences are thought to follow from the greater deterrent effects of clamping compared with vehicle removal, and result probably from the greater conspicuousness of clamps and clamping teams. In contrast, once a vehicle has been removed, nothing visible remains as a deterrent to others."

Use in Amsterdam

According to a short report (3), wheel clamps have been in use to enforce parking regulations in Amsterdam since August 1983. First results were encouraging: the level of noncompliance was reduced from 60 to 20 percent, and long-time overstaying at meters lessened from 30 to 10 percent.

SUMMARY AND DISCUSSION

Wheel clamping is a means of enforcing parking prohibitions that enables carrying out an aggressive policy of enforcement. With relatively restricted means, a stronger impact can be created with this tactic than with any other accepted one (towing, fines, etc.).

The experience of the two largest cities in Israel (Jerusalem and Tel Aviv) points out, however, that this bitter medicine has to be used selectively. At least in the initial stages of its introduction, wheel clamping has to be purposefully directed only at areas where severe traffic obstructions are caused because of the illegal parking of vehicles. Drivers apparently find it easier to come to terms with this particular penalty when they understand the severity of the offense. In cases in which the wheel clamp was used on vehicles that officially were committing an offense but were not actually interfering with traffic, drivers found it difficult to accept the penalty and there was deep bitterness. It is reasonable to assume that after the population of drivers has become accustomed to a high level of enforcement of parking regulations, it will be possible to expand the use of the wheel clamp to other areas.

In contrast to the situation that prevailed before the introduction of wheel clamping, the quantity of offenses following its employment decreased immeasurably. Despite the fact that the vehicle clamped continues to constitute an obstruction until its release, the overall effect is that of a significant improvement in the traffic flow. It should be noted that it is always possible to combine conventional enforcement means, like towing, with wheel clamping; in such a case, the towing could be intended for those places where the traffic offense is especially obstructive.

The wheel clamp is an effective lever for enforcing traffic prohibitions so that traffic management plans that authorities hesitated to implement in the past can be carried out. In Haifa, for example, the police believed that they could not enforce a parking prevention policy with conventional means. Accordingly, when the second author of this paper was Deputy Mayor of Haifa, he formulated a plan to give priority to public transport in the CBD, in which two of the three lanes in each of two main arterials were specified for public transport. Wheel clamping was to be an integral part of the enforcement tactic. Its use would have provided a solution for implementing an aggressive policy of parking prevention. As part of the plan, too, the areas of permitted parking in the CBD were expanded on the basis that these new parking spots did not constitute traffic obstructions.

ACKNOWLEDGMENT

The authors would like to express their thanks to H. Yossef, Chief of Traffic Police Department, Haifa, and to H. Eini, Chief of Parking Department, Jerusalem Municipality, for their valuable assistance.

REFERENCES

1. H. Eini. Enforcement Through Denver Booting (in Hebrew). Traffic and Transportation, No. 7, 1985.
2. R.M. Kimber. The Effects of Wheel Clamping in Central London. TRRL LR 1136. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1984.
3. Traffic Engineering and Control, Vol. 25, No. 6, June 1984.

Publication of this paper sponsored by Committee on Parking and Terminals.