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Transportation System Management—Parking, Enforcement, and Other Issues

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Evaluation of Traffic Management Strategies in Central Business Districts

SAID M. EASA AND ADOLF D. MAY

A network traffic model, Micro-Assignment, has been refined and applied to the central business district (CBD) of San Jose, California. The model is capable of simulating the fine network details and the wide variety of intersection control that normally exist in downtown areas and can be used for assessing the impacts of control plans both on the local network and on the surrounding highway facilities. Model refinements included a procedure for estimation of fuel consumption that is compatible with the characteristics of such dense networks and additional input and output capabilities. The model was calibrated to the conditions of the summer of 1979 by using measured traffic volumes and travel times and was used for evaluating the impacts of selected control plans. Network data and origin-destination (O-D) demand data were established for the 1-h afternoon peak period. A set of O-D demand data that was available for an earlier year was updated for the 1979 conditions, taking into account the various changes in land use activities and natural growth in the CBD area. Three improvement plans proposed by the city were evaluated and included a new highway facility that bypasses the CBD, a transit mall, and a new office-garage building. The impacts of these plans on both the CBD and the surrounding highways were analyzed and evaluated. This application was considered successful because the model was shown to be capable of simulating actual traffic operations effectively and of predicting the impacts of a wide variety of control plans. Furthermore, this application may be viewed as an analytic framework that illustrates in a step-by-step fashion the procedure of data collection, model calibration, and evaluation of control strategies in CBDs. It also points out several common problems that may be encountered in the application of such operational models and suggests possible ways for resolving them.

Traffic system management in dense urban networks, particularly central business districts (CBDs) and residential areas, has received much attention in recent years. In order to prevent or alleviate the traffic problems in these operating environments, a wide variety of control plans has been proposed and implemented in several cities in the United States and abroad. Evaluation of the impacts of the control plans has been one of the important tasks that should be accomplished before a particular plan is implemented. Due to the complexity of network structure and traffic characteristics in these operating environments, however, evaluation of the control plans often requires an analytical technique. Not only should such a technique be capable of modeling the fine network details, it should also provide the analyst with a wide range of measures of effectiveness. In addition, the technique should be easy to understand and use and should facilitate the analysis needs of dense urban networks.

As part of the traffic management research at the Institute of Transportation Studies at Berkeley (1), a project sponsored by the California Department of Transportation (Caltrans) that dealt with dense urban networks (downtown and residential areas) was completed. The primary objective of the project was to provide a model that exhibits the features mentioned earlier and to apply that model to two operating environments. Specifically, the project involved four major tasks, which included a literature review of existing experience and analytical techniques, model selection, refinement of the selected model, and application of the refined model to a CBD and a residential area. These activities are described in detail elsewhere (2-6); a brief description of the major findings is given below.

The process of reviewing existing experience (2) included, along with approximately 400 references, several important aspects. It identified the operational problems often encountered in dense networks and various types of transportation system management (TSM) strategies that have been implemented to solve these problems. In addition, specific measures of effectiveness appropriate for dense networks were established. The study of these aspects was enhanced by the review of about 20 case studies both in the United States and abroad (e.g., 7-10). In parallel, existing analytical techniques for a transportation network system were identified (2) and found to lie in five major categories: planning, optimization, equilibrium, simulation, and operational models. More than 30 models within these categories were analyzed and 6 models in the last category were selected for further evaluation.

The six models were then evaluated (3) based on several theoretical features and by using an arbitrary rating scheme. As a result, two models that exhibited close rating scores were selected for a hands-on application and further evaluation. These were the CONTRAM model developed by Leonard and others (11,12) and the Micro-Assignment model developed by Brown and Scott (13) and further modified by Caltrans (14). The two models were then applied to an existing network and were further evaluated with respect to several features related to their use and ease of modification (4). The evaluation results indicated that selection of CONTRAM or Micro-Assignment depends on the particular consideration of short- and long-term modification to be implemented. On consideration of these results, the Micro-Assignment model was selected for purposes of this project.

The third task was to refine the Micro-Assignment model to increase its operational capabilities (5, 6). Three refinements were implemented: (a) incorporation of a procedure for fuel-consumption estimation, (b) addition of more flexibility in input data manipulation, and (c) modification of the computer output to enhance clarity and completeness of output results. The fuel-consumption procedure, together with the other measures of effectiveness, provided more complete information on the impacts of improvement plans evaluated in this application. The second refinement allows the user to prepare the results for a specific group of links and was particularly useful in the application presented here, where the impacts on city streets and the surrounding major highways were analyzed separately. In the last refinement, the output results are organized in such a way that they are immediately grasped and easily interpreted.

The final task (5) was to apply the refined Micro-Assignment model to a residential area and a CBD. In the residential area, the model was calibrated to actual 1979 conditions, selected control plans were evaluated, and preliminary guidelines for traffic management were developed. Details concerning the application results are given in a companion paper (15). The purpose of this paper is to report the application to the CBD.

THE MODEL

The original version of the Micro-Assignment model developed by Brown and Scott (13) was modified by Caltrans (14) to improve the traffic assignment procedure implemented in the model. As part of this project, the Caltrans version of the model was refined to incorporate a procedure for estimation of fuel consumption and to facilitate flexibility and clarity of the input-output aspects of the computer program. A detailed description of the refined model can be found elsewhere (5,6), and only a brief description of the basic model structure will be given here.

As any operational technique of this type, the model requires two types of input: network data and a set of origin-destination (O-D) demand data. These data are first processed and verified by two separate programs. The verified data are then input to the main program, which performs the traffic-assignment process, and the results can then be summarized and output by a separate program. In addition, the model includes three separate programs for plotting activities.

Network Representation

The Micro-Assignment model employs an offset system of network representation. In this system, nodes are located at midblocks along the approaches to an intersection, and each permissible traffic movement at the intersection is represented by a separate link, as shown in Figure 1. At each midblock, there are two nodes, one on each side of the street, which represent origins or destinations. One of the node pair is assigned an even number and the other node is assigned the successive odd number. This numbering system allows the demand from any of the two nodes to use both directions at the respective street (note that this implies that no median exists on the street). A maximum of three links can emanate from a particular node, but there is no restriction on the number of links that go into a node. This method of representation closely resembles actual network trip loading and has the advantage of prohibiting illogical movements and U-turns.

In some real situations, however, network streets may exhibit specific characteristics that require special treatment (6). Such characteristics may include one-way streets, streets that have a median and prohibit U-turns, and streets that have a median and permit U-turns. The representation of the first two cases is a straightforward exercise, and the last case (although not common in practice) was a characteristic feature of the CBD area studied in this paper and only this case is discussed below.

One way of representing such a configuration is given in Figure 2, which includes a major arterial and two cross streets. The major arterial has a median along the intermediate block and the respective U-turns are permitted at both intersections. In this representation nodes 6 and 16 are used as loading nodes for the trip demand on the respective side of the street. Two dummy links (6-8 and 16-18) are used so that the number of links that emanate from the node does not exceed three. The two links (16-6 and 6-16) are used by the U-turn traffic. Note that the U-turn movement may occur at or before the two major intersections shown in Figure 2 and the length of the U-turn links should be calculated accordingly. In addition, this method of representation implicitly assumes that the left-turn movement (which is associated with the U-turn) is not interfered with by opposing traffic. In cases where there is interference with the left-turn traffic another, more complicated, method of representation can be devised.

Traffic Demand Assignment

The model employs an iterative multipath assignment method that was introduced by Caltrans as part of model validation to the San Jose CBD (14). This method allows the user to assign a given O-D trip demand to a maximum of six paths between the respective origin and destination. The first path is obtained based on free-flow speeds. Delays may be frequently updated (based on assigned traffic volumes) after a specified number of trees, and new travel times calculated. The second path is then obtained based on the travel times that result from the first path, and demands are assigned to the two paths in inverse proportion to their respective travel times. The process continues until convergence is obtained or six paths have been used. Experience with the model has shown that convergence is generally obtained after four paths.

The travel time along a link consists of three components, including the free-flow travel time, the delay accrued at the intersection by a vehicle traveling alone on the link (zero-volume delay), and the delay experienced because of the existence of other vehicles (congestion delay). Further details on the traffic-assignment method and the associated delay calculations can be found elsewhere (5).

Special Features

The Micro-Assignment model exhibits several important features. The model can simulate the operations of a wide variety of intersection controls. These include signalized intersections (and synchronization) and nonsignalized intersections controlled by stop signs (on one or more approaches) or by yield signs. The interactions among the various movements at the intersection are accounted for. Left-turn interference and a lane shared by through and right-turn movements are examples of such interactions. In addition, the model simulates the operations on freeway facilities. Another feature is related to the plotting capabilities. The model incorporates three plotting programs that can be used for plotting the network (including links, nodes, and street names), plotting the minimum time paths, or plotting the predicted link volumes. The network plot may be used to ensure that the network is properly coded and the other two plots are particularly useful in the analysis of results.

Finally, the model provides a wide range of measures of effectiveness, including traffic volume, speed, delay, and fuel consumption. The fuel-consumption procedure was developed as part of this project. The procedure used the fine treatment embodied in the model of such characteristics as acceleration and deceleration, free-flow speed, zero-volume delay, and congestion delay. In addition, the procedure was established for two types of facilities, city streets and freeways, and conceptually lies between the existing aggregate (planning) and disaggregate (simulation) methods of estimation of fuel consumption. The fuel data built in the program are based on Claffey (16) and may be re- placed by the user's input data. A detailed description of the estimation procedure and the built-in data can be found elsewhere (5).

APPLICATION

The refined Micro-Assignment model was applied to an existing CBD in which several control plans were implemented or proposed for implementation. Specifically, the model was calibrated for traffic operating characteristics of the afternoon peak period in summer 1979.

Study Area

The San Jose CBD was selected because it exhibits typical characteristics of downtown areas and be-

Figure 1. Link-node representation of unit traffic cell.

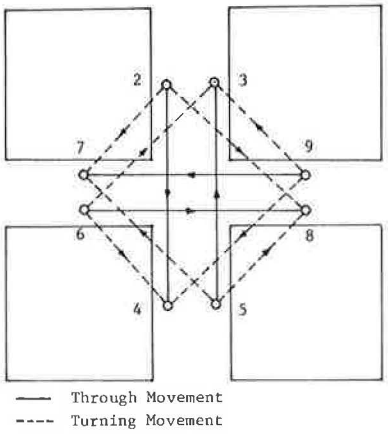
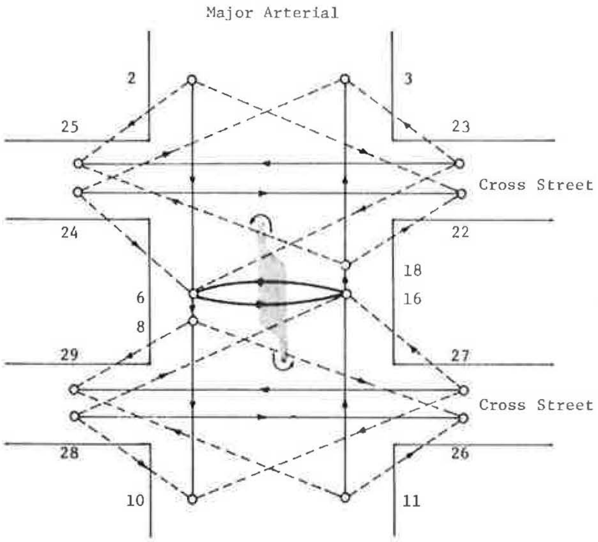


Figure 2. Representation of street with median and permissible U-turns.



cause of the availability of O-D data and the excellent cooperation of the city staff. A map of the study area is shown in Figure 3. The study area is approximately 1.3 miles long and 0.7 mile wide and contains 69 blocks and 75 intersections. Of the intersections, 52 are signalized; the remaining intersections are controlled by stop signs. The area is bound by Julian Street in the north; CA-280 in the south; Santa Teresa, Almaden, Prevost, and Vine Streets in the west; and Fourth Street in the east. Note in Figure 3 that only the westbound direction of CA-280 was included. The eastbound direction was not included because it has only one exit ramp and one entrance ramp from and to the study area and, consequently, it did not provide an alternative route for the CBD traffic. This is unlike the westbound direction, which has two entrance ramps, and traffic may enter the highway at Fourth Street or travel on the city streets and then use the entrance ramp at Vine Street.

The study area shown in Figure 3 is the one used for model calibration and corresponds to conditions in June 1979. Since that time, the CBD has undergone major changes, including the opening of CA-87 (which lies just west of the study area) and several modifications to street configuration and intersection contol. In addition, several control plans are being considered by the city and include a transit mall along First Street and Second Street, a garage-office building, a light rail along San Carlos, and modification to the loop along Market Street.

Data Collection

The Micro-Assignment model required network-related data and O-D demand data. These data were available as a result of the Micro-Assignment validation to the San Jose CBD in June 1975 (14). In order to update these data to the calibration date of June 1979, it was necessary to collect information concerning network changes and the changes in the O-D demands.

Network Data

The network was coded in terms of links and nodes, as depicted in Figure 4. There was a total of 408 nodes and 500 directional links. Links shown with solid lines are straight-ahead links and links shown with dashed lines represent turning movements. Links without arrowheads represent two-way traffic and links with arrowheads represent one-way traffic. For each directional movement, several physical and operating characteristics are required. The physical characteristics include number of lanes and link length, and examples of the operating characteristics include legal speed, type of intersection, and left-turn interference.

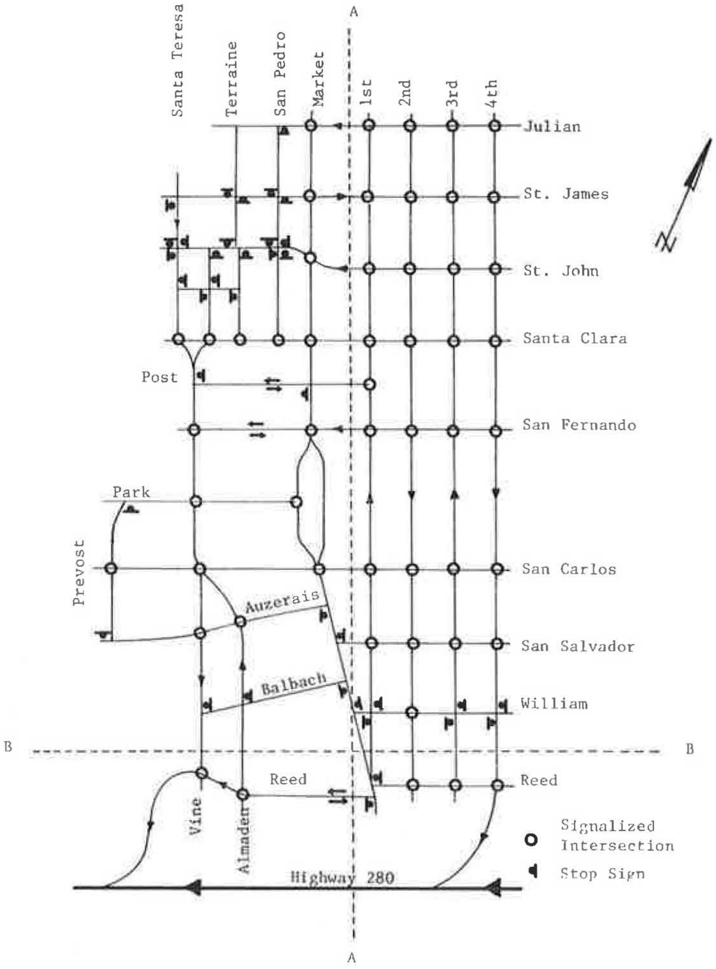
As mentioned earlier, several changes have been made in the network since 1975. These include changes in signal timings, changes in intersection control such as conversion of a two-way stop sign to a signal, modification to street configuration, and changes in street control such as conversion of a one-way street to a two-way street. The 1975 network data were obtained from Caltrans and modified to account for the above-mentioned changes. In addition, the data on network changes were obtained from records in the files of the city of San Jose and Caltrans (district 4). In order to verify the completeness and accuracy of this network data, several field trips were made to the study area.

Origin-Destination Data

The O-D demand data used in this study were established from the O-D demands of the afternoon peak period (4:00-5:00 p.m.) developed by Caltrans in 1975. In establishing the O-D demands for 1979, three alternatives that had varying degrees of complexity were available. The first alternative, the simplest one, was to apply an annual growth rate to the 1975 data. The second alternative, the most complex one, was to collect the entire O-D data from the field, and the third alternative was a combination of the other two.

In evaluating these options, the first alternative was not selected because there have been significant changes in land use activities within the study area. The second alternative was not considered feasible for purposes of this project. It was decided, therefore, that the third alternative be implemented by explicitly accounting for land use changes at specific locations within the CBD and by applying an average annual growth rate at the remaining locations. The above procedure represents the temporal adjustment of the O-D demands; however, the process of establishing the O-D demands for 1979 involved two main tasks. The first task was devoted to the spatial adjustment, and the second task was concerned with the temporal adjustment of the 1975 O-D demands. A brief description of these tasks is given below.

Figure 3. Study area.



Note: A-A and B-B are cordon lines used for evaluation

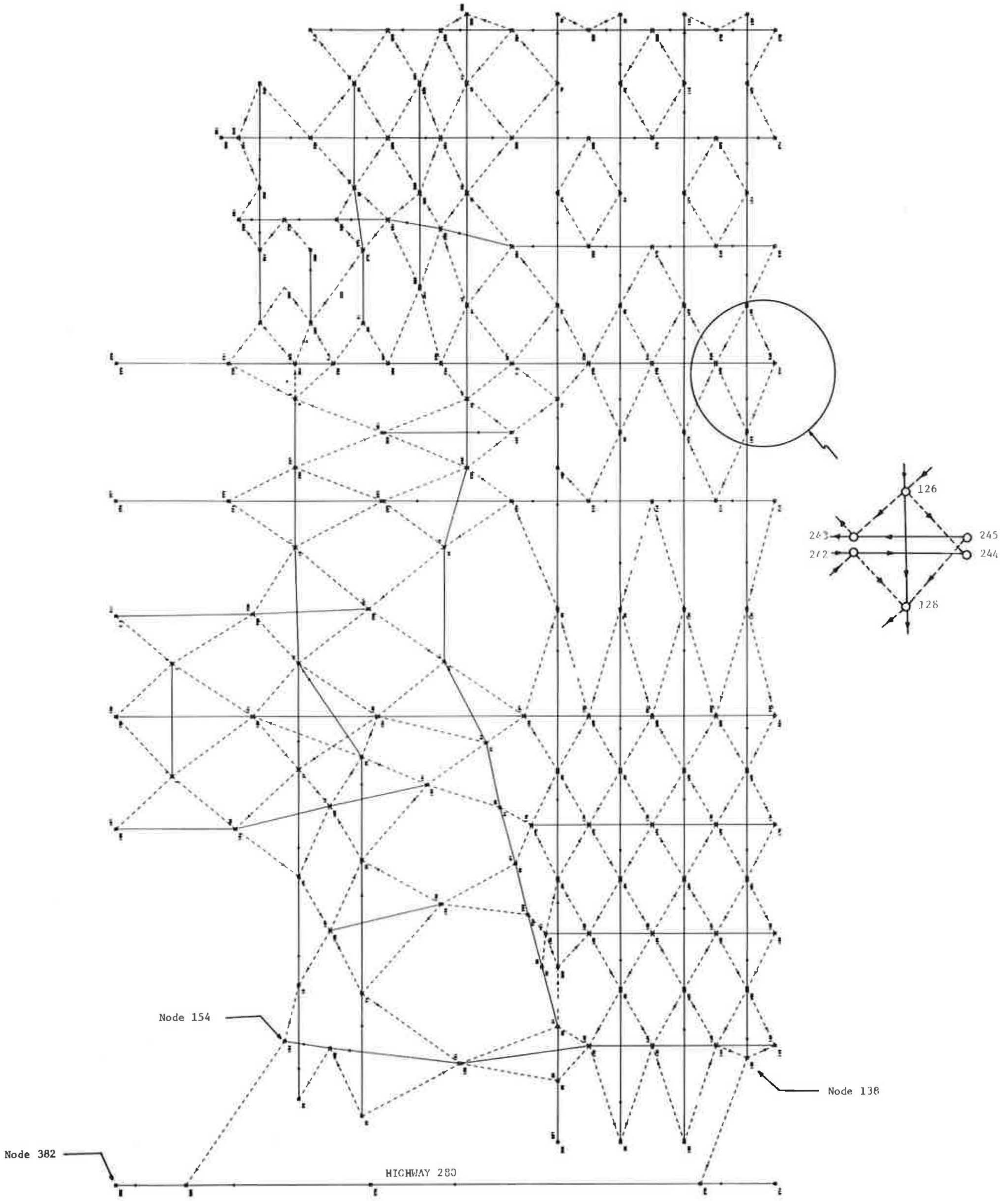
The spatial adjustment was necessary since the O-D demands of 1975 corresponded to a network that did not include CA-280. Therefore, the O-D table was adjusted to incorporate the origins and destinations along this additional facility. This was done by allocating the demands for destinations 138 and 154 in the vicinity of Reed Street (Figure 4) to destination 382 along CA-280. In addition, a fictitious demand was added along CA-280 to produce the actual traffic volume that prevailed in 1975. With this spatial adjustment, the O-D demand for 1975 was established for the study network and the temporal adjustment was then made.

The purpose of the temporal adjustment was to update the 1975 O-D demands to 1979. This adjustment consisted of three parts: new constructions, building occupancy shifts, and average annual growth rate. The new constructions in the CBD resulted in new origins and destinations in the San Jose CBD. Fortunately, information concerning the new constructions and the associated number of employees was available as part of a survey being undertaken by the city of San Jose. The number of employees was then converted to number of vehicles by assuming a modal split value of 25 percent for public transit and a car occupancy value of 1.1. After the number of trip demands (or vehicles) for each new construction was established, this number was then assigned to the proper origin in the study network. In addition, the number of trips from a particular origin to the various destinations was established based on the prevailing demand pattern (or distribution) for a nearby origin. Clearly, implicit in this procedure is the assumption that the employees of these new constructions are not shifted from existing demand sources in the study area.

In regard to the adjustment of building occupancy shifts, information at the major buildings in the CBD was available for both 1975 and 1979. This information was used to adjust the demands at the corresponding origins in the study area. The data showed that the number of employees has declined at some locations by 7 percent, but at other locations it has increased by 47 percent. Similar assumptions were implemented to convert the number of employees to number of vehicles, and adjustments to the trip demands at the respective origins were then properly made.

It is clear that the previous two adjustments concern only specific locations (or origins) within the area and a further adjustment to account for the natural growth of traffic at other locations is required. To determine the value of the annual growth rate, a trial-and-error procedure was adopted. A value of the growth rate was assumed and the predicted volumes (and travel times) were then compared with the observed values. Based on this comparison, another value of the growth rate was assumed and the process continued until a reasonable match with actual values was obtained. In fact, this was part of the calibration process that will now be described.

Figure 4. Reduced computer plot link-node representation of study area.



Model Calibration

The preparation of the O-D demands for 1979 was not a separate task from the calibration process. After the O-D demand data had been adjusted to account for new constructions and building occupancy shifts at the respective locations, it was necessary to select the annual growth rate that provided the least differences between observed and predicted values of traffic volumes and travel times.

Selection of Growth Rate

Annual growth rates of 5 and 10 percent were tested initially. The results indicated that the O-D demand obtained by a 5 percent increase from 1975 data better predicted the traffic conditions in 1979. Note that this growth rate was not applied to the origins at which an adjustment of building occupancy shift has been made. In addition, this growth rate was applied to both local and through traffic.

Discussion of the results with the staff of the city of San Jose revealed that the results could be improved further by refining the growth rate and other operating characteristics. Specifically, three improvements were identified and included:

1. Use of a different growth rate for local trips and through trips,
2. Investigation of the changes in the parking characteristics in the vicinity of the locations that exhibit high differences between observed and predicted volumes, and
3. Modeling of the allowed U-turns in the link-node representation at specified locations in the study area.

The above improvements were then made and more refined O-D demand data were established. The growth rates were found to be 5 percent for local trips, 2 percent for through trips east of (and including) First Street, and 4 percent for through trips west of First Street. In addition, the changes in the parking characteristics at the specified locations were rather insignificant and resulted in only minor modifications to the O-D data. In regard to the modeling of the allowed U-turns, a method was devised to model the allowed U-turns and the network representation was then modified so that U-turns were allowed for in the assignment procedure at the major locations. Those refinements resulted in a better agreement between predicted and observed characteristics.

Comparison Results

The comparison of the calibrated values with the actual values in June 1979 included two measures: traffic volumes and travel times. The actual data were collected during the afternoon peak period (4:00-5:00 p.m.). Traffic volumes were collected at 15 intersections and standard travel time runs were conducted on five selected routes.

There were 66 locations at the intersections where volume counts were made. At these locations the predicted and observed volumes were compared. A summary of the distribution of differences between the predicted and observed volumes is given in Table 1. Shown also in the table is the number of locations for various ranges of percentage differences and various ranges of traffic volumes. The majority of locations that exhibit a difference of more than 50 percent is in the volume range of 0-500 vehicles/h. In addition, more than 50 percent of the locations in the volume range of 500-1000 vehicles/h exhibit a difference of less than 10 percent. In general, a better prediction is seen for higher volume levels. This was achieved because, during the calibration process, attempts were made to improve not only the locations that have higher percentage differences but also those that have large volume differences.

Travel time runs were conducted along five routes, including Market, Third, Fourth, San Carlos, and Santa Clara (Figure 3). The first three streets lie in the north-south direction and the other two lie in the east-west direction. Along each route, five travel time runs were made. The average of these runs was then compared with the travel time predicted by the model. A summary of the predicted and observed results is shown in Table 2.

The predicted travel times tend to be lower than the observed values. In particular, on Santa Clara (eastbound) the difference is -23 percent. One possible reason for this relatively high difference is the rather heavy interference of pedestrians and buses along Santa Clara Street; such factors are not explicitly accounted for in the refined Micro-Assignment model. Another possible reason for the underestimation along this and other routes is the time lag between predicted and measured travel times. The travel time runs were conducted in March 1980; however, the predicted values corresponded to June 1979. During that period, the increase in traffic volumes would tend to increase the actual travel times. This may not be as significant because the opening of CA-87 (in December 1979) attracted some of the CBD traffic. Overall, the average of the absolute differences for all routes is approximately 10 percent.

EVALUATION

The next step after calibration of the model was to use the model to evaluate the impacts of a variety of control plans that have been, or will be, implemented in the San Jose CBD. This section presents the evaluation results of selected control plans.

Control Plans

Four control plans, including the calibrated conditions, were evaluated. The first plan corresponds to the calibrated conditions of June 1979 and will be referred to as plan O. The second plan includes the construction of CA-87, which was opened late in 1979, and corresponds to June 1980 conditions. In addition to CA-87, this plan also includes network changes that occurred since June 1979. This highway plan will be referred to as plan H. Only the southbound direction was analyzed because it represented the heaviest direction of travel during the afternoon peak period.

In the third plan, a transit mall is proposed on both First and Second Streets, extending from Julian to San Salvador. This transit mall will allow a limited circulation of automobile traffic. Specifically, automobile traffic would be able to use these streets for only one block. Clearly, physical and operational measures would be taken to enforce this type of operation. The transit mall plan is expected to be completed in 1982. The network used for evaluating this plan was prepared by updating the network that corresponded to plan H. In addition, two other network changes are expected and were incorporated in the transit mall plan. These changes include elimination of Post Street between Market and First and conversion of San Fernando Street to a two-way operation east of Market Street. The transit plan will be referred to as plan T.

In the fourth plan, garage and office buildings are proposed north of San Carlos Street between First and Second Streets. The office building is designed to accommodate 1200 employees and the capacity of the garage building is 580 spaces. In addition, the Bank of America building that currently exists at the proposed location will be relocated north of San Fernando Street between Third and Fourth Streets. The garage building is primarily intended for the new employees. Since its capacity can accommodate only a portion of these

Table 1. Distribution of the differences between predicted and observed volumes from 4:00 to 5:00 p.m.

	No. of Locations with Traffic Volume Between				Total	
Difference (%)	0-500 Vehicles/h	500-1000 Vehicles/h	1000-1500 Vehicles/h	>1500 Vehicles/h	No.	Percent
0-10	2	16	5	1	24	35
10-20	2	4	3	2	11	17
20-30	3	4	4	0	11	17
30-40	3	3	2	0	8	12
40-50	1	2	0	0	3	5
>50	8	1	0	0	9	13
Total	19	30	14	3	66	

Table 2. Comparison of travel times.

		Travel Time (s)		
Street	Direction	Predicted	Measured	Difference (%)
Market	Northbound	209	223	-6
	Southbound	222	268	-17[a]
3rd	Northbound	169	173	-2
4th	Southbound	179	204	-12
San Carlos	Eastbound	176	198	-11
	Westbound	171	162	+6
Santa Clara	Eastbound	194	252	-23
	Westbound	180	174	+4

Note: Average of absolute differences is 10 percent.
[a] Based on only four travel time runs, since the travel time in one of the runs was considerably higher due to a stalled truck.

employees, a shuttle bus service for the remaining employees will be provided to and from the parking lot located near Vine Street and CA-280. The network used for the garage plan is an update of plan H and also includes the two network changes mentioned earlier. This plan is expected to be in effect in 1982 and is designated as plan G.

The selection of the above control plans was made so that a variety of improvements may be evaluated by the model. Plan H represents an improvement outside the CBD area, plan T represents an improvement within the area, and plan G is a major change in the trip demand at a specific location within the area.

Evaluation Results

As mentioned above, each of the control plans corresponds to a different network structure. In addition, the O-D demand data are also different. The demand data for plan O were used to establish the O-D demands for the other three plans by using an annual growth rate of 3 percent. Further modifications to the O-D demand data were also required for plans T and G. After the preparation of the network data and the demand data, several runs (iterations) for each plan were made until convergence was obtained. (The model converged after either four or five iterations.) The analysis of the results was then performed for selected locations and for the network as a whole. In this analysis the latter three plans were compared with plan O.

Location-Specific Comparison

The two sections selected for volume comparison are shown in Figure 3. Section A-A is parallel to the longitudinal direction of the study area and lies approximately in the middle of the area. Section B-B is parallel to cross streets and would capture the impacts on through traffic. Traffic volumes for the four plans were determined for each of the streets at sections A-A and B-B and the results are summarized in Table 3. As would be expected, plan H resulted in a significant increase in volume on Julian Street (35 percent), as noted in Table 3. Also, it increased traffic volumes on St. James and San Carlos. Also note that 473 vehicles diverted to CA-87 from the CBD. This, in effect, reduced traffic volumes on CA-280, as indicated by the decreases in traffic volumes on the streets at section B-B.

The results of plan T were also as expected. The transit mall increased traffic volumes significantly on the cross streets; more than 50 percent at most of the streets on section A-A. Only at San Fernando and Reed did traffic volumes decrease. The decreases on San Fernando are apparently due to the traffic being diverted to CA-280, as indicated by the considerable increase in volume on Fourth Street at Reed (31 percent). Also note that the amount of diverted traffic to CA-87 is less than that for plan H, since the increase in travel times on cross streets made CA-87 less attractive for the through traffic that originates from or is destined for the north-east part of the study area.

With plan G, traffic volumes increased on most of the streets that lie in the lower portion of the study area (section B-B). In particular, a considerable increase (61 percent) is noticed on Almaden, which is due mainly to the employees of the new office building that are using the parking lot at the south part of the study area rather than the garage building. In addition, this plan resulted in a greater number of vehicles diverting to CA-87 and also in a slight increase in traffic volumes along CA-280. A quick comparison with plan H revealed that this plan resulted in greater increases in traffic volumes on the cross streets and a considerable volume increase on the longitudinal streets.

Overall Comparison

The overall impacts of the control plans were analyzed with respect to two features and seven measures of effectiveness, and the results are shown in Figure 5. The two features include the number of links and the number of O-D trips and are shown in parts (a) and (i), respectively. The former indicates the amount of network changes and the latter shows the amount of changes in the trip demands. As noted, network changes during the period 1979-1980 (plan O to plan H) are relatively greater than those during the period 1980-1982 (plan H to plans T or G). In addition, changes in the trip demands of the plans are due to the natural growth, and for plans H and G are, in addition, due to the induced demand and the new demand source, respectively.

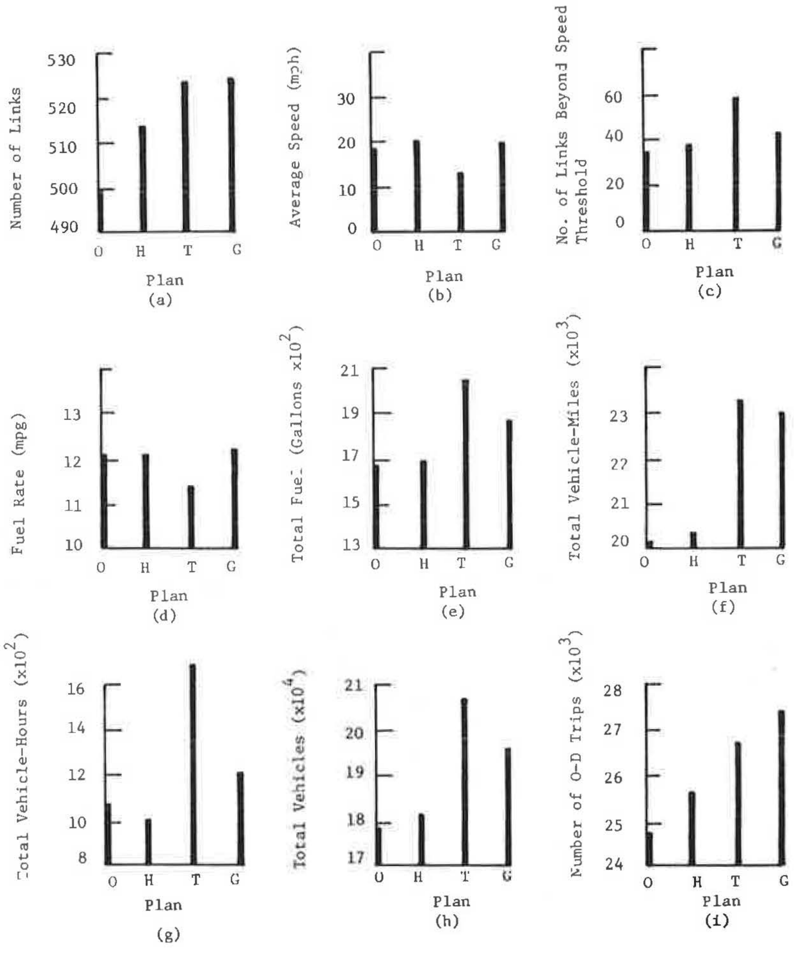
The seven measures of effectiveness shown in Figure 5 (b) through (h) exhibit a consistent trend. For the positive measures (the higher the better), the results exhibit a V-shape, as noted in parts (b) and (d), for average speed and fuel rate, respectively. Except for plan T, the changes in these measures are relatively small, with no appreciable difference in fuel rate between plan O and

Table 3. Comparison of predicted volumes from 4:00 to 5:00 p.m.

	Plan O		Plan H		Plan T		Plan G	
Roadway	Volume	Percent	Volume	Percent	Volume	Percent	Volume	Percent
Section A-A								
Julian	760	0	1028	+35	1434	+87	1157	+52
St. James	1164	0	1333	+15	1795	+54	1455	+5
St. John	712	0	721	+1	1222	+72	751	+6
Santa Clara[a]	721	0	720	0	1594	+121	897	+22
San Fernando	851	0	843	-1	750	-12	795	-7
San Carlos[a]	695	0	784	+13	1065	+56	821	+18
San Salvador[a]	576	0	562	-2	671	+16	581	+1
Reed[a]	825	0	701	-15	683	-17	737	-11
CA-280	5738	0	5564	-3	6057	+6	5987	+4
Section B-B								
CA-87[b]	-[c]	-[c]	473	-[c]	357	-[c]	562	-[c]
Vine	1839	0	1797	-2	1904	+4	2081	+13
Almaden	710	0	681	-4	724	+2	1145	+61
Market[a]	2767	0	2860	+3	3507	+27	2763	0
1st	764	0	752	-2	281	-63	816	+7
2nd	1459	0	1303	-11	803	-45	1371	-6
3rd	903	0	902	0	1009	+12	942	+4
4th	1216	0	979	-19	1595	+31	1359	+12

[a] Both directions.
[b] Volume indicated is the traffic diverted from CBD to CA-87.
[c] Not applicable because plan O, which is used for comparison, does not include CA-87.

Figure 5. Comparison of overall impacts of control plans.



plan G. For the remaining negative measures, the results exhibit a reversed V-shape, with plan O exhibiting the least impacts followed by plans H, G, and T. It is seen that plan T exhibits a considerably higher impact than other plans, except for the total vehicle miles, part (f), where the impacts of plans T and G are noticeably close. This is probably due to the fact that plan T exerts a major influence only on those measures that depend on the delay time.

In order to show the relative changes in the measures of effectiveness with respect to plan O, three measures of effectiveness were selected for comparison. These included total fuel, total vehicle miles, and total vehicle hours. A summary of the percentage changes compared with plan O is given in Figure 6. These results show that plan H improved the total vehicle hours in the entire network (-5 percent) and resulted in a slight increase in both total fuel and total vehicle miles. Such an increase is due primarily to the induced traffic on CA-87, which, for purposes of this analysis, was fictitiously incorporated in the O-D demand data. Plan T, on the other hand, increased the three measures of effectiveness--in particular, the total vehicle hours (60 percent). This is again due mainly to the increase in traffic volumes on the cross streets. Plan G exhibited considerably lower impacts than plan T and resulted in an increase of about 14 percent in all measures.

In order to analyze the impacts on only the CBD streets, Figure 7 shows the percentage changes with respect to plan O. In this case, plan H improved not only the total vehicle hours but also the other two measures. This is expected because a substantial number of vehicles were diverted from the CBD to CA-87. Both plans T and H exhibit a lesser impact on the CBD streets than on the entire network, except for the total vehicle hours in plan T. This again indicates the greater impact of the transit mall plan on increasing the travel times on the CBD streets.

Discussion of Results

In the analysis of the highway plan, only the heaviest direction of travel was incorporated and the induced demand due to the construction of the highway was modeled only approximately. In addition, only the westbound direction of CA-280 was included in the study network. The eastbound direction was not considered because it did not provide an alternative route to the CBD traffic. However, this eastbound direction could be used by the through traffic destined north of the area if the northbound direction of CA-87 became congested. Fortunately, the level of traffic volume on CA-87 was not particularly high in the direction considered, and traffic volumes on the other direction are likely to be even lower. This is especially true because, during the afternoon peak period, the majority of traffic originates from (rather than is destined for) the CBD. Consequently, should CA-87 become congested or other peak periods be studied, the two directions of both highways should be considered.

In addition, in modeling the transit mall plan no shift to public transit was considered. Furthermore, the locations of origins and destinations of existing traffic demands were assumed to remain the same. The results of the transit mall plan should be viewed in light of the above assumptions.

CONCLUSIONS AND FUTURE RESEARCH

As a consequence of the study results and experience gained while conducting this project, several observations are considered worthy of note.

The refined Micro-Assignment model was shown to be capable of predicting the impacts of a wide variety of traffic management plans, which included a new freeway facility, a transit mall, and a garage-office building. The model provided such impacts not only for the entire network system but also at selected locations. These impacts were analyzed by using the various measures of effectiveness provided by the model, including fuel consumption. The procedure for estimation of fuel consumption embodied in the model appears to provide a useful addition to the operations of such models, particularly when applied to dense urban networks.

This paper described in a step-by-step fashion the procedure of data collection and reduction, model calibration, and evaluation of control plans. Furthermore, it pointed out several difficulties associated with these aspects and suggested ways of dealing with them. In particular, the O-D demands were established from the demand data that were available for an earlier year. The procedure adopted to accomplish this task was relatively easy to apply and resulted in a reasonable match between observed and calibrated characteristics. In addition, minor difficulties may be encountered in evaluating public transit improvements such as a transit mall. In an attempt to solve this problem, the procedure adopted in this application assumed no shift to occur to public transit (which might be reasonable on the first day of operation). The model could have been used to determine the impacts of the other extreme; that is, all trips along the transit mall will shift to public transit. Between these two extremes lies the actual operation of the transit mall.

Some insight into the implementation of the transit mall plan was gained from this application. Experience has provided guidelines for such plans, which may be stated as follows:

1. Peripheral routes should be available to through traffic,
2. Malls may be successful in areas where CBD travel demand is already high, and

Figure 6. Overall comparison of entire network.

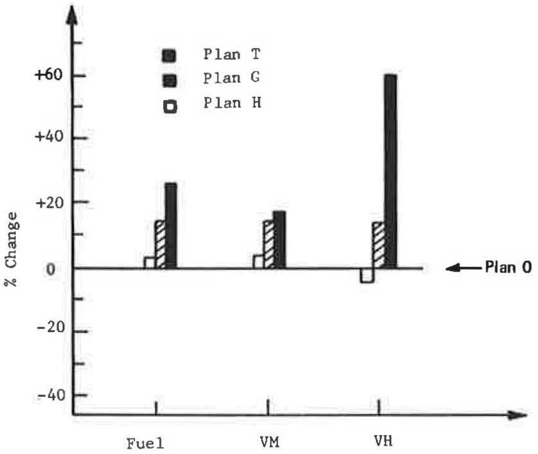
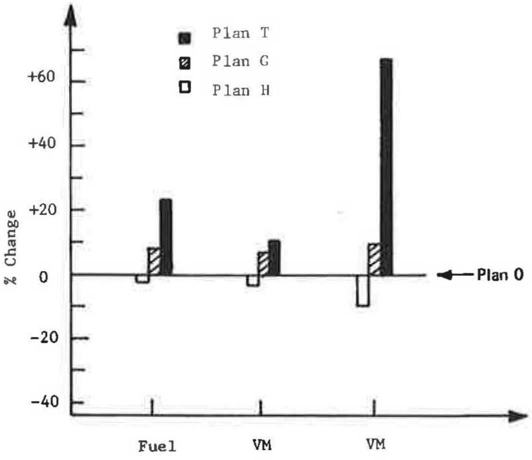


Figure 7. Overall comparison of CBD only.



3. Transit malls must provide good accessibility, including parking facilities and efficient transit operations.

With these guidelines in mind, the transit mall plan seems to be particularly suited to the operating characteristics of the San Jose CBD. The CBD area provides an excellent route (CA-87) for through traffic and the level of traffic volume, as indicated by the application results, is relatively high. In addition, the results of the transit mall plan were based on the assumption that all vehicles that originated from or were destined for locations along the transit mall would be allowed to use the mall for only one block. In cases where it is desirable that fewer vehicles use the transit mall, special attention should be given to the management of parking facilities along and in the vicinity of the transit mall.

Several areas for future research have been identified and are outlined below:

1. Further model refinements with emphasis on traveler responses, impact assessments, and program input and output capabilities;
2. Development of an interactive version of the model to permit rapid analysis of incremental control plan improvements;
3. Further investigation of studied operating environments to evaluate additional control plans with modified interactive model;
4. Investigation of other operating environments such as industrial sites, sports locations, shopping centers, and locations for mode transfer;
5. Experimentation with synthetic O-D demands and comparison with measured O-D demands to determine their applicability in dense networks; and
6. Establishing guidelines for traffic management in CBDs with emphasis on objectives and measures of effectiveness, selection of control plan, impact assessments, and anticipated problems.

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Flexible Work Hours and Mode Change: Interpretation of Empirical Findings from San Francisco

PAUL P. JOVANIS

A series of surveys was conducted at four San Francisco Bay Area firms in 1979 to study the effect of flexible work hours on choice of mode for the work trip. Analysis of nearly 1200 individual responses showed consistent and statistically significant decreases in solo driving, even after mode changes that were estimated to be caused by 1979 gasoline shortfalls and skyrocketing energy prices were screened out. Individuals who changed to transit were found to be from generally lower-income households and thus susceptible to gasoline price increases; flextime further assisted their shift to transit by alleviating anxieties about being late for work due to unreliable transit service. These individuals frequently traveled during the off-peak hours, when seats were more readily available. Individuals who changed to ridesharing ranked congestion avoidance as high or higher than the ability to coordinate work schedules with fellow carpoolers (frequently a working spouse for employees at three downtown firms). Although there were diversions from ridesharing to transit, the net result was a statistically significant increase in ridesharing. The evidence from these four Bay Area firms strongly suggests that flextime is complementary to transit marketing and ridesharing promotions, although the net change in mode share is likely to be modest (less than 5 percent).

Since 1975, transportation professionals have placed increased emphasis on transportation system management (TSM)--the improvement of the existing transportation system through relatively low-cost incremental management techniques (1). Options under the TSM umbrella range from carpool matching to priority lanes, improved transit management, and alternative work schedules. Although some tactics, such as carpool matching, have been studied heavily for several years, others, such as alternative work schedules, have only recently appeared in the literature.

The goal of this paper is to contribute to the expanding literature on alternative work schedules. The major transportation aim of most alternative work schedule programs has been to spread peak-period work trips over a wider time period and thus reduce the intensity of congestion. Alternative schedules have been somewhat successful in spreading the work schedules of individuals; however, a deeper policy-related concern has emerged concerning the compatibility of alternative work schedules with campaigns to promote ridesharing and encourage transit use. A report on alternative work schedules by the Urban Consortium for Technological Initiatives states (2), "A serious and tricky problem with alternative work schedule strategies is the fact that they may have negative impacts on transit and carpooling, depending on how the strategies are designed and applied and upon the particular characteristics of each alternative."

The motivation of this paper was to study mode changes that have actually occurred at firms that have alternative work schedules, with the specific aim of providing guidance on how the design of the schedules affected the mode changes. It was decided that this could be done only if the research was able to study the magnitude of mode changes for large groups of employees while simultaneously attempting to understand the causes underlying individual mode changes. Table 1 summarizes a review of the existing literature concerning mode changes and motivations for change with alternative work schedules.

Four large areawide promotions were reported in the literature. The New York City study reported that insignificant mode changes occurred during a demonstration of flexible work hours at the Port Authority of New York and New Jersey (3) and did not report on mode changes that occurred during a larger demonstration of staggered work hours at numerous firms (4-6). The studies in Ottawa (7,8) and Toronto (9,10) report increases in transit ridership and carpooling, respectively; however, these studies were conducted during the 1973 energy crisis, so that alternative work schedules alone could not be isolated as a causal factor. In addition, the Ottawa study attempted to use actual traffic counts on streets and bus stops to determine the temporal spread in travel. Unfortunately, fluctuations in traffic volumes due to seasonal and monthly variations made it impossible to ascertain the contribution of work schedules to the changes in flow.

A work schedule promotion was also undertaken in Vancouver (11), but it was terminated after 6 months because of a lack of employer participation. None of the areawide promotions studied motivations for the reported mode changes.

All five of the studies at individual firms reported mode changes that occurred during alternative work schedule promotions. Studies of New Zealand government employees showed decreases in transit ridership and increases in solo driving (12). A study at the Department of Water Resources in Sacramento, California, reported increased use of transit and ridesharing with flexible work hours (13). Unfortunately, the flextime promotion occurred during transit service expansion and the end of the 1973 energy crisis. Studies of Transportation Systems Center (TSC) employees in Cambridge, Massachusetts (14), showed small increases in ridesharing and transit use. A study at the New York Department of Transportation in Albany reported similar findings, but the study was conducted during a vigorous ridesharing promotion campaign (15). A survey of state employees in Denver who had alternative work schedules indicated that only 71 percent retained the same mode after the experiment, but the study did not report the modes in which the changes occurred (16).

Only the Sacramento study was able to obtain an idea of motivations for mode change, but these were largely through survey margin comments and could not be extrapolated to the entire employee population.

In summary, the literature has reported mode changes with alternative work schedules; but the changes have generally been of small magnitude or have occurred during confounding events such as energy crises, ridesharing promotions, or transit service expansions. With the exception of the Sacramento study, little has been published concerning motivations of mode changers.

Rather than study mode changes that occur with all three types of alternative work schedules, this study concentrated on flexible work hours. Alternative work schedules can be divided into three basic types:

1. Four-day workweek--Rather than work five days per week, the employee works the same number of hours over a four-day period and either rotates different days off during different weeks or retains the same day off every week.
2. Staggered work hours--The employee works a

Table 1. Effect of alternative work schedules on work trip mode choice: summary of existing research.

Study Area	Magnitude of Mode Change Considered	Motivations for Mode Change Assessed
Citywide		
New York City	Partly[a]	No
Ottawa	Partly[b]	No
Toronto	Partly[b]	No
Vancouver	No	No
Individual firms		
Government employees, New Zealand	Yes	No
Department of Water Resources, Sacramento	Partly[b]	Partly[c]
State employees, Albany	Partly[b]	No
Transportation Systems Center, Cambridge	Yes	No
State employees, Denver	Yes	No

[a] Staggered work hours promotion did not consider mode change, but flexible work hours experiment did.
[b] Partly analyzed but confounding events occurred, which limited the strength of conclusions.
[c] Largely from survey margin comments.

five-day week, but start and end times are deliberately spread or staggered to distribute work schedules over a wider time period (note: employees generally do not choose their schedules, but are assigned to a schedule by management).

3. Flexible work hours--A work schedule system in which the employee chooses his or her schedule, with some constraints; he or she may be free to vary the schedule daily, vary the lunch hour, or bank hours from one day to the next or one pay period to the next, depending on the design of the program. All employees are generally required to be at work five days per week during designated core periods but may otherwise arrange their work schedules within the constraints imposed by the particular program.

Flextime is being actively promoted in several U.S. cities (17-19), enhancing its relevance for study in this research. Interestingly, after a five-year study of staggered work hours and a brief flextime experiment, the Port Authority of New York and New Jersey concluded (20), "The concept of flexible work hours appears to be superior to staggered work hours and the four-day week, particularly in the area of reduced transportation congestion and improved employee attitude."

The objective of this paper is to report empirical findings of mode changes observed at five San Francisco firms that have flextime, and to interpret the findings vis-à-vis ridesharing and transit use.

EXPERIMENTAL DESIGN

The development of the experimental design has been driven by the two major objectives of the study:

1. To assess the magnitude of mode changes that occur with flextime and
2. To assess the motivations that underlie the changes in mode.

The joint consideration of magnitudes and individual motivations leads to an experimental design that considers a survey of individual employees before and after flextime is instituted at the workplace. The mode of travel before and after flextime can be determined as well as motivations of changes in mode. The individual survey format also allows the collection of socioeconomic data to study the distribution of flextime benefits and possible effects of household structure, income, age, and automobile ownership. Individual surveys also avoid the difficulty of field measurement encountered by the Canadian researchers.

Based on the literature review and consideration of possible travel effects of flextime, a series of hypotheses was developed concerning flextime and mode change. The attempt was to be comprehensive, so that the survey could be designed to examine when particular hypotheses were accurate.

The hypothesis that created the biggest concern for transportation analysts and policymakers is that flextime makes the single-passenger automobile comparatively more attractive than carpool and transit, because flextime allows the automobile to be driven in the off-peak when congestion is less onerous. In areas where restricted parking supply is an incentive for carpool and transit use, flextime may encourage individuals to switch to automobiles and arrive early to capture the premium parking spaces. Flextime affords individuals more spare time to arrange for errands and personal business; some individuals may shift to driving alone to capitalize on this new freedom. There, are however, countervailing arguments that favor shifts from single-passenger automobiles to both carpool and transit.

One argument states that flextime will increase mass transit use because it allows travelers to ride during times when seats are more readily available and service is more reliable. Flextime also makes transit more attractive because it eliminates schedule buffering that may be due to a mismatch between fixed start times for work and arrival times available via transit. The problem is manifested by travelers who have to arrive at work 10 min early so that they are not 15 min late. Obviously, this problem becomes most acute when bus headways are large. Flextime can also allow travelers to deal better with the unreliability of transit schedules, because the workday starts when the worker arrives and he or she is thus freed from the worry of punitive action due to tardiness (13).

A similar argument can be made in support of flextime as a positive factor in carpool formation. Flextime allows greater freedom to adjust an individual's work schedule to the schedules of potential carpool mates. For two-worker households, an increasing socioeconomic phenomenon in the United States, there is a particular benefit in allowing greater freedom to match up with a spouse for the work trip. Carpools may be disrupted, however, because of incompatibilities in the work schedule that arise due to flextime privileges (13).

To the extent to which any one of these hypotheses is a reflection of an individual's changed perception of one mode, the remaining modes are comparatively worse off. Freedom to match up with carpool mates who were previously unavailable may therefore result in diversions from transit to shared ride as well as from driving alone.

Individuals' perceptions of these mode-change motivations were assessed in the survey by asking each individual who changed mode to indicate the importance of each of the motivations in his or her decision to change mode. Each motivation had a five-point scale that ranged from not important through very important. If, for example, someone changed from drive alone to transit, he or she might check very important for saving money on gasoline and being able to cope better with transit unreliability, and not important for all other motivations. The answers to these motivational questions contribute to a better understanding of the causes for the mode changes.

The hypotheses about flextime and mode change described in previous paragraphs led to the development of a questionnaire for individual employees.

The questionnaire was pretested (21,22), revised, and used in a final survey at a suburban firm as well as central business district (CBD) firms. The analyses of the data used statistical tests to determine the significance of magnitudes of mode change; studied motivations for mode change; and used socioeconomic data to study distributional benefits and possible life-style effects. Details of questionnaire design are contained elsewhere (22).

DATA COLLECTION

After the questionnaire pretest, several firms in San Francisco were contacted concerning their potential participation in the study. No firms were adopting flextime at that time, so a strict before-and-after experiment was not possible. Instead, 10 firms that had flextime were contacted as potential participants; 5 agreed to participate. One, the California Department of Transportation (Caltrans) district office in San Francisco, had very strong ridesharing incentives. These incentives were not typical of those likely to occur at other firms that adopt flextime or typical of other major employers in San Francisco. For these reasons, the balance of this paper discusses findings at the four remaining firms: Lawrence Berkeley Laboratories (LBL) in Berkeley; and Chubb-Pacific Indemnity Insurance, Standard Oil of California, and Metropolitan Life Insurance in downtown San Francisco.

The four firms had nearly identical flextime programs. Flexible periods were typically 7-9:30 a.m. and 4-6:30 p.m. Employees were generally allowed to vary their start times within the morning band, so long as they worked five days per week and a full work day (e.g., 8 h) each day.

As an introduction to the data set used in the analysis, a brief description of flextime operations at each firm follows, including information regarding the number and proportion of survey respondents and the type and duration of the flextime program. Also, unique transportation characteristics related to the firm or its location are examined. Much of the transportation-related data is summarized in Table 2.

LBL

LBL employs approximately 3500 people, of whom 2800 have flextime privileges. Located in the hills above the city of Berkeley, the laboratory conducts high-technology, government-sponsored research on nuclear energy, as well as other research in the physical and life sciences. Because of the nature of the work, the composition of the work force is extraordinary for Bay Area firms that have flextime; a large number of the employees are research scientists and joint-appointed faculty members affiliated with the University of California. The rest of the work force consists largely of administrative, clerical, and technical support staff. Demographic data on the work force indicate the following significant features:

1. The age distribution is heavily skewed toward older employees, 36 percent are 46 years of age or older;
2. The occupational distribution is dominated by professionals (41 percent), consisting of scientists who conduct experiments and engineers who plan, operate, and maintain the physical plant;
3. Employment at LBL has increased dramatically in the past 5 years; this is reflected in the high percentage (51 percent) of employees who began employment at the laboratory in the 1970s; and
4. Seventy-one percent of the work force is male.

The automobile is used for 73 percent of the work trips; other mode shares are as shown in Table 3. The heavy automobile mode share is due to a number of factors. Parking is free and, although supplies of close-in parking have been diminishing, conversations with LBL employees indicate that spaces are still available. Because the laboratory is located in the Berkeley Hills, it is not served by direct public bus and rail transit, which necessitates that the laboratory run its own shuttle bus. The virtually mandatory transfer makes public transportation that much less attractive. Most LBL employees live within the cities of Berkeley or Oakland, which means a very short automobile trip and, concurrently, makes the schedule and transfer delays of transit even more onerous. The laboratory does participate in the university vanpool and carpool promotion, thus slightly better ridesharing incentives are offered here than at the other three firms.

Because of these unique travel characteristics, virtually all of the analyses in subsequent sections were conducted separately for LBL employees and the rest of the survey respondents.

Table 2. Summary of transportation supply information for four selected Bay Area firms.

Firm	Total Respondents	Response Rate (%)	Parking Availability	Parking Cost	Transit Availability	Carpool Incentives
LBL	689	25	Excellent	Free	Poor	Limited
Chubb-Pacific Indemnity Insurance	152	81	Good	High	Excellent	None
Standard Oil of California	89	45	Good	High	Excellent	None
Metropolitan Life Insurance Company	300	38	Good	High	Excellent	None

Table 3. Mode shares for four selected firms.

Firm	Automobile	Carpool	Bay Area Rapid Transit	Transit	Walk	Other
LBL	46.2	27.3	4.8	8.9	4.9	7.3
Chubb-Pacific Indemnity Insurance	3.3	20.4	21.1	47.4	2.6	4.6
Standard Oil of California	4.5	18.0	38.2	34.8	3.4	1.1
Metropolitan Life Insurance Company	2.0	20.0	24.0	45.0	1.3	7.7

Chubb-Pacific Indemnity Insurance

Chubb has approximately 187 employees who have flextime privileges, of whom 152 responded to the survey (81 percent response rate). The work force is largely clerical and administrative staff. The principal office tasks are to process insurance applications and claims. The flextime program has been in operation for approximately one year.

The transportation characteristics for Chubb are similar to those of the other San Francisco-based firms. Chubb offices are located in the Bank of America Building on California Street, which is well served by all mass transit in the Bay Area. No special parking provisions exist for carpoolers, and parking supplies are scarce and expensive (\$3-\$6/day). These factors account for the high transit mode shares illustrated in Table 3.

Standard Oil of California

Standard Oil, although a very large employer in San Francisco (approximately 3000 employees), has only about 200 people on flexible work hours. The employees are not located in one work unit but are spread across many divisions. The 89 employees who responded to the survey (45 percent response rate) all work in the Standard Oil Building on Bush Street in the financial district of San Francisco. Like Chubb-Pacific, it also is well served by all mass transit in the Bay Area. No special parking is provided for any employees. As in the case of Chubb-Pacific, the mode share for transit is very high (see Table 3).

Metropolitan Life Insurance

Metropolitan employs 1200 people at its downtown headquarters on Market Street. Approximately 800 of these employees have flextime privileges. The remainder (telephone operators, security personnel, and computer systems people) are excluded from flextime by the demands of their jobs.

There were 300 respondents to the questionnaire, for a 38 percent response rate. To test that the responses were representative of the entire firm, Metropolitan provided work start times from employee time sheets. A chi-square test failed to reject the hypothesis that the reported work schedules were drawn from the same population (with a significance probability, p = 0.45).

Transportation supply conditions at Metropolitan are similar to those at Chubb-Pacific and Standard Oil. Metropolitan offers no parking incentive and is equally well served by transit. Table 3 indicates the high mode share for transit.

Summary

The total flextime sample includes approximately 1200 individual responses. The transportation supply characteristics of the downtown firms are significantly different from those at LBL, and, therefore, the data analysis in the subsequent section is conducted for two groups: LBL employees and the employees at the three financial district firms.

DATA ANALYSIS

The experimental design illustrated in Figure 1 was used as a framework for the data analysis. The aim was to build on the information obtained during survey pretest. Separate analyses were conducted for the three San Francisco firms (hereafter referred to as CBD firms) and for LBL because of the different travel and socioeconomic characteristics of individuals at the firms.

Magnitudes of mode changes for each of the two groups of data are examined and tested statistically. Next, the individuals who changed modes were compared both with individuals who retained modes and with other mode changers for several socioeconomic variables. The aim was to identify profiles of the mode changers. The motivations for the mode change were then examined to see which, if any, of the hypotheses discussed were prevalent for our sample. As stated previously, the objectives of these analyses were the testing of the magnitudes of mode change and a study of motivations for mode change in order to provide guidance regarding the effect of flextime on mode change.

LBL

Mode changes reported at LBL are summarized in Table 4. Diagonal elments in the table represent individuals who retained specific modes (e.g., 76 used transit before and with flextime); off-diagonal elements represent individuals who changed from one mode before flextime to another mode with flextime (e.g., 20 individuals changed from driving alone to transit). The findings are similar to those observed during the survey pretest in that all types of mode shifts occurred. Note, however, that the overwhelming shift was from driving alone to both transit and ridesharing.

Statistical tests can be used to test the symmetry of Table 4. Mathematically, the null hypothesis is

$$p_{ij} = p_{ji} \quad i \neq j \tag{1}$$

where p_{ij} and p_{ji} are the off-diagonal row proportions in the tables. Stated in words, the test examines whether the proportional change from each mode is equal to the proportional change to that mode; for example, if the proportional change from bus to carpool is equal to the change from carpool to bus. The test statistic is given (23) as

$$\chi^2 = \sum_{i>j} [(X_{ij} - X_{ji})^2/(X_{ij} + X_{ji})] \tag{2}$$

where the X's are the numbers of observations in the off-diagonal cells. The test statistic is asymptotically χ^2-distributed with I(I-2)/2 degrees of freedom, where I is the number of cells in one dimension (in this case, 3).

As can be expected by inspecting the table, the null hypothesis was rejected at a very high level of confidence. This is not surprising since, for example, the mode change from drive alone to transit (20) is substantially more than the change from transit to drive alone (2). As mentioned previously, a gasoline supply and price crisis struck California in late May and early June of 1979. Fortunately, questions were added to the questionnaire to attempt to screen temporary transit and ridesharing arrangements that were stimulated by the energy problem alone. Ridesharers were screened to eliminate new carpools (less than two months' duration) in which saving money on gasoline was checked as a very important motivation. New transit users were screened by using the gasoline motivation alone; if it was the only very important motivation for using transit, then the user was considered temporary. These controls were selected before the analysis so that they could be used to obtain a conservative estimate of flextime mode changes that were independent of energy shortages. The lower half of the table shows small decreases in diversions from driving alone but still strongly rejected the hypothesis of symmetry.

Figure 1. Experimental design for study of mode changes with flextime.

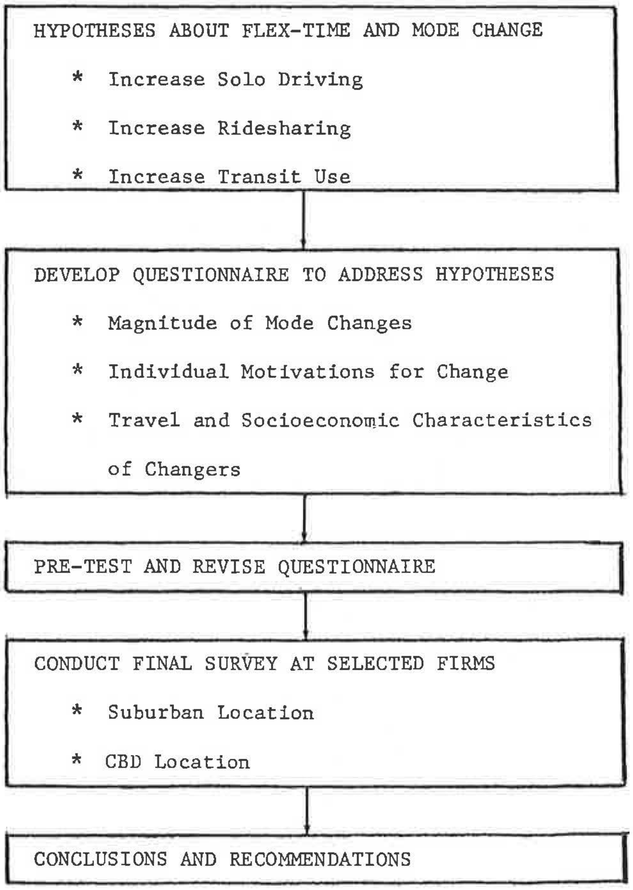

Table 4. Summary of mode changes with flextime for LBL.

Mode Used Before Flextime	Mode Used with Flextime			
	Transit	Drive Alone	Shared Ride	Total
Before Screening for Energy Shortage				
Transit	76	2	5	83
Drive alone	20	312	23	355
Shared ride	2	5	160	167
Total	98	319	188	605
After Screening for Energy Shortage				
Transit	76	2	1	79
Drive alone	16	312	21	349
Shared ride	2	4	160	166
Total	94	318	182	594

Note: Table entries are the number of respondents who report use of specific modes before and with flextime.

This test for symmetry can be considered a first cut at examining the magnitude of mode changes with flextime. A relevant policy questions is, "Has there been a significant increase (or decrease) in an individual mode share?" This question can be analyzed statistically by collapsing the 3x3 tables shown in Table 4 into a set of three 2x2 tables as shown below.

Mode Before	Mode with Flextime		
Flextime	Transit	Other	Total
Transit	76	7	83
Other	22	500	522
Total	98	507	605

Mode Before	Mode with Flextime		
Flextime	Drive Alone	Other	Total
Drive alone	312	43	355
Other	7	243	250
Total	319	286	605

Mode Before	Mode with Flextime		
Flextime	Carpool	Other	Total
Carpool	160	7	167
Other	28	410	438
Total	188	417	605

The same test for symmetry can be conducted on each 2x2 table; however, the interpretation of the test is slightly different. The hypothesis $P_{ij} = P_{ji}$ essentially tests whether the mode share before flextime is equal to the mode share after flextime. The results of these tests both with and without energy controls are shown in Table 5. Notice that even with energy controls there is a statistically significant reduction in solo driving and significant increases in transit use and ridesharing.

The next step is to compare the socioeconomic and travel characteristics of the mode changers with those who retained existing modes. It was hoped that profiles of likely mode changers could thus be identified. A wide range of variables was used in the comparison, including household location, automobile ownership per worker and per licensed driver, occupation, marital status and family structure (children, working spouse), household income, and age. In addition, for carpools only, comparisons were conducted regarding carpool composition, for number of riders, length of time in the carpool, and composition vis-à-vis spouse, children, other household members, non-household-members employed at same firm, and non-household-members employed at different firms.

Very few (7) LBL employees shifted to driving alone, so there are insufficient data to perform statistical analyses. Of practical significance is that the magnitude of the change is very small. It appears that the motivations of congestion avoidance, capturing parking places, and the freedom to run errands with a car contribute to mode changes to solo driving but for very few employees.

The diversions from solo driving to transit and ridesharing were much more prevalent. The diversions from solo driving occurred more frequently for clerical and administrative personnel than for professionals and managers. The changes also occurred more often in lower-income households, a largely corroborative finding. These income pressures are not directly reflected in levels of automobile ownership, however, as more than 73 percent of the changers to transit and carpool had automobile ownership levels (per licensed driver and per household worker) equal to or greater than one. The interpretation is that the vast majority of changers to higher-occupancy modes had an automobile available for a solo commute to work. The motivations for the changes illustrated in Table 6 support this income-centered view of mode change, but also show that flextime travel opportunities were crucial to the mode change decisions.

The income-related pressures are revealed as responses to the gasoline-price motivation (Table 6). More than 83 percent (15) of the changers from drive alone to transit stated that the saving of money on gasoline was a very important motivation for their change in mode. Nearly as great a number (12) stated that flextime enabled them to use transit in spite of unreliable service. The ability to ride when seats are available and mesh with transit schedules also contributed to the mode changes.

Table 5. Results of hypothesis tests for mode share changes for LBL employees.

	No Energy Controls		With Energy Controls	
Mode	χ^{2a}	Significance Probability	χ^{2a}	Significance Probability
Transit	7.76	<0.005	10.71	<0.005
Drive alone	27.94	<0.005	24.85	<0.005
Shared ride	12.60	<0.005	9.72	<0.005

[a] Reject H_0 with $\alpha = 0.05$.

Table 6. Summary of mode change motivations for LBL.

	Changes from Drive Alone to Transit				Changes from Drive Alone to Ridesharing			
Motivation	NA	NI	SI	VI	NA	NI	SI	VI
1. Arrive early to find parking	8	4	4	2	3	4	6	7
2. Use car for errands	9	5	3	1	3	10	2	6
3. Avoid rush-hour traffic	9	4	2	3	1	1	5	15
4. Adjust work schedule to share a ride with a family member	8	5	2	2	7	4	4	6
5. Adjust work schedules to join or form a carpool	13	2	0	2	4	4	6	7
6. Able to use transit even if it is unreliable	1	0	5	12	10	6	2	3
7. Able to use transit when seats are available	1	5	6	6	11	6	1	2
8. Easier to meet transit schedules	1	4	5	8	11	6	0	3
9. Able to save money on gasoline and leave car at home	1	0	3	15	4	2	6	6

Notes: NA = not applicable, NI = not at all or not too important, SI = somewhat important, and VI = very important.

The interpretation is that income-related pressures caused individuals to consider alternative modes, and flextime's freedom from tardiness helped individuals lessen concerns for transit unreliability, allowing them to use public transit for their work trips. The reliability question is particularly important at LBL since more than half of the mode changes were to Bay Area Rapid Transit (BART), which experiences frequent service disruptions, breakdowns, and strikes. Individuals do not appear to be as strongly motivated by the ability to find seats or to buffer schedules as the hypotheses suggest.

Interestingly, mode changers from drive alone to ridesharing reflect a rather different set of concerns. Table 6 indicates that the most important motivation was the ability to avoid rush-hour traffic. Although gasoline prices were not inconsequential (very important for six respondents), the ability to adjust schedules to form a carpool and the ability to arrive early and find a parking space were of nearly equal importance. The use of a car for errands was also important for eight of the respondents.

The importance of the rush-hour avoidance motivation is reflected in the behavior of the new carpoolers. Nearly 62 percent of the new carpoolers saved time in their commute, compared with their travel time when driving alone. They were able to save time by traveling in the off-peak hours (near 7:00 or 9:30 a.m. for the morning commute). Because many of these new carpools have only two occupants, the driver toured to pick up only one passenger, and was able to decrease the total commuting time by traveling when streets and highways were uncongested.

Individuals who shifted to carpools did not have income levels significantly different from those of other carpoolers, but they tended to be newer employees (employed less than 9 years) and were more likely to form two-occupant carpools (with a signficance probability, p = 0.14). Interestingly, the two-occupant carpools were formed with coworkers nearly 70 percent of the time. LBL's relatively isolated location has resulted in a lower number of carpools composed of spouses than the hypotheses would suggest.

Comparisons of the income levels of changers to carpool and transit revealed that the new transit riders had significantly lower household incomes than the new carpoolers. The transit riders had a mean income of $22 000; carpoolers had a mean income of $27 000. More significantly, 84 percent of the new carpoolers had incomes above $20 000; 47 percent of the transit riders had incomes below $20 000. These findings corroborate the survey responses discussed previously: The new transit riders respond more strongly to income pressures, and the ridesharers are availing themselves of a new travel mode facilitated by flextime.

The other motivations listed in Table 6 are of only marginal significance and importance. For example, motivations 6-8 (transit related) were very important for the few individuals who indicated that they occasionally take transit when not sharing a ride. Similarly, two or three of the changers from drive-alone to transit rate factors 1-3 very important because they use the automobile for access to transit (primarily BART).

The other mode changes that were shown in Table 4 occurred for so few employees that analyses of socioeconomic characteristics and motivations could not be conducted.

Only a few of the hypotheses concerning flextime and mode change appear to be prevalent at LBL. Employees have shifted in significant numbers from solo driving to both ridesharing and transit, despite the prevalence of free parking and relatively poor transit service. Changers to transit seem to be strongly driven by increases in gasoline price but are able to use transit without the fear and stress of being late because of service unreliability. Hypotheses concerning schedule buffering and finding a seat during off-peak hours are supported by the findings, but they do not appear to be as strong a motivation as coping with service unreliability.

CBD

Mode-change findings for the three CBD firms are shown in Table 7. The pattern of mode change in these firms is substantially more complex than at LBL. The decrease in solo driving was substantial and significant (19); only one individual shifted to driving alone. There were, however, substantial diversions between transit and shared ride--26 individuals shifted from transit to shared ride and 21 from shared ride to transit. These numbers do not change substantially, even after the gasoline-crisis mode changers are screened.

Table 8 shows the results of hypothesis tests for significant mode changes. Before controls for energy are applied, there is a strongly significant reduction in driving alone and marginal increases in ridesharing and transit use. After the controls for energy shortages, there was only a small decrease in the number of individuals who changed from drive-alone to both transit and shared ride; nearly all of the mode changes were tested as being independent of the energy crisis. There was enough of a decrease in transit riders to make the increase in transit use statistically insignificant; however, the increase in ridesharing was of marginal statistical significance.

The CBD employees were analyzed for mode changes relating to transit and shared ride only because there were so few solo drivers that statistical comparisons were not possible. Concerning shifts to and from transit, trip distance was significant. Interestingly, individuals who had long-distance trips were more likely to shift both to and from transit. For all the mode changes that occurred between ridesharing and transit, trip distance was very significant: The individuals who changed from both ridesharing and transit had significantly longer trip lengths than did those who retained each mode. Commuting is certainly most onerous for these long-distance commuters, so it is not surprising that they are highly represented among the mode changers. The individuals who did change may have been dissatisfied with their previous choices but, until flextime, had no alternative available.

Shifts from transit (which occurred exclusively to shared ride, except for one individual) occurred more frequently for married individuals who have working spouses and in households where incomes are higher (once again, highly corroborative). Comparison of automobile ownership levels indicates that these shifters did not have statistically different levels of automobile ownership from that of individuals who remain transit riders.

Table 7. Summary of mode changes for CBD.

Mode Used Before Flextime	Mode Used with Flextime: Transit	Drive Alone	Shared Ride	Total
Without Energy Controls				
Transit	344	1	26	371
Drive alone	14	14	5	33
Shared ride	21	0	77	98
Total	379	15	108	502
With Energy Controls				
Transit	344	1	26	371
Drive alone	12	14	2	28
Shared ride	20	0	77	97
Total	376	15	105	496

Note: Table entries are the number of respondents who report use of specific modes before and with flextime.

Table 8. Results of hypothesis tests for mode share changes for CBD employees.

Mode	Without Controls for Energy: χ^2	Without Controls for Energy: Significance Probability	With Controls for Energy: χ^2	With Controls for Energy: Significance Probability
Transit	1.035	>0.25	0.42	>0.50
Drive alone	19.78[a]	<0.005	13.44[a]	<0.005
Carpool	1.935	>0.1	1.34	>0.25

[a] Reject H_0 with $\alpha = 0.05$.

Analysis of motivations for mode change (see Table 9) helps to explain the causes for the mode changes. Responses to motivations 4 and 5 indicate that flextime was important in allowing individuals to share rides with family members and adjust work schedules to form a carpool. These results are consistent with the hypotheses that argue for increases in ridesharing. Surprisingly, the most important motivation for these new ridesharers is the ability to avoid the rush hours. In fact, 89 percent of the new ridesharers reported decreased commute times compared with those for their old transit mode, and 79 percent were able to save time by arranging shared rides to arrive at work before 8:00 a.m. (the most congested portion of the peak period). Of the 79 percent who reported time savings, nearly half had work arrival times before 7:00 a.m.; another 35 percent arrived between 7:00 and 8:00 a.m.

The other motivations in Table 9 indicate that former transit patrons still rate the ability to find seats on transit fairly highly (12 of 26 rate it as somewhat or very important). Survey comments indicate that these individuals occasionally use transit and also value the ability to use it if necessary. The great importance of saving money on gasoline is explained by the fact that individuals are comparing their money savings if they drove alone rather than carpooled. Interestingly, the capturing of parking spaces and use of car for errands are relatively unimportant. Remember that these switchers from transit to carpool have long trip lengths; therefore, the concern for congestion avoidance is rational. Commuting corridors in San Francisco are frequently congested for two hours or more during the morning and evening peak periods. These individuals have shifted from crowded, slow-moving transit to ridesharing arrangements that allow travel in the prepeak period with concomitant savings in travel time.

Analysis of individuals who changed from ridesharing to transit yield rather complementary findings. Individuals who switched to transit were frequently single or the sole wage earner. Once again, analysis of automobile ownership levels failed to detect differences, compared with levels for ridesharers who remained in their carpools. As at LBL, however, there appears to be an income effect: Mode changers from shared ride to transit had significantly lower average incomes than did those who retained the ridesharing mode. Further, mode changers from transit to shared ride had a mean income of

Table 9. Summary of mode change motivations for CBD.

Motivation	Changes from Transit to Ridesharing: NA	NI	SI	VI	Changes from Drive Alone to Ridesharing: NA	NI	SI	VI	Changes from Drive Alone to Transit: NA	NI	SI	VI	Changes from Ridesharing to Transit: NA	NI	SI	VI
1. Arrive early to find parking	12	7	3	3	2	0	1	2	6	2	1	5	15	3	0	2
2. Use car for errands	9	8	6	3	2	0	0	3	4	3	2	4	7	4	4	2
3. Avoid rush-hour traffic	7	0	7	12	0	0	1	4	6	2	0	6	12	2	3	3
4. Adjust work schedule to share a ride with a family member	9	1	5	11	3	0	0	1	9	3	1	1	14	3	1	2
5. Adjust work schedules to join or form a carpool	7	4	3	11	1	0	1	3	8	4	2	0	15	3	1	0
6. Able to use transit even if it is unreliable	13	2	7	4	1	0	1	2	1	3	3	7	1	3	5	9
7. Able to use transit when seats are available	13	1	5	7	1	0	0	3	1	1	4	8	2	2	4	12
8. Easier to meet transit schedules	13	3	6	4	1	0	1	2	1	1	5	7	0	3	7	10
9. Able to save money on gasoline and leave car at home	14	1	3	7	1	0	0	3	2	2	1	9	5	0	3	13

Notes: NA = not applicable, NI = not at all or not too important, SI = somewhat important, and VI = very important.

$26 000; however, changers from shared ride to transit had a mean income of $21 000; 62 percent of the new transit patrons had incomes below $20 000, but only 31 percent of the new ridesharers had household incomes less than $20 000. Responses to motivations for mode change in Table 9 support these findings: Saving money on gasoline is the motivation checked as very important by most people. Notice, however, that all the other transit-related motivations are nearly as important. Transit that arrived in the San Francisco CBD was usually very crowded during peak periods; some operations had frequent reliability and schedule-adherence problems as well. It is therefore not surprising that these service-related motivations are ranked high by new transit patrons. Responses to the importance of carpool and automobile-related motivations reflect the use of these modes for access to transit. Table 9 indicates that the pattern of motivations for individuals who change from drive-alone to transit is nearly identical to the results for changes from ridesharing to transit.

In summary, the costs of long-distance commuting appear to bear heavily on the lower-income households that used to drive or ride in an automobile to work. These individuals are able to switch to transit because of the additional latitude that flextime provides to avoid service unreliability, lack of seats, and mismatched schedules, by permitting them to arrive at work in the prepeak period. Ridesharers also travel in the prepeak hours, but do so to avoid rush-hour congestion, and arrive at work (and home) earlier in the day.

SUMMARY

Only some of the hypotheses discussed appear to have motivated mode changes at the firms studied. Individuals at the CBD firms were most easily able to share rides with spouses, but at the more isolated site (LBL) this was not a major phenomenon. Neither group of individuals showed a significantly increased incidence of ridesharing with individuals at other firms. Surprisingly, at both sites these new ridesharers were attracted by the ability to avoid congestion as much as (if not more than) by the flexibility to form new carpool arrangements.

New transit riders were strongly motivated by income constraints and increased gasoline prices, but flextime allowed them to deal with unreliable transit service (particularly on BART), and to travel during times when seats were available on transit vehicles. The hypothesis of schedule buffering did not receive much support for either group of employees.

In many ways, the most satisfying finding was the significant decrease in solo driving for both the LBL and CBD groups as well as for the survey pretest. For the individuals in this study, the freedoms available to avoid the rush hour, find parking spaces, and arrange work schedules to use a car for errands were not sufficient inducements to increase solo driving in large numbers. In fact, many new ridesharers were able to avail themselves of these opportunities while traveling with a spouse or coworker.

Flextime did not favor any one mode over all others. Clearly, each of the individuals who changed modes had improved commuting time as a result. Society as a whole can be said to benefit by the decreased numbers of solo drivers. To answer the question originally posed as the motivation for this research: Yes--flextime is compatible with ridesharing and transit promotions, according to the responses to our study. Note, however, that only one of the many variants of flextime was studied. It is hoped that the findings help allay fears of transportation professionals regarding flextime and mode change.

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Assessment of Flextime Potential to Relieve Highway Facility Congestion

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Travel surveys of flextime workers at three firms in downtown San Francisco are used to assess the potential impact of flextime for relief of congestion on a freeway facility. The changes in work schedules for the survey respondents are extrapolated to reflect the effects of a large, areawide flextime promotional campaign. The freeway-corridor model FREQ was used to investigate two simulation scenarios. The first scenario resulted in few vehicles (less than 4 percent) changing their times of travel but yielded substantial improvements in facility traffic flow. The second scenario resulted in a much larger number of vehicles changing their time of travel, and actually revealed a worsening of traffic-flow conditions on the Bay Bridge. Interpretation of the simulation results vis-à-vis the survey responses of individuals at the three firms indicates that these worsened traffic conditions are unlikely to occur for extended periods of time or on facilities that have different operating characteristics. It is clear that very few vehicles need to change their time of travel to have facility impacts, and that the numbers of vehicles needed are within the reach of modestly successful flextime promotion campaigns. Interpretation of the simulation findings generally supports the promotion of flextime programs by transportation professionals to provide clear travel benefits to program participants, and possible travel benefits to users of a freeway facility who do not have flexitime privileges.

Since the inception of the transportation system management (TSM) regulations in 1975 (1), alternative work schedules have been included in the list of tactics to be considered in the attempt to better manage the existing transportation system. Proponents of these tactics hope that the removal of a few individuals from the peak will result in decreased congestion for travelers who remain peak-period commuters.

Several areawide demonstrations have already illustrated the effects of two alternative work-schedule policies--staggered work hours and flextime. A major promotion of staggered work hours in New York City (2-4) reported decreased peaking at several subway stations in the study area (e.g., passenger counts at the three busiest subway stations decreased by 6 percent in the peak 10 min). Even more dramatic decreases in peak flows under flextime and staggered work hours were reported in Toronto (5). Before the demonstration, peak passenger flows occurred between 8:00 and 8:30 a.m.; after six months of the demonstration program, the peak shifted to between 7:45 and 8:00 a.m. and flattened considerably. Many people traveled before 7:45 a.m. and considerably fewer traveled during the former peak.

These studies provide evidence of reduced peaking for subway lines; however, the situation for bus and highway systems is less clear. Results of a work-schedule promotion in Ottawa (6) indicate that traffic flows at screenlines and parking facilities changed during the promotion, but the effect of changes in the work schedule could not be separated from seasonal flow variations and the influence of the 1973 energy crisis.

Several recent studies have reported changes in the quality of the commute for individuals who have flextime. Findings from Albany, New York (7); Cambridge, Massachusetts (8); and San Francisco, California (9), indicate that individuals who have flextime were able to save up to 15 min in travel time by commuting during the off-peak period.

Two studies used analytic models to examine impacts of alternative work schedules. Tannir and Hartgen (10) used transportation planning models to assess areawide impacts of a hypothetical four-day workweek at the New York State Department of Transportation in Albany, New York, and found 4-9 percent reductions in vehicle kilometers of travel near the work site, but negligible impacts areawide. Jones and others (11) used a freeway-corridor simulation model (FREQ) to study corridor impacts of flextime promotions in San Francisco. The analysis assumed that time shifts would occur to eliminate congestion during the peak period. The results of eliminating congestion were a 16 percent decrease in travel time; 1.4 percent decrease in fuel consumption; and 6-7 percent decreases in hydrocarbon and carbon-monoxide vehicle emissions for the evening peak only.

These findings suggest that areawide impacts are likely to be negligible, but that impacts at the corridor level (particularly for heavily traveled freeway corridors) are possible. Stronger conclusions are not possible because both studies were based solely on hypothetical work schedules. Tannir selected the four-day workweek because it was most popular in a survey of preferred work schedules (12). Jones did not have data on the time of actual work trips before and after flextime. He conducted the research as an if-then experiment, i.e., if the peak were eliminated, then the stated impacts would result.

This paper uses actual changes in work schedules reported by individuals who have flextime and extrapolates them to a hypothetical areawide promotion to determine whether the changes in work schedules result in decreased congestion for nonflextime travelers.

FLEXTIME TRAVEL SURVEY

Data concerning the changes in travel patterns of individuals who have flextime were collected at three firms in downtown San Francisco in mid-1979. Two of the firms, Chubb-Pacific Indemnity and Metropolitan Life Insurance, are regional offices for insurance companies. The largely clerical and administrative work forces at these offices process insurance applications and claims and maintain company records. The third firm, Standard Oil of California, is a corporation headquarters operation that has a small portion (approximately 10 percent) of its nearly 3000-person work force on flextime.

All three firms have a nearly identical flextime policy. Employees may start work between 7:00 and 9:30 a.m. and are required to put in a full work day during each weekday. Nearly all employees can vary their start time daily, although the surveys indicated that few chose to do so. The number of survey responses from each firm varied widely: 309 from Metropolitan Life, 153 from Chubb-Pacific, and 89 from Standard Oil (a 46 percent overall response rate).

All three firms are located in the San Francisco financial district, an area of intense high-rise development that has the following transportation system supply features:

1. Transit access is extremely good for all commuting corridors. Streetcars, buses, and trolley coaches provide access for San Francisco residents and transfer passengers. A Bay Area Rapid Transit (BART) rail rapid-transit line runs under Market Street, which is within walking distance of all three offices.
2. Parking costs average $3-$6/day and are not provided by any of the three employers. None of the employers provides subsidized parking for carpools or vanpools.
3. Automobile access to the financial district is very difficult during peak periods; bridge access to the north and east and limited highway access from the south combine to produce delays that are commonly 15-20 min. Both bridges have priority treatments for bus and carpool travelers.

Further details of the data-collection procedure are contained elsewhere (13).

STUDY SITE--OAKLAND BAY BRIDGE

The westbound Oakland Bay Bridge was selected as a study site because of the availability of previous reports by the Institute of Transportation Studies (ITS) at Berkeley, California (14), and because of ongoing data collection sponsored by the Urban Mass Transportation Administration (UMTA) (15). The westbound Bay Bridge is fed by a 0.75-mile-long approach roadway that leads to a toll plaza. The plaza has 17 booths, 3 of which are dedicated to priority vehicle traffic. In the morning peak period, queues due to toll collection frequently spill back beyond the beginning of the priority lanes, so that even priority vehicles (buses and carpools that have three or more occupants) are delayed on the bridge approach.

An additional device used for priority treatment is a set of traffic signal meters approximately 0.25 mile downstream of the toll. The meters control flow onto the bridge itself, so that queues do not form on the bridge upgrade. Priority vehicles pass through the meters directly, but nonpriority traffic is subject to additional delays that can reach 3-5 min during peak congestion.

Congestion on the approaches to the Bay Bridge is a serious problem from 6:30 to nearly 9:15 a.m. each morning. Peak traffic delays, which occur near 7:30 a.m., frequently exceed 15 min. Considering the duration of congestion (6:30-9:15 a.m.) and its intensity (15-min delays), the westbound Bay Bridge is one of the most heavily congested facilities in the Bay Area.

The conditions described above were typical of Bay Bridge operations during 1978. Because of two BART closings and the nationwide gasoline shortages, traffic conditions on the Bay Bridge varied widely during 1979. For this reason, 1978 conditions were taken as a baseline for the flextime simulation studies.

The FREQ model's basic structure involves division of a directional facility (freeway) into subsections of equal capacity and division of time into discrete slices (usually of 15 min). For each subsection the user specifies the total freeway capacity, number of lanes, geometric information (e.g., gradient and curvature), and a function that describes the speed-flow relation for the traffic on the roadway. For each time slice the user provides origin-destination tables of the number of vehicles that demand service (traffic demand) from each freeway on-ramp (origin) to each off-ramp (destination) (14).

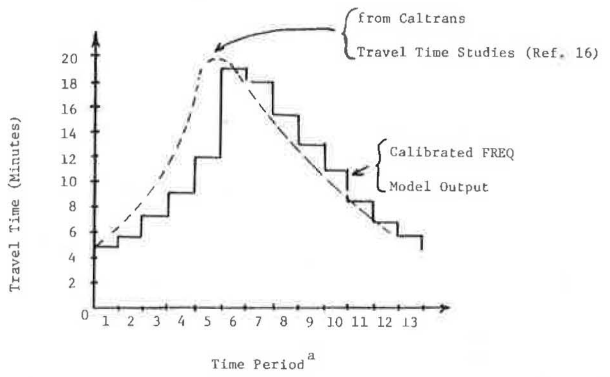
By applying the 15-min traffic demand to the described freeway facility, the peaking pattern of traffic and its associated queues and delays can be replicated. The model, when properly calibrated, has been shown to be an accurate predictor of freeway travel conditions. The basic simulation outputs of speed and travel distance are used to compute fuel consumption and vehicle emission impacts for the vehicles on the facility. Data from the 1971 ITS Bay Bridge study (14) were modified to reflect 1978 geometrics and traffic demands.

Figure 1 compares travel times for the study section from the California Department of Transportation (Caltrans) field studies (16) and from the FREQ model. Caltrans engineers familiar with Bay Bridge operations examined these and additional model outputs and agreed that the FREQ model provided a reasonable representation of 1978 traffic-flow conditions for incident-free conditions and good weather. Further details of model calibration can be found elsewhere (13).

COMPARISON OF FLEXTIME TRAVEL SURVEY WITH OTHER BAY AREA TRAVEL SURVEYS

The flextime survey results were compared with a Metropolitan Transportation Commission (MTC) workplace survey (17) and with travel modeling results conducted for MTC by Harvey of ITS (18). Both the MTC and ITS studies included employees from areas outside of the financial district but were used to test the representativeness of the flextime survey data.

Figure 1. Travel time by time of day for Oakland Bay Bridge: base conditions.



^a Time Periods are 15 minutes in duration, starting at 6:30 a.m.

The mode shares from the three surveys (Table 1) are dramatically different. Conversations with MTC officials indicated that the survey questions that relate to the shared-ride mode may not have been correctly interpreted by survey respondents. The mode share developed by Harvey for shared ride was acknowledged to have been more representative of travel conditions in 1978. Further comparisons between the MTC and flextime surveys were conducted for occupational classification, age, and household income to determine whether the mode share differences resulted from transportation supply differences or from differences in the individuals surveyed.

The flextime survey had nearly the same proportion of managers and professionals as did the MTC survey but had a much higher proportion of clerical workers (Table 1). One can argue that clerical workers are heavy transit users, thus the low automobile mode shares are explained; however, when mode shares were cross-tabulated with occupation, the shares were consistent across occupational groups among the flextime employees. The implication is that the high transit mode share at the flextime firms may be due largely to the locational characteristics at the financial district: superior transit access, high parking cost, and heavy automobile congestion.

This conclusion was strengthened by additional survey comparisons. The age distribution of the survey respondents was not statistically different--a chi-square test fails to reject the hypothesis that the flextime results were drawn from a population characterized by the MTC results. The income comparison (discounting to the same base year) resulted in rejection of the hypothesis that the income distributions were the same. The flextime sample had fewer low-income households and more in the $40 000 and higher category.

The conclusion is that the results of the flextime survey are not directly comparable to those obtained by MTC, particularly regarding composition of the work force and mode share. The composition of the work force is at least partly explained by differences in the types of firms surveyed, and the differences in mode share seem to be due to the locational attributes of the three financial district firms. To assess the implications of these findings for a transportation facility, it is proposed to conduct one simulation by using data primarily from the flextime survey and a second simulation by using mode shares and other travel data from the MTC and ITS surveys. The first simulation is called the financial district scenario, and the second simulation is called the central business district (CBD) scenario. The experimental design, revised for the alternative scenario analysis, is shown in Figure 2.

Financial District Scenario

The procedure used to estimate the facility impacts is outlined below and is summarized on the following pages. Further details of the procedure are given elsewhere (13).

1. Determine total number of new flextime employees,
2. Use proportion of people traveling from the East Bay to determine transbay person trips,
3. Use mode shares before flextime to place people in a mode (single-passenger automobiles, carpools that have two occupants, carpools that have three or more occupants),
4. Use ridesharing data to convert person trips by mode to vehicle trips,
5. Use survey mode shares after flextime to account for mode shifts,
6. Translate work arrival times at the workplace to approach arrival times at Bay Bridge,
7. Distribute vehicles from time period of travel before flextime to time period of travel with flextime,
8. Alter FREQ origin-destination tables to account for vehicle time shifts, and
9. Compare basic FREQ6T simulation without flextime to simulation with altered origin-destination tables from step 8.

The first step in the analysis is to determine the number of employees expected to participate in the promotion. This study used 25 000 individuals, which represents approximately 10 percent of the downtown work force. The flextime travel survey indicated that 35 percent of the respondents live in the East Bay (and use the Bay Bridge for commuting). The mode shares before flextime were 6 percent drive alone, 18 percent carpool, 68 percent transit, and 8 percent other. These mode shares result in 525 drive-alone persons and 1575 person-trips in carpools from the East Bay.

Once we know that the proportion of two-occupant carpools in the sample is 36 percent and that the average occupancy for carpools that contain three or more people is 3.44 for the Bay Bridge, we can find the number of carpool vehicles by simultaneously solving

$$1575 = 2x + 3.4y \tag{1}$$

$$z = x + y \tag{2}$$

$$x = 0.36\,z \tag{3}$$

where x and y are the number of two-occupant and three-or-more-occupant carpools, respectively, and z is the total number of carpool automobiles. The computations yield x = 196, y = 348, and z = 544. Therefore, an hypothesized flextime promotional campaign that has 25 000 new flextime employees would directly affect 525 drive-alone vehicles and 544 carpools on the Bay Bridge.

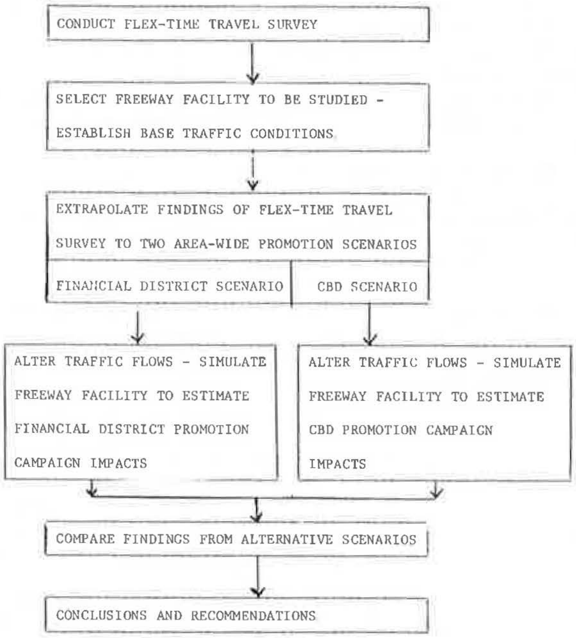
The next step is to account for mode changes expected to occur with flextime. Although detailed analyses of flextime mode changes, reported in my other paper in this Record and elsewhere (13), indicate general decreases in driving alone and increases in transit use, they could not completely isolate the effect of flextime from other influences on mode change, such as the increased price and decreased availability of gasoline. The motivations

Table 1. Comparison of flextime travel survey findings and other San Francisco travel studies.

Item	MTC Workplace Survey (%)	ITS (%)	Flextime Survey (%)
Mode			
Drive alone	25.7	32.4	6.4
Shared ride	8.3	21.5	18.4
BART	18.2	46.2[a]	25.0
Bus	39.2		42.7
Walk	5.1		2.1
Other	3.5		5.2
Occupation			
Professional	17.2		19.6
Clerical	45.1		61.9
Managerial	16.9		14.6
Technical and other	20.8		3.9

[a] BART and bus combined.

Figure 2. Revised design of experiment.



for mode change, however, clearly indicate that flextime provided opportunities to form carpools and use transit in the face of service unreliability. These opportunities provided by flextime were essential in the decision to change mode. The flextime procedure will, therefore, use the reported mode changes that occurred for the three financial district firms. The mode shares after flextime were 3 percent drive-alone, 20 percent carpool, 69 percent transit, and 8 percent other. These mode changes result in a decrease of 262 single-passenger automobiles and increases of 22 two-occupant automobiles and 38 three-occupant carpools. Mode changes to transit were assumed to be assimilated into existing services because of this study's focus on highway congestion. In practice, mode changes and time shifts of flextime travelers may bring pressures to stretch transit service. Although this is an important consideration, it is beyond the scope of this paper.

Automobiles that contained flextime travelers were shifted one-half hour from their reported start time before flextime to account for travel from the Bay Bridge to the workplace (including in-vehicle travel time, parking, and walk access). Thus, an individual who reported to work at 8:10 a.m. was located at the Bay Bridge approach at 7:40 a.m. (time slice 7).

Vehicles were then shifted from the time slice that represents their travel before flextime to a time slice that reflects their time of travel with flextime by using data in Figure 3. Data from all downtown automobile and carpool trips were used to construct the figure. It would have been preferable to develop separate tables for automobile and carpool and to use data for travelers who come from East Bay only. These considerations would have resulted in the construction of a 169-cell diagram with an extremely small sample size (less than 30). Cross-tabulation results for the limited observations indicated very small differences in carpool and automobile arrival times and in arrival times for East Bay residents compared with all residents in the sample. The conclusion was that Figure 3 was the most reasonable one to use for a hypothetical study of 25 000 flextime employees. The diagram is used by considering horizontal slices as the distribution of vehicles from a time slice before flextime to new time slices after flextime. For example, if one considers the row for time slice 2 before flextime, the diagram indicates that 75 percent of the travelers remain in time slice 2, but the remaining 25 percent shift from time slice 2 to time slice 6.

The diagram assumes that changes to the work schedule do not vary. Although flextime employees have the ability to vary work schedules daily, previous research indicates that most individuals select a favorite work schedule and stick to it (9,13). Figure 3 can therefore be regarded as representing these favorite work schedules.

The final step is to alter the FREQ origin-destination tables to reflect the time shifts shown in Figure 3 and to compare simulation results for the financial district scenario and the base conditions.

Figure 4 shows the queuing diagram for the Bay Bridge with the financial district flextime program in effect; comparison with the base conditions reveals several important changes. First, queuing is initiated during time slice 2 rather than time slice 3. Further, queue lengths in time slices 2-6 are longer than or as long as those that occurred without flextime. These increased queues were caused by the changes to earlier time periods of travel that were illustrated in Figure 3. However, after time slice 6, queues with flextime are shorter than before flextime. Congestion now terminates in time slice 10 rather than time slice 13. The duration of congestion has shortened by half an hour, and has been shifted in time by 15 min.

The aggregate effects of the financial district flextime program are summarized below.

Item	Percentage Change Financial District	 CBD Scenario
Travel distance	-1	0
Travel time	-8	10
Gasoline	-3	5
Hydrocarbons	-6	9
Carbon monoxide	-7	10
Nitrous oxide	3	-8

The overall effects are quite positive: a 1 percent reduction in travel distance (due to the mode changes from solo driving to both carpools and transit); a substantial reduction (8 percent) in vehicle hours of travel; and fuel and vehicle-emissions savings. The exception is the 3 percent increase in the emission of nitrous oxides, an inevitable result when travel speeds increase.

These aggregate benefits are very promising;

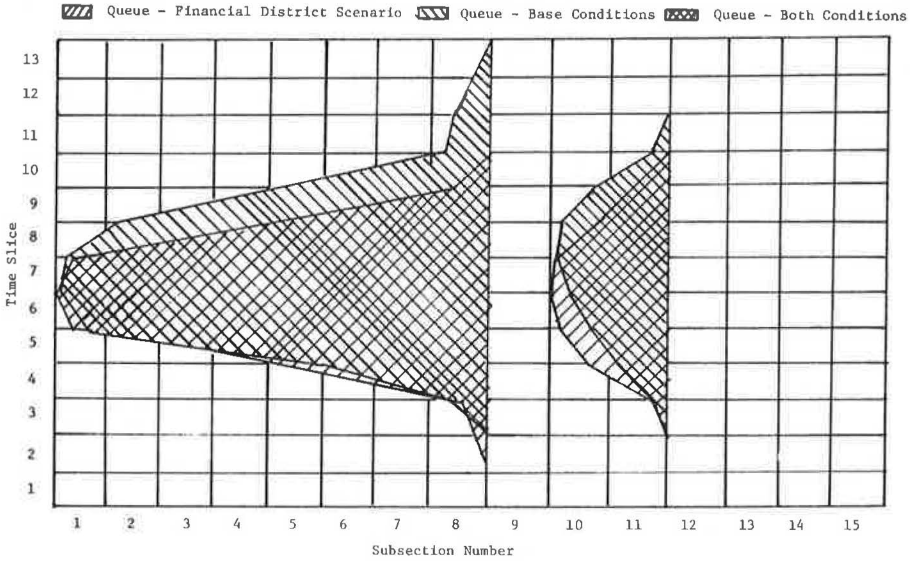
Figure 3. Distribution of flextime workers before and after flextime.

Time Slice After Flex-time

Time Slice Before Flex-time	1	2	3	4	5	6	7	8	9	10	11	12	13	Row Total
1	100.0													3.2
2		75.0				25.0								4.2
3	50.0	25.0	25.0											4.2
4				66.7	33.3									3.2
5		25.0	12.5	12.5	37.5	12.5								8.4
6		27.8	5.6	5.6	5.6	33.3	11.1				11.1			18.9
7	10.0	5.0	15.0	15.0	25.0	10.0	15.0	5.0						21.0
8	7.7	26.9	11.5	23.1	7.7		15.4			7.7				27.4
9	11.1	11.1	11.1	11.1			11.1		11.1	11.1			11.1	9.5
10														0.0
11														0.0
12														0.0
13														0.0
														100.0

Note: Table entries are row percentages of the row total.

Figure 4. Queuing diagram of Oakland Bay Bridge-financial district flextime promotion.



however, an even more interesting perspective of flextime is obtained by examining the distribution of the travel-time savings for various groups in the Bay Bridge driving population. A presentation of these benefits is illustrated in Figure 5, which displays travel-time differences for a trip that travels the entire length of the study section. The diagram is similar to Figure 3, except that it displays travel-time differences rather than numbers of vehicles. The figure is interpreted as follows: Entries along the diagonal (dark squares) represent travel-time changes for two groups of travelers, those who have flextime who did not change their trip timing and nonflextime travelers. For example, the diagram shows a 0.2-min increase in travel time for travelers in time slice 2 after flextime. All cells below the diagonal represent travel time changes for flextime travelers who shifted to earlier work arrival times, and entries above the diagonal represent changes to later work arrival times.

Concerning all travelers in time slices 1-6 after flextime, the distribution of travel-time changes may be summarized as follows:

1. Flextime travelers who shifted to earlier time periods (particularly to time slices 1-4) saved substantial amounts of time--one group saved 12.8 min and five other groups of flextime travelers saved more than 5 min.
2. Flextime travelers who shifted from earlier time periods to time slices 5 and 6 generally had longer travel times (4.9-13.6 min longer). These shifts to more congested time periods are rational when considered with respect to survey responses that indicated that office needs and family schedule coordination influence some individuals to arrive at work near 8:00 a.m., which would necessitate travel in periods 5 and 6 (8,13).
3. Nonflextime travelers and those who had flextime who retained old work schedules experienced generally small increases in travel time. The increases were generally caused by flextime travelers who shifted to earlier time periods. Although the flextime travelers saved time in doing so, they imposed additional delays on other travelers of those earlier time periods who were unable to shift.

The distribution of travel-time savings for

Figure 5. Travel differences for flextime and nonflextime travelers in nonpriority vehicles: financial district flextime program.

Time Slice After Flex-time[a]

Time Slice Before Flex-time	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.0												
2		0.2				13.6							
3	-1.6	-0.8	0.3										
4				0.8	4.9								
5	-7.3	-6.5	-5.4	-2.6	1.6	6.9							
6		-12.0	-10.9	-8.1	-4.0	1.3	-1.1						
7		-11.2	-10.1	-7.3	-3.2	2.1	-0.3	-3.6			-11.5		
8	-10.2	-9.4	-8.3	-5.5	-1.4		1.5	-1.8		-8.0			
9	-7.8	-7.0	-5.9	-3.1			3.8		-2.8	-5.6			-7.5
10										-3.0			
11											-2.6		
12												-2.0	
13													-0.7

[a] Table entries are changes in travel time (minutes).

travelers after time slice 6 is dramatically different for both flextime and nonflextime travelers. There are consistent travel-time savings for nonflextime travelers and for those who had flextime who did not change time periods (those along the diagonal from time slice 7 to 13). The time savings were as small as 0.3 min and as large as 3.0 min. The savings were caused by the shift of travelers from later to earlier time periods and also by the fact that congestion ended earlier with flextime (time slice 10) than before flextime (time slice 13).

Entries below the diagonal indicate that flextime workers who shifted from time slices 8 and 9 to time slice 7 experienced an increased travel time in doing so. As before, these shifts are rational, according to survey analyses that reveal office needs and family schedule coordination as motivations for work arrivals near 8:00 a.m. (travel in time slice 7 at the bridge would place individuals downtown between 8:00 and 8:15 a.m.).

All flextime travelers who shifted to later arrivals (those above the diagonal) saved time in doing so. Four groups of travelers saved more than 5 min; the largest time savings were for those who shifted from time slice 7 to 11. Once again, these changes in time period are rational with regard to survey findings that reveal desire to sleep late as the major motivation for later work arrivals.

Alternative Flextime Scenario--Promotional Campaign Throughout the CBD

The same 25 000 flextime employees were used as a target of the CBD flextime promotional campaign. Data from the MTC workplace survey indicate that 23 percent of the CBD trips originate in the East Bay; this yields 5750 person-trips. Mode shares before flextime were taken from transportation planning analyses by Harvey (18). The analyses were used to obtain mode shares for CBD employees who live in the East Bay, as follows: 28 percent drive-alone, 16 percent ridesharing, and 56 percent transit. These mode shares yield 1610 solo drivers and 920 people in carpools. The average carpool occupancy for the CBD is 2.44 (18), which yields 377 carpool vehicles. As in the financial district scenario, mode shares were decreased by 3 percent for drive-alone and increased by 2 percent for ridesharing and 1 percent for transit. The CBD scenario thus resulted in 1861 vehicles that have the possibility of changing their time period of travel on the Bay Bridge.

The queuing diagram in Figure 6 illustrates the Bay Bridge congestion with the hypothetical CBD area flextime program. The queuing starts one time slice earlier and terminates one time slice earlier, but the queues are much longer in time slices 4-7 than they were in the base conditions. The implications of this increased queuing are revealed in the previous table. There is a very small decrease in vehicle mileage due to mode changes, but there are substantial increases in all other impacts except nitrous oxides. The findings are generally very unfavorable and very different from those obtained for the financial district analysis. Analysis of the diagram in Figure 7 helps to explain why these travel-time increases occurred.

Considering entries along the diagonal, all individuals who retained old work-start times have increased travel times during time periods 1-6. The size of the travel time increases are much larger than those observed in the earlier simulation (Figure 5). In fact, all travelers who retain work schedules in time slice 5 have their travel time increased by 8.2 min. Interestingly, entries below the diagonal for time slice 4 and earlier generally show travel-time savings. However, all travelers in time slice 5 after flextime (the vertical column) have increased travel times (one by 11.5 min).

Examination of Figure 8 illustrates what has caused these results. Use of the methodology described resulted in a very large number of vehicles (216) being added to time slice 4. These additional vehicles caused rapid queuing, which made the addition of only 99 vehicles to existing traffic demands at time slice 5 an even more serious problem. If one examines the vertical column for time slice 5 after flextime, one can see that all travelers of that time period have much higher travel times. Given the findings in the literature (8,13) regarding the importance of avoiding the rush hours, it seems unlikely that many travelers would actually remain in time slice 5 for very long. Those who have flextime would seek to find alternative, less congested time periods. When considering the results in this perspective, it appears that these travel conditions may exist on the first day of operations, but eventually flextime travelers will find more suitable times to travel and probably produce less delay for others (nonflextime travelers).

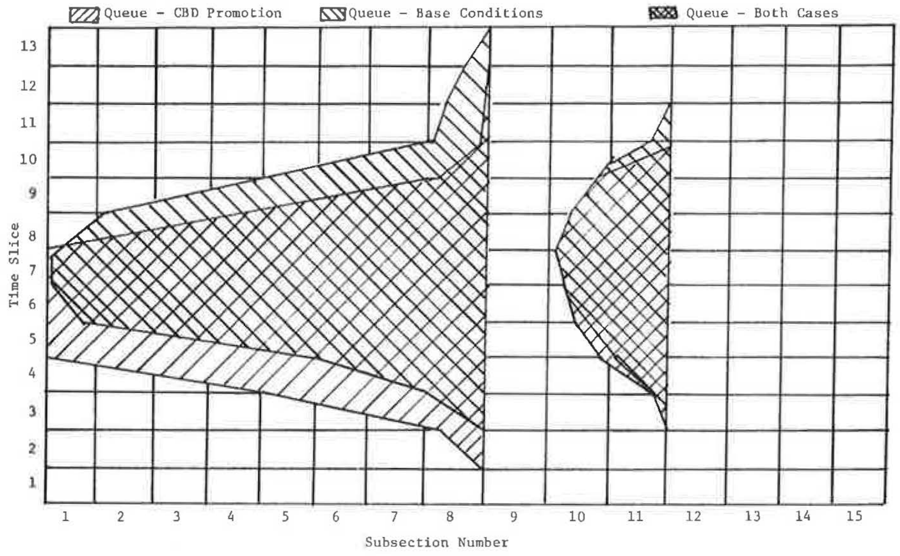


Figure 6. Queuing diagram of Oakland Bay Bridge: CBD flextime promotion.

Figure 7. Travel time differences for CBD flextime program.

Time Slice After Flex-time

Time Slice Before Flex-time	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.1												
2		1.1				13.5							
3	-1.5	0.1	2.6										
4				4.8	11.5								
5		-5.6	-3.2	1.4	8.2	6.8							
6		-11.2	-8.7	-4.1	2.6	1.3	-1.2				-11.8		
7	-12.0	-10.4	-7.9	-3.3	3.4	2.1	-0.4	-2.3					
8	-10.2	-8.6	-6.1	-1.5	5.2		1.4	-0.5		-7.6			
9	-8.1	-6.5	-4.1	0.5			3.4		-2.4	-5.5			
10										-2.6			
11											-2.1		
12												-1.8	
13													-0.7

The findings for time slices 7-13 are similar to those for the financial district alternative. Travelers who retained existing work hours had decreased travel times, which ranged from 0.5 min to about 2.5 min. Travelers who changed from time slices 8 and 9 to time slice 7 had increased travel times.

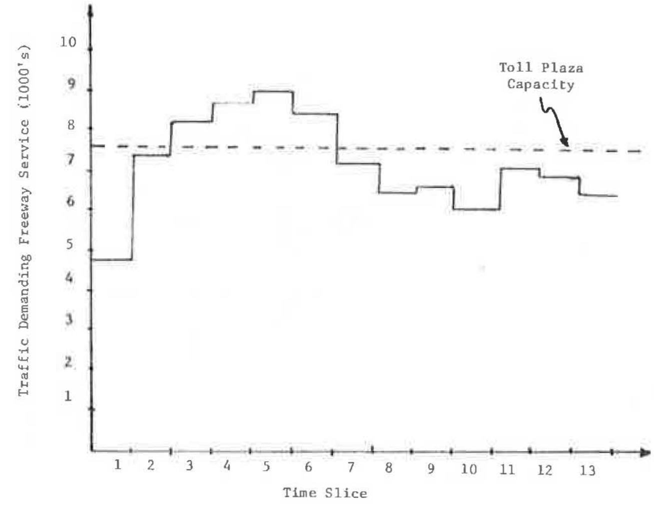
The major finding of this simulation of this areawide plan is the substantial negative consequences that ensue. Congestion was actually worse with the hypothetical program than before. Although some of the work-arrival time changes inherent in the scenario are unlikely, the analysis does suggest one boundary condition where negative impacts are possible with flextime.

SUMMARY

This paper described the use of a freeway-corridor-traffic simulation model, FREQ, to study the effect of flextime promotional campaigns on traffic operations at the Oakland Bay Bridge. Two hypothetical flextime programs were tested by using the model. The first simulated the effect of a flextime promotional campaign that concentrated on the financial district and resulted in employees with travel characteristics from that area being placed on flextime. Because of rather small automobile and carpool mode shares, this scenario resulted in a rather small number of vehicles changing time periods of travel. Nevertheless, substantial travel-time savings accrued overall, as well as fuel consumption savings and carbon monoxide and hydrocarbon pollutant decreases. Nitrous oxides increased, an inevitable result when travel speeds improve.

The second scenario examined a hypothetical flextime promotional campaign in the CBD as a whole. Employees had mode shares that were close to average values for the San Francisco downtown. The results of the simulation studies were strongly negative: travel time, fuel consumption, carbon-monoxide emissions, and hydrocarbon emissions increased substantially. Only nitrous oxide emissions decreased. The negative results were due to the large numbers of vehicles that changed to earlier time periods, which resulted in increased congestion early in the morning (6:15-7:30 a.m.). Survey responses indicate that this phenomenon is unlikely to occur for extended periods of time, as most flextime travelers value avoiding rush hours very highly. It is, therefore, likely that these travelers would shift to some other time periods where they would individually save some travel time (a new traffic equilibrium would be established).

Figure 8. Traffic demand versus capacity at Bay Bridge toll plaza: base conditions.



Note: Time Slices are 15 minutes in duration, starting at 6:30 a.m.

The simulation findings provide a basis for suggesting expected impacts of flextime promotions in alternative operating environments. The interpretation of the research findings indicated that three traffic-flow characteristics strongly affected the simulation results for the Bay Bridge.

First, the degree of peaking at the Bay Bridge was relatively steep (see Figure 8); traffic demands exceeded facility capacity for only 1 h of a more-than-3-h peak period. Second, the duration of congestion is long (3 h), because of the number of time periods when traffic demands are close to but do not exceed capacity. The large number of these time periods means that queues formed when demands exceed capacity take a long time to dissipate; congestion is therefore of long duration. Third, the Bay Bridge is one of the few travel corridors into San Francisco from the East Bay. The lack of alternative routes partly explains the peak and long-duration queuing that occur on the bridge. More importantly, perhaps, the lack of alternative routes causes all changes in flextime travel patterns to be focused on one route rather than dispersed on a number of commuting corridors.

The effects of these three factors are illustrated in the table below, which summarizes expected impacts of flextime promotional campaigns in various operating environments.

Operating Environment	Expected Impact
Few travel corridors, traffic heavily concentrated	
Intense congestion of extended duration	Congestion improvement or degradation possible; recommend detailed site-specific studies to assess reserve capacity
Intense congestion of brief duration	Strong likelihood of travel-time savings, either small or large
Little congestion	Small traffic impacts, primary benefits to flextime travelers; may shift incidence of congestion to earlier time periods

Operating Environment	Expected Impact
Many travel corridors, traffic spatially dispersed	
Intense congestion of extended duration	Improvement or degradation possible; risk of increased congestion on some facilities near major generators; recommend site-specific analysis
Intense congestion of brief duration	May have small traffic benefit near large generators
Little congestion	Small traffic impacts; small chance of shifting the incidence of congestion to earlier time periods

The environment studied via simulation can be considered as operating environment number one. When small numbers of automobile drivers are placed on flextime, the outcome is likely to be positive at the facility level. When large numbers of automobile drivers are on flextime, the CBD scenario revealed that this operating environment runs the strong risk of increased congestion for nonflextime travelers. In particular, facility demand-capacity diagrams (see Figure 8) may be helpful in assessing potential facility impacts. Analyses showed that a moderate number of individuals on flextime may result in substantial increases in travel time, fuel consumption, and vehicle emissions. One can use the facility peaking data to see where spare capacity is available, then decide if flextime is likely to shift traffic into those time periods.

For facilities that have highly peaked traffic patterns (case 2), the likelihood is that substantial travel-time savings will result. There is a slight chance of retaining existing congestion and moving it earlier with flextime; but this seems unlikely based on flextime arrival profiles collected in this research. Many individuals changed work arrival times by more than an hour--this should be sufficient to have large facility impacts when only a few individuals are on flextime.

Operating environments that have few travel corridors and congestion is not peaked can generally expect small facility impacts, since there would be little delay during base conditions. Primary benefits in these environments are likely to accrue to flextime travelers.

In areas that have many travel corridors, the effect of areawide flextime promotion is likely to be diluted. If traffic flows result in highly peaked and spread congestion on many routes (as is the case in cities like New York or Los Angeles), then there is a chance of increased facility congestion, particularly for highways near large generators that adopt flextime. In this case, the individual travelers will benefit but may impose some additional costs on nonflextime travelers.

In areas that have many travel corridors that have highly peaked traffic flows, small, facility-specific improvements in travel time are likely, and larger savings, again, accrue to highways near large traffic generators that adopt flextime.

Areas with many travel corridors and generally spread traffic flows are likely to experience minor facility impacts. The major effect will be the individual benefits that accrue to travelers with flextime.

In summary, the travel implications of areawide flextime programs argue for their active support by transportation agencies. Significant travel and personal benefits occur for the individuals who have flextime: opportunities to avoid congestion, plan evenings with family and friends, resolve household schedule conflicts, have a more comfortable and worry-free commuter trip on transit, and coordinate ridesharing arrangements with spouse of coworkers (8,9,13). The simulation studies indicate that relatively small numbers of automobile travelers who have flextime can have substantial effects on congestion on the highway traffic system. In the financial district scenario, only 1069 of more than 21 000 peak-period vehicles belonged to flextime travelers, yet their changes in travel resulted in substantial aggregate travel-time savings. Clearly, very few vehicles need to change their time of travel to have facility impacts, and the number of vehicles needed are within the reach of modestly successful flextime promotional campaigns.

Even in areas that experience small aggregate travel-time increases, there are still substantial travel benefits that accrue to flextime travelers. The situation faced by policymakers is not unlike that involving the decision to install traffic signals at intersections: traffic on side streets and pedestrians are provided safe access at the cost of additional delays imposed on main-street travelers. There is a clear decision to provide benefits to some groups of travelers at the expense of others. With flextime, the benefits clearly go to individuals who participate in the program, and possibly to nonflextime travelers through decreased traffic congestion. Even in areas where small increases in congestion may occur, flextime is still a policy worth advocating and pursuing.

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Fuel Saving Potential of Low-Cost Traffic Engineering Improvements

J.W. HALL

The objective of this project was to develop priorities for certain low-cost urban traffic engineering improvements based on their potential for saving fuel. The study procedure involved the use of a test vehicle equipped with a precision fuel meter. Test runs were conducted on selected routes in Albuquerque and in off-road simulated conditions. Data from the field tests were processed with linear regression techniques to develop a model for the prediction of a rate of fuel consumption. The principal independent variable in the model is the rate of vehicular motion, although a correction for gradient is required to provide consistency between the model and the results of field tests. The model was applied to certain traffic improvements that could not be evaluated through before-and-after field tests. With respect to fuel saving, the most cost-effective improvements were found to be flashing signal operation, use of longer curb radii, and better use of existing coordinated signal systems and one-way streets. Pedestrian grade separations at school crossings cannot be justified solely on the basis of fuel savings, and the operation of neighborhood traffic diverters was found to result in an excess of fuel use.

Virtually all studies of energy consumption in the United States report that approximately 25 percent of the energy used is devoted to transportation. Although all modes contribute to this consumption, highway vehicles account for nearly 80 percent of the transportation-related energy consumption (1). These facts, coupled with the exclusive reliance of highway vehicles on petroleum products, have prompted a broad-based examination of methods for reducing automotive fuel consumption. The technical literature reports on a variety of techniques for reducing automotive fuel consumption. The principal methods are increases in efficiency of energy conversion and load factors, shifts to more efficient modes, reduction in travel, and improvement in use patterns (2). Many specific programs within these five categories have been proposed, and potential fuel savings from some programs have been estimated. The consensus appears to be that, during the next decade, improvement in the fuel economy of new vehicles will have the most pronounced effect.

The principal involvement of the traffic engineer is in the area of improved use patterns, which encompasses most improvements to traffic flow. Many traffic engineers feel that their actions can help reduce fuel consumption. The technical literature related to the anticipated benefits from traffic engineering improvements abounds with citations of the energy-saving merits of the improvements. In the typical case, however, the benefits are not quantified, nor is a basis proposed for such a quantification. The qualitative basis for potential fuel savings due to roadway improvements include the following:

1. Studies of fuel consumption, beginning in the 1930s and continuing through the 1960s, on the effects of major geometric changes, which have been updated economically but not technically (3);
2. Theoretical studies that use computer modeling techniques for vehicle flow and fuel consumption;
3. Common sense, which suggests that reduced vehicle idling time and more uniform travel speeds will reduce fuel consumption; and
4. Limited recent real-world studies of urban fuel consumption.

Although the work that has gone into the previous studies is significant, the studies have deficiencies that limit their usefulness in 1980. The changes in vehicle mix and performance characteristics limit the value of older data. In addition, the transportation system management (TSM) improvements that are being emphasized today differ significantly from the major projects that were studied extensively earlier. And finally, some difficulties remain with the quality of data used in the computer-modeling procedures.

The purpose of this study was to develop a cost-effectiveness hierarchy of urban traffic engineering improvements on the basis of their fuel-saving potential. Although the study was conducted in Albuquerque, the findings may have broader applicability.

STUDY PROCEDURE

The examination of traffic improvements when the individual savings per vehicle are small requires the use of a field study of actual and simulated traffic conditions. For this purpose, a precision displacement fuel meter was purchased. The meter, which is factory calibrated to be accurate over all expected automotive fuel-consumption rates, measures fuel consumption in cubic centimeters and simultaneously records fuel temperature and elapsed time. The unit consists of an underhood transducer assembly and a display unit mounted on the dashboard. All fuel readings were adjusted for the equivalent fuel consumption at 15.6°C for both fuel and air temperature (4) by using procedures established by the Society of Automotive Engineers.

The meter was installed in a 1977 model compact vehicle. The fuel economy reported by the U.S. Environmental Protection Agency (EPA) for this vehicle is close to the average for 1977 compact vehicles and is slightly less than that for all 1977 vehicles. At the time this project was completed approximately 28 percent of the vehicles on the road were newer than the test vehicle. The vehicle was kept in good condition throughout the field testing period, and no major repairs were made during testing. For all field tests, cold tire pressure was kept at 2.25 kg/cm².

In the initial stages of test vehicle use, a series of constant speed runs was made on two test routes for calibration purposes. Test route 1 parallels the Rio Grande River north of Albuquerque and has a grade of 0.13 percent, and test route 2 is perpendicular to the Rio Grande River and has a significant (4.11 percent) grade. Calibration runs were conducted on test routes 1 and 2 during the early morning hours to minimize the influence of other traffic. On test route 1, a series of constant speed runs was made at 8 km/h speed increments from 32 to 96 km/h, and at 113 km/h. On test route 2, runs were made at 16 km/h increments from 32 to 96 km/h.

The field data from these and subsequent test routes were coded onto computer cards. The coding format varied slightly among the test routes, but the basic information common to all test routes included route number, date, starting time, fuel consumption, temperatures, and travel time. For certain test routes, incremental fuel consumption and travel time, delay, acceleration time, curb radius, and number of delayed vehicles were also coded. Although the data processing differed somewhat for the various test routes, many of the processing steps were similar. A general flow chart for the processing is presented in Figure 1. Initially, fuel data were adjusted for temperature according to Society of Automotive Engineers procedures. Fuel-consumption rates, based on adjusted fuel consumption and test route length, were calculated. The commonly specified fuel-consumption value, miles per gallon, was calculated but it is not convenient for analysis purposes. Its reciprocal, gallons per mile, is more useful, but is not consistent with the values reported by other researchers who used the metric system. Several technical articles use liters/100 km or milliliters per kilometer, neither of which is consistent with established procedures for specifying metric values. The fuel-consumption rate, which is proper dimensionally, is cubic millimeters per meter. This rate, which is numerically equal to the value for millileters per kilometer, was used in this research. For comparison purposes, a vehicle that has a fuel economy of 20 miles/gal has fuel-consumption rates of 0.05 gal/mile and 117.6 mm^3/m.

The processing of data continued with the printing of the original data and calculation of fuel-consumption rates. The data were then separated by direction of travel or field test condition. Separate calculations of average statistics were performed by direction or condition. In some cases, regression analyses were performed with the fuel-consumption rate as the independent variable. In these cases, the program prepared plots of the observed and predicted rates. The t-test was performed to compare appropriate variables by direction or condition. In certain cases, the data were processed by using correlation or discriminant analyses.

Following these runs, the engine oil was changed and the vehicle was taken to an authorized Ford dealer for a minor tuneup. The spark plugs and air cleaner were replaced, and the fuel and ignition systems were adjusted to the manufacturer's specifications. The vehicle was then retested on routes 1 and 2. The fuel-consumption rates for these test routes are plotted in Figures 2-4. As shown in Figure 2, the minimum fuel-consumption rate on test route 1, which is virtually level, is in the range of 48-64 km/h. Figure 3 indicates that the minimum fuel-consumption rate occurs near 64 km/h on the 4.1 percent downgrade and near 48 km/h on the 4.1 percent upgrade. Both figures indicate that the tuneup had little effect on fuel consumption for this test vehicle. For test route 1, the average fuel-consumption rate for all speeds changed form 104.92 mm^3/m (before) to 103.24 mm^3/m (after), a 1.6 percent decrease. The change is not statistically significant, and as indicated by Figure 2, at some speeds the fuel-consumption rate increased in the after study. On test route 2, the fuel-consumption rates in the after study were 2 percent higher on the upgrade and 6.5 percent lower on the downgrade. On this route, the round-trip fuel-consumption rate was 0.2 percent higher in the after study. A comparison of the round-trip fuel-consumption rates on test route 1 versus the similar data for test route 2 showed that, for comparable running speeds, rates averaged 25 percent higher on the grade. In other words, the fuel saved while traveling downgrade is less than the excess fuel used on the upgrade.

All of the data for test route 1 were combined and are shown in Figure 4. The combining of data is acceptable because the route is level, and there was no significant difference between the before and after tests. The minimum fuel consumption occurs at approximately 48 km/h, although the fuel-consumption curve is nearly constant at 93 mm^3/m between 48 and 56 km/h. This is the speed range that should be maintained to minimize fuel consumption. Figure 4 clearly shows the fuel penalty associated with higher speeds. What is less obvious from the graph is the penalty associated with low speeds. It has been reported that elimination of speeds less than 32 km/h would reduce vehicle fuel consumption by more than that due to the the 88-km/h speed limit (5). This has led to the suggestion that the adoption and enforcement of a minimum speed limit should be considered as part of a fuel-saving program. The apparent problem with the 88-km/h speed limit is achieving motorist compliance; however, the most serious problem with a minimum speed limit of 24 or 32 km/h is for the traffic engineer to provide a roadway environment that would permit motorists to comply with the limit. As a practical matter, a minimum speed limit for urban streets is not obtainable. However, the objective of reducing driving at low speeds, complete stops, vehicle idling time, and keeping speeds near the optimum level of about 48 km/h can be partly accomplished through the application of traffic engineering principles.

Since money for traffic engineering improvements in an urban area such as Albuquerque is limited, it is important to know which types of improvements have the most substantial effect on fuel consumption. This information can assist in establishing priorities for improvements. To evaluate the effect of various types of traffic-engineering improve-

Figure 1. General flow diagram for data analysis.

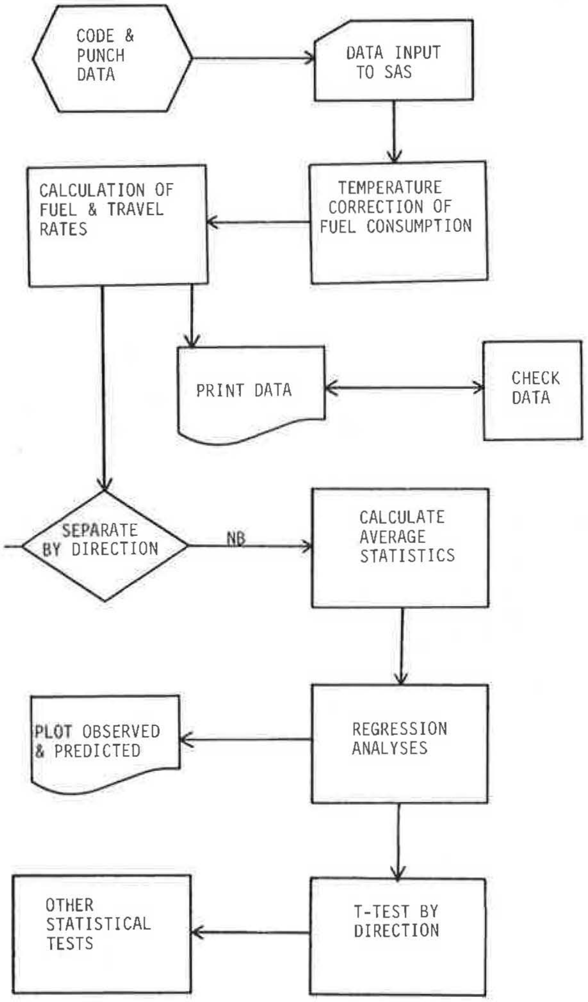


Figure 2. Fuel-consumption rates at selected constant speeds on test route 1, before and after vehicle tuneup.

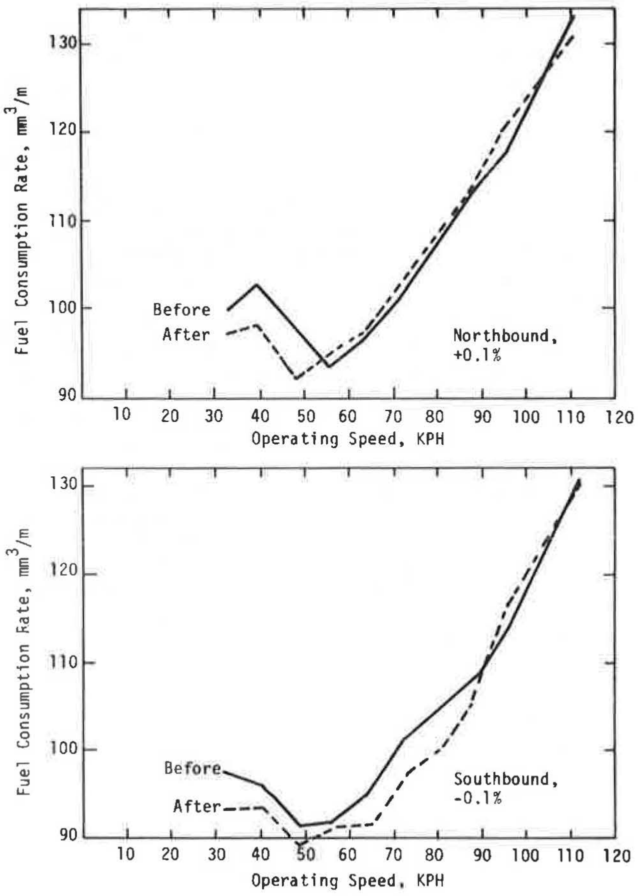


Figure 3. Fuel-consumption rates at selected constant speeds on test route 2, before and after vehicle tuneup.

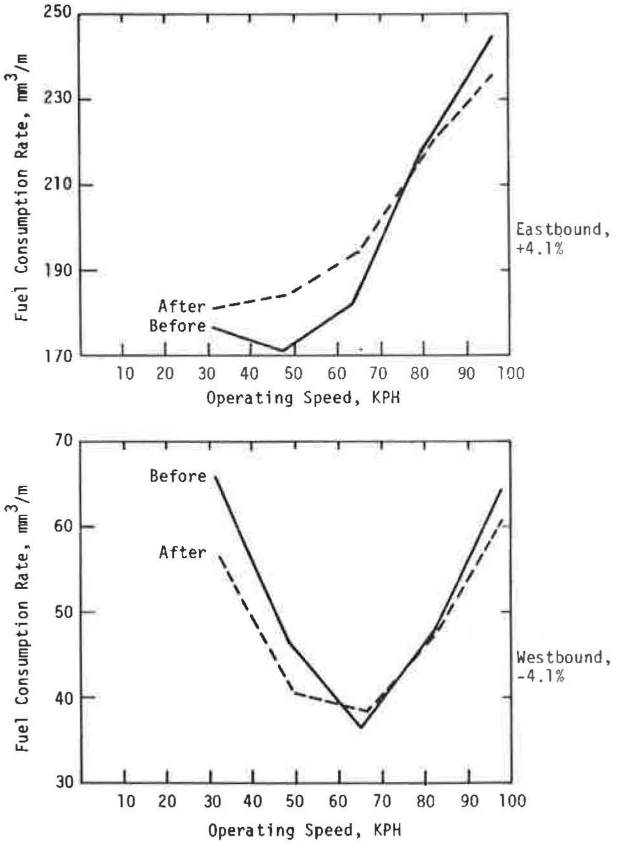
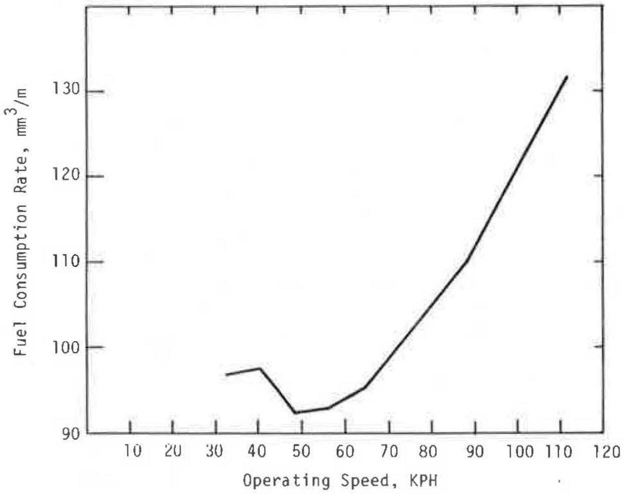


Figure 4. Fuel-consumption rates at selected constant speeds on level test route—combined results from all test runs.



ments, a number of field experiments were conducted by using the instrumented test vehicle.

Effect of Stop Sign

One of the most visible forms of traffic control is the stop sign. Its use is required by law in certain cases, and the Manual on Uniform Traffic Control Devices provides some guidelines for the use of stop signs. Numerous studies have shown that stop signs will have only a limited effect on the occurrence of traffic accidents. It has also been established that the installation of stop signs for the purpose of controling vehicular speeds does not achieve the desired intent. Despite these facts, citizens frequently request the installation of stop signs to solve perceived traffic problems.

A disadvantage of the installation of stop signs is that extra fuel is consumed by a vehicle to decelerate to a stop and then regain speed. Winfrey (6) reports data from the mid-1960s that is based on a 1815-kg passenger car that has an optimum fuel consumption of 100.7 mm^3/m. He reports the excess fuel consumed by this vehicle in one speed change cycle, which is defined as the process of reducing speed from and returning to an initial speed. In the case of a speed cycle from an initial speed of 56 km/h to a stop and back to 56 km/h, the vehicle consumed 37.2 cm^3 more fuel than by driving at a constant speed of 56 km/h. Travel time was increased by 14 s for this speed change, assuming no delay caused by other vehicles.

Two parallel test routes were established to determine the current effect of stop signs on fuel consumption. Both routes were approximately 1.26 km long and had +2 percent grades in the eastbound direction. Test route 3 had no stop signs, and test route 4 had a stop sign at one intersection. A comparison of the fuel-consumption and travel time data for the two test routes under conditions of low traffic volume is presented in Table 1.

The excess fuel consumed by the 56-km/h speed change cycle was 36.1 cm^3 eastbound and 37.8 cm^3 westbound. The average of 37 cm^3 and the excess travel time (13.5 s) are both in close agreement with the values reported by Winfrey. The data suggest that, although fuel consumption is clearly related to the grade, the excess fuel consumption associated with the speed change cycle is independent of the grade.

Table 1. Average data for test routes 3 and 4.

Item	Direction	No Stop Sign	With Stop Sign
Fuel consumption (cm^3)	Eastbound	162.9	199.0
	Westbound	59.9	97.7
Rate (mm^3/m)	Eastbound	131.3	156.9
	Westbound	48.3	77.1
Travel time (s)	Eastbound	79.6	93.4
	Westbound	79.3	92.4

Note: Grade of roadway is +2 percent eastbound and -2 percent westbound.

Table 2. Average data for center section of test route 5.

Item	Direction	Without School Zone	With School Zone
Fuel consumption (cm^3)	Eastbound	152.5	169.6
	Westbound	85.3	114.0
Rate (mm^3/m)	Eastbound	126.3	140.5
	Westbound	70.7	94.4
Travel time (s)	Eastbound	76.9	102.6
	Westbound	75.6	96.3

Note: Grade of roadway is +1.4 percent eastbound and -1.4 percent westbound.

Effect of 24-km/h School Zones

Albuquerque has approximately 120 posted school zones where the speed limit is reduced to 24 km/h during the hours when children are crossing. Although crossing hours vary among schools, the lower speed limits are typically in effect from 8:00 to 9:00 a.m., during the lunch period, and from 3 to 4 p.m., for a total of 3 h. The zones, which are controlled by adult crossing guards, are typically on arterials that normally have posted speed limits of 48-56 km/h. The zones vary in length, but a survey found that they averaged 130 m. A 1978 study found that motorists generally comply with the speed limit (average speed = 26.5 km/h), but that they quickly regain normal speeds once they have left the zone. It is hypothesized that compliance with the reduced speed limit is enhanced by the presence of the adult guard and by the short zone length, which is marked by appropriate traffic signs.

There is no doubt that the lower speed limit causes excess fuel use. Winfrey (6) reports that a speed change cycle from 56 to 24 km/h and returning to 56 km/h uses 24.7 cm^3 excess fuel. This estimate does not include the excess fuel used while traveling through the school zone, or the effect of a complete stop if children are crossing. Since the lower speed through the school zone defeats one of the objectives of a coordinated signal system, as motorists move through a progressive system, they may encounter delay and excess fuel consumption at nearby signalized intersections.

To evaluate this situation, test route 5 was established along a 1.63-km roadway section that has a 124-m school zone near the middle of the section. The route has a 1.4 percent grade eastbound, and a normal speed limit of 56 km/h. The test route was subdivided into 3 sections, one on the approach to each of the signalized intersections at the terminal points and a central section that included the school zone. Separate fuel and travel time data were collected by direction for each section. The data for the center (school zone) section of test route 5 are shown in Table 2.

The excess fuel used due to the operation of the school zone was found to be 17.1 cm^3 eastbound and 28.7 cm^3 westbound. Travel time through the section varied as a function of whether a complete stop was required to permit children to cross. The travel time averaged 23 s longer when the school zone was in operation. The excess fuel consumption through the school zone is less than that that would be predicted from Winfrey's data. Further, analysis showed that the effect of the school zone on progressive movement of traffic on this test route was negligible. In other words, the entire difference in both fuel consumption and travel time for the total test route was attributable to the section that contained the school zone.

One-Way Streets

The technical literature (7) suggests that one-way streets offer the potential for reduced fuel consumption, improved operations, and increased capacity. Because of the many variables involved in the design and operation of one-way streets, the technical literature does not indicate the amount of fuel savings that can be obtained from operation of a one-way street. The ideal approach to evaluating fuel savings would be through before-and-after studies. However, since Albuquerque was not planning to implement any new one-way-street systems during this project, it was necessary to select existing one-way streets and generally comparable two-way streets. It is not possible to choose routes that are completely identical, but two pairs of routes were selected as the best available alternatives. Test routes 6 (one way) and 7 (two way), eastbound and westbound in a suburban-commercial area, had some differences in traffic volume and roadside development. Test routes 9 (one-way) and 10 (two way), northbound and southbound in a central business district (CBD) fringe area, had similar geometric and operational characteristics.

A series of test runs was conducted to compare the fuel-consumption effect of the one-way streets. The results are presented in Table 3. The excess fuel consumption on test route 7 versus the one-way couplet is 36.2 cm^3 eastbound and 58.9 cm^3 westbound. While these differences are statistically significant, the actual differences are probably even more substantial because test route 6 had some rise-and-fall, but the two-way route had an essentially constant grade. The fuel saving is primarily attributable to the smoother flow of traffic on the one-way couplet, which resulted in less delay. At a constant speed of 56 km/h, route 6 could theoretically be driven in 194 s. The actual average travel time was 210 s, only 8 percent above the theoretical minimum. On the other hand, the travel time on route 7 was 35 percent higher (75 s) than on the one-way couplet. The additional travel time, much of which was spent idling at traffic signals, accounts for a substantial part of the increased fuel use on the two-way street. Based on the observed idle fuel-consumption rate of 0.53 cm^3/s, an additional 75 s of idling time would use approximately 40 cm^3 of fuel. The remainder of the observed difference in fuel consumption is due to the excess used during acceleration.

As shown in Table 3, there is very little difference between the average fuel and travel time

Table 3. Average data for one- and two-way streets—test routes 6, 7, 9, and 10.

Item	Direction	One-Way Street	Two-Way Street
Fuel consumption (cm^3)	Eastbound	350.4	386.6
	Westbound	240.3	299.2
	Northbound	201.5	207.8
	Southbound	178.3	195.3
Rate (mm^3/m)	Eastbound	115.2	132.7
	Westbound	79.4	102.9
	Northbound	119.3	125.2
	Southbound	106.5	117.7
Travel time (s)	Eastbound	207.5	279.8
	Westbound	213.8	291.5
	Northbound	166.4	181.1
	Southbound	168.0	210.2

characteristics on test routes 9 and 10 (northbound and southbound directions). Although the fuel consumption is slightly less on the one-way couplet and could be explained by the slightly longer travel times on test route 10, further testing showed that, with the exception of the southbound travel time, none of the apparent differences are statistically significant.

The explanation for the lack of a fuel savings on these one-way streets in the CBD fringe is fairly straightforward. The traffic signals along the one-way couplet are not operated in a coordinated manner. Because of the lack of signal coordination that is generally obtainable on a one-way street, the potential fuel saving of this traffic control technique is not being achieved on this couplet.

Although this one-way couplet is not producing any benefits, it is still operating at a significantly better rate of fuel consumption than more congested two-way streets in the CBD. This is verified by the results from test route 13, a 1.08-km section of the main street through downtown. The route, which carries two-way traffic and has a -0.14 percent grade in the westbound direction, has six traffic signals. The average fuel-consumption rate on this section was 170 mm^3/m. This is the highest rate found for any extended test route evaluated in this study. The rate is 50 percent higher than for the one-way couplet (test route 9) and is 30 percent higher than the average rate of fuel consumption for this test vehicle operating at a constant speed of 113 km/h. This is a further indication that low travel speeds, such as average 24 km/h on test route 13, have an extremely adverse effect on fuel consumption.

Curb Radii

One of the factors that influences intersection operation is turning vehicles. The standard conditions for capacity calculations at signalized intersections assume that an average of 10 percent of the approaching traffic turns right and another 10 percent turns left. Actual turning percentages are dependent on time of day and the particular intersection, but percentages higher than those cited above are found at many locations.

A vehicle approaching an arterial intersection must slow considerably to make a turn. In the case of a vehicle turning right that approaches the intersection in the right-most lane available for moving traffic and turns into the nearest lane on the cross street, the extent to which the vehicle must slow is primarily determined by the radius of the curb. At most right-angle intersections, the curbline is described by a constant radius circular arc. Measurements in older parts of Albuquerque found that most curb radii were between 3.5 and 5 m.

Winfrey (6) presents some data on the excess fuel consumption due to 90° corners. The data are of little value for most urban intersections because they are for radii from 7.6 to 76 m, in 7.6-m increments. Because of physical limitations, pedestrian considerations, and other factors, radii in excess of 12 m are impractical for unchannelized urban intersections.

The basic advantage of a larger curb radius is that a vehicle turning right does not have to slow down as much to safely negotiate the turn. On dry pavement, a vehicle can safely make a 90° turn with a 15-m radius at approximately 27 km/h, while the same turn with a 1.5-m radius requires a speed of 10 km/h or less. The travel at low speed plus the acceleration back to normal speed will result in excess fuel use. To evaluate this situation, an off-road test was conducted in a large, vacant parking lot. This route, identified as test route 8, consisted of two sections 53 m in length at right angles to each other. Various curb radii, from 1.5 to 15 m in 1.5-m increments were laid out and delineated with chalk marks and traffic cones. A series of 12 test runs were conducted for each radius. During the test run, the vehicle entered the test route at 32 km/h, slowed to an appropriate speed to safely negotiate the curve, and accelerated back to 32 km/h.

The results of this test are summarized in Table 4. The fuel-consumption rate shows a dramatic decrease, from 201 mm^3/m at 1.5 m to 103 mm^3/m at 15 m. The fuel-consumption rate for the 15-m radius, which was achieved with an average travel speed of slightly less than 32 km/h, is consistent with the values found on test route 1 for constant speed operation at 32 km/h. Although the use of 15-m curb radii is not generally practical in an urban area, the data in Table 4 show a significant reduction in fuel-consumption rate for intermediate values of the radius. The reduction in travel time is minimal. As shown in Table 4, the change is only 5 s with an increase in the radius from 1.5 to 15 m.

Turning Movements

In addition to the curb radii, another factor that can affect the fuel consumption of turning vehicles is the provision of exclusive turn lanes. These exclusive lanes are most commonly used near the center of the roadway for vehicles turning left, but at some locations they are installed near the edge of the roadway for vehicles turning right. They are frequently employed at signalized intersections, but on several major arterials in Albuquerque they are installed at nonsignalized intersections and at entrances to major traffic generators.

The most suitable method for evaluating the effects on fuel consumption of exclusive turn lanes would be by a before-and-after study at an improved intersection. Since this was not possible in Albuquerque during the study period, the effect of an exclusive right-turn lane was evaluated on test route 11, a pair of opposing approaches to a major intersection. Traffic volumes are similar on both approaches, but only the south approach had an exclusive right-turn lane. The test routes consisted of a 0.16-km section that included the approach to the intersection and a short distance around the corner. Test runs were conducted alternately, by direction, during both the morning and the evening peak periods. The average data for this test route are presented in Table 5.

There is a fuel saving for the exclusive right-turn lane during the morning peak period; however, during the evening peak period, fuel consumption is

Table 4. Fuel-consumption effect of various curb radii.

Radius (m)	Fuel (cm^3)	Rate[a] (mm^3/m)	Travel Time (s)
1.5	21.9	201.1	18.0
3	20.4	188.0	16.9
4.5	19.4	180.5	16.4
6	17.9	167.9	15.6
7.5	15.0	140.9	14.7
9	14.7	139.3	14.1
10.5	13.8	131.5	13.7
12	12.3	118.1	13.2
13.5	11.1	107.0	13.0
15	10.6	103.2	13.0

[a] Rate includes correction for test route length, which varies because of radii and assumed vehicle placement at the center of a 3.6-m lane, from 109 m at a 1.5-m radius to 103 m at a 15-m radius.

Table 5. Fuel-consumption effect of exclusive right-turn lane.

		Approach	
Item	Time	South	North
Fuel consumption (cm^3)	Morning	14.9	25.0
	Evening	24.1	22.2
	Both	18.6	23.9
Rate (mm^3/m)	Morning	93.0	156.0
	Evening	150.9	138.6
	Both	116.2	149.1
Travel time (s)	Morning	20.9	35.8
	Evening	31.4	33.4
	Both	25.1	34.9

slightly higher. Statistical testing showed that the morning differences were significant, but those in the evening were not. The reason for the lack of fuel saving in the evening peak is attributable to the substantially higher volumes on the south approach at this time of day. On the average, there were two vehicles in the queue in the exclusive right-turn lane versus only one vehicle in the right lane queue on the north approach. Because of high eastbound evening volumes on the intersecting street, opportunity for turning right on red from the south approach was limited. Depending on traffic conditions, individual test runs recorded widely varying amounts of fuel consumption. On the south approach, fuel consumption ranged from a minimum of 5 cm^3 to a maximum of 42 cm^3; on the north approach, values ranged from 9 to 60 cm^3.

FUEL CONSUMPTION MODEL

Since every possible traffic improvement cannot be tested, it is appropriate to develop a model of fuel consumption that can be used to estimate the effect of various improvements. The technical literature suggests that the rate of fuel consumption is related to the reciprocal of speed. One source reports that this type of relation applies to urban conditions and speeds up to approximately 56 km/h. This speed corresponds to a rate of motion of 64 ms/m (8).

To test this theory, the data from several hundred test runs on routes that have lengths of at least 0.8 km were analyzed by using linear-regression techniques. The resultant equation obtained for the rate of fuel consumption (R) as a function of the rate of motion (V*) was

$$R(mm^3/m) = 48.82 + 0.74\ V^*(ms/m) \qquad (1)$$

Although the correlation coefficient is a comparatively low 0.69, it is highly significant due to the large sample size. However, review of a plot of observed versus predicted rates of fuel consumption revealed that data for test routes with grades deviated substantially from predicted values. Specifically, observed fuel-consumption rates for upgrades were higher than predicted, and those for downgrades were lower than predicted.

In an attempt to correct this condition, an analysis was made of the data presented by Winfrey for fuel consumption on grades. The test vehicle used in this study has a rate of fuel consumption of approximately 92 percent of that for Winfrey's vehicle. A regression model that used Winfrey's data for grades between -4 and +4 percent and speeds between 8 and 64 km/h was developed. The model, which has a correlation coefficient of 0.97, is given by

$$R = 278.71 - 8.19S + 18.45G + 0.088S^2 + 0.66G^2 \qquad (2)$$

where

R = fuel-consumption rate (mm^3/m),
S = vehicle speed (km/h), and
G = grade (%).

This equation was used to develop a correction factor (K) that could be applied to observed fuel-consumption rates on grades. For a specific test route with a grade (G') and a particular test run with a speed of S', the correction factor is

$$K = R(S = S', G = 0)/R(S = S', G = G') \qquad (3)$$

The fuel-consumption data used to develop Equation 1 were adjusted with the appropriate correction factor, and the resultant data were processed with linear-regression techniques. The equation produced by this process has a correlation coefficient of 0.91 and is given by

$$R(mm^3/m) = 44.11 + 0.77\ V^*(ms/m) \qquad (4)$$

Chang and others suggested (9) that the first two coefficients in the equation have physical interpretations. The first coefficient (44.11) is the fuel consumed per unit distance to overcome rolling resistance. This coefficient, which in theory is directly proportional to the mass of the vehicle, is consistent with data reported in the technical literature. The second coefficient (0.77) is the fuel consumed per unit of time (mm^3/ms) to overcome mechanical losses. This coefficient for various vehicles is reportedly a linear function of their idle fuel-consumption rate. In the case of this test vehicle, the value of this coefficient is 1.44 times the idle fuel-consumption rate.

The estimate of the fuel-consumption rate given by Equation 4 is applicable for rates of motion in excess of 64 ms/m. In comparison with the constant speed runs on test route 1, the model provides estimates that exceed the observed fuel-consumption rates for speeds of 48 km/h and less. At a speed of 56 km/h, the estimate from the equation and the observed rate are identical. The equation is not intended to be used for extended operation at constant speed, however, but is applicable to real traffic situations under stop-and-go conditions.

Strictly speaking, the estimates of fuel consumption from this model apply only to the vehicle that was used in the field tests. As previously noted, however, the size and reported fuel economy of this vehicle are near the average for all current passenger vehicles.

As would be expected, there is some variation between the results of individual test runs and the rates predicted by Equation 4. However, the equation is reliable when applied to the average values of V* for test runs on a particular route, when adjustment is made by using Equation 3. The model predicted fuel-consumption rates quite closely (typically within 2 percent) for individual test routes. This finding is not surprising, and in fact is a bit weak, because this testing made use of subsets of the data used to develop the model. It was not possible in this project to conduct independent verification of the model.

Application of the Model

Certain traffic improvements that were initially considered for study were not directly evaluated through field studies. Some of these improvements, such as rest in red and flashing signal system operation, are not currently used in Albuquerque. Another improvement, the two-way left-turn lane, is used extensively in Albuquerque, but since such a lane was not constructed during the study period, a before-and-after study was not possible. And finally, some improvements, such as changes in speed limit, can be evaluated with the model rather than through field testing. The results of the application of the model to these and other changes, including progressive signal systems and neighborhood traffic diverters, are discussed in the project report (10).

Establishing Improvement Priorities

Under certain assumptions, the results of the field tests and application of the model permit a comparison to be made among the various improvements. In accord with the objectives of this research, the principal components used in these comparisons will be the potential for fuel saving and the relative cost of the improvement. Note that a change in traffic control that produces a fuel saving could, at certain locations, create other problems that outweigh its energy benefit. The following comparisons are therefore not intended to eliminate the need for proper engineering study, which must precede the implementation of traffic improvements. Rather, the results of the comparisons will add a new dimension to the traditional analysis of proposed improvements.

The principal basis for comparing improvements is the number of liters of fuel saved per year if one vehicle/day is affected by the change (1/v). Certain improvements in Albuquerque, such as a speed limit change, could easily affect several thousand vehicles per day; however, other changes, such as a neighborhood diverter, would probably affect considerably fewer vehicles per day. In computing annual benefits, it is assumed that the school zone is in operation for 180 days/year, and all other improvements are applicable for 365 days/year.

Table 6 presents estimates of 1/v for 10 traffic engineering improvements. A properly operated one-way-street system and signing to achieve efficient motorist use of a coordinated signal system result in the largest annual fuel saving per vehicle. Removal of an unwarranted stop sign or its equivalent, the decision not to place an unneeded stop sign, also shows a high benefit. The value of 1/v is considerably less for the other improvements.

The actual saving for a particular improvement is clearly a function of affected volume, the characteristics of the particular location, and driver behavior. Assumptions for typical locations led to the calculation of a realistic saving, which is presented in the third column of Table 6. The specific assumptions used in these calculations are identified in footnotes to the table. The table shows that encouragement of proper travel speed through a progressive signal system has a high potential for fuel saving. One method for realizing this benefit would be through the posting of standard signs to advise drivers of the speed for which the signals are set. The benefit would result only if drivers observed the signs and accepted their suggestion. The benefit for through traffic from the removal of a stop sign is also substantial. The apparent benefit becomes a deficit when a stop sign that cannot be justified on technical grounds is installed in response to other pressures. The realistic saving specified for the one-way street assumes that attempts are made to divert some traffic from an existing two-way street to an existing one-way street. The benefit should be considerably larger for a new one-way-street installation. The saving associated with the pedestrian grade separation assumes moderate arterial traffic volumes during the school crossing hours. The right-turn-lane saving is for a major signalized intersection. The operation of traffic signals in a flashing mode during periods of low traffic volume results in a saving equivalent to that for an exclusive right-turn lane. The remaining improvements have comparatively small realistic savings, and the neighborhood diveter shows a negative fuel benefit. However, the importance of anticipated traffic volumes should not be overlooked in evaluating any of these improvements at a specific location. Certain situations may deviate from the assumed volumes used in the calculation of realistic savings for the general case, and in these instances it would obviously be appropriate to calculate the saving by multiplying the volume by 1/v.

Three other criteria can be considered in the evaluation of traffic improvements. Cost per improvement is obviously important but is difficult to determine with any degree of accuracy without a thorough study at specific locations. Right-of-way, construction, and operation costs should all be considered. The extent to which a particular improvement can be used is also important. For example, pedestrian grade separations have limited applicability, but curb radii improvements could be made at a substantial number of locations. A third criterion is the other (nonfuel) benefits associated with the improvements. The traffic engineering literature suggests that many of the improvements evaluated in this project have benefits for travel time, capacity, safety, or pollution reduction. These criteria were subjectively evaluated with respect to the street system in Albuquerque, and the results are presented in Table 7.

Table 6. Annual fuel savings.

Improvement	1/v[a]	Realistic Saving[b]
One-way street[c]	17.4	15.1
Coordinated signals[d]	17.4	30.3
Stop sign removal	13.6	26.5
School pedestrian crossing[e]	4.1	10.2
Right-turn lane	3.6	3.8
Two-way-left-turn lane[f]	3.4	1.9
Curb radius, 3–9 m	2.2	1.1
Flashing signal operation[g]	2.1	3.8
Speed limit, 40-48 km/h[h]	1.1	0 to −3.8
Neighborhood diverter	−6.8	−1.1

[a] Liters of fuel saved/year/affected vehicle per day.

[b] Annual liters of fuel saved per improvement under conditions of moderate volume, reasonable motorist compliance with regulations, and other conditions listed in this paper.

[c] Assume 3.2 km long, good signal coordination.

[d] For 0.8 km section, one-direction, with signing.

[e] Grade separation, crossings 3 h/day.

[f] One block long, replaces previous median barrier.

[g] Operation for 8 h/day versus isolated pretimed signal.

[h] Optimistic assumption of motorist compliance with 40-km/h limit for 1/v calculation.

Table 7. Cost, applicability, and other benefits of improvements.

Improvement	Cost	Applicability	Other[a]
One-way street[b]			
New installation	High	Very limited	Very positive
Existing installation	Low	Limited	Positive
Coordinated signals[c]	Low	Limited	Neutral
Stop sign removal	Low	Moderate	Positive
School pedestrian crossing[d]	Very high	Limited	Very positive
Right-turn lane	Medium	Moderate	Positive
Two-way-left-turn lane[e]	Medium	Moderate	Very positive
Curb radius			
New installation	Low	Limited	Neutral
Reconstruction	Medium	Extensive	Positive
Flashing signal operation[f]	Low	Moderate	Uncertain
Speed limit[g]	Low	Moderate	Positive
Neighborhood diverter	Medium	Limited	Positive

[a] Other benefits include travel time savings, increased capacity, improved operation, and safety.
[b] Assume 3.2 km long, good signal coordination.
[c] For 0.8-km section, one-direction, with signing.
[d] Grade separation, crossings 3 h/day.
[e] One block long, replaces previous median barriers.
[f] Operation for 8 h/day versus isolated pretimed signal.
[g] Optimistic assumption of motorist compliance with 40-km/h limit.

The results presented in Tables 6 and 7 were used to develop a general hierarchy of low-cost traffic engineering improvements to promote fuel savings. The priorities, listed below and limited to the improvements studied in this project, must be considered general in nature. The ranking differs from one that would be established on the basis of other criteria, such as safety. As noted before, the application of a particular improvement at a specific location requires a study of sufficient detail at that location.

Priority	Improvement
High	Flashing signal operation
	Larger curb radii for new installation
	Progressive signal system signing
	Diversion to existing one-way streets
	Stop sign evaluations
	Lengthening existing curb radii
	Exclusive right-turn lanes
	Installation of two-way left-turn lane
	Installation of new one-way streets
	Change urban speed limits to optimal values
	Grade separations at school crossings
Low	Neighborhood traffic diverters.

Despite these limitations, the findings summarized above warrant some consideration in the development of a traffic engineering improvement program for energy conservation.

SUMMARY

This study has found that there are modest but discernible fuel benefits associated with traffic engineering improvements. The savings are small in comparison with other programs to cut fuel consumption such as improved vehicles, vanpools, and reduced travel. However, the traffic improvements are often low in cost and have the potential for providing benefits on a daily basis for an extended time period.

The study has a deficiency that is worth noting. The time and financial constraints on the project, coupled with the nature of traffic improvements made in Albuquerque during the study period, limited the types of improvements that were evaluated. There are clearly other TSM improvements that should be evaluated in a more comprehensive evaluation of this subject.

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Assessment of Neighborhood Parking Permit Programs as Traffic Restraint Measures

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Residential parking permit programs have become an important component of traffic restraint schemes designed to improve the social and environmental characteristics of neighborhood areas. By restricting nonresident and commercial vehicle parking, such programs are effective in controlling the use of the

neighborhood street network; however, these programs could also have many other effects that were never anticipated. This paper assesses the impact of neighborhood parking permit programs on economic, system efficiency, mobility, equity, environmental, and amenity objectives. Experiences with recently implemented permit programs are used to illustrate these impacts. A conceptual perspective on how such programs fit into a regional transportation system is also provided. This paper concludes that residential parking permit programs are generally beneficial to the neighborhoods in which they are implemented and have no discernible impact at the regional level, if their implementation considers that the result might be a simple redistribution of unwanted traffic rather than its absolute reduction. Finally, long-term evaluations of permit programs is recommended to discern those impacts that can only be identified over longer periods of time.

When the Federal Highway Administration (FHWA) and the Urban Mass Transportation Administration (UMTA) issued joint planning regulations on transportation system management (TSM) in 1975, a major step was taken to encourage, on a more formal basis, many new types of transportation actions and programs (1). Initial descriptions of the TSM program emphasized its orientation toward efficiency: The aim was to expand service without the use of significant levels of resources. However, another set of objectives related to amenity considerations soon became important to many program constituents. This amenity orientation was expressed in one form as a desire to reduce (2) "the impacts on neighborhoods from traffic dangers and pollution, and to encourage designed environments requiring restraint of traffic."

The purpose of this paper is to examine one type of TSM action, neighborhood parking permit strategies, that has objectives that fit more closely within this latter category. Such strategies are designed to improve the social and environmental characteristics of neighborhood areas by restricting nonresident and commercial vehicle parking, by providing adequate parking for residents, and by discouraging high volumes and high speeds. Until recently, however, the development of a coordinated approach to parking management has been either nonexistent or has focused solely on the objective of congestion relief, not yet totally accepted in principle by agencies that are traditionally associated with provision, management, and regulation of parking supply. What has been lacking is the perspective that parking strategies, no matter at what geographic level they are implemented, have the potential of affecting more than one urban objective (3). To illustrate this relation, the impacts of neighborhood parking management strategies are examined from a multiobjective perspective.

RECENT EXPERIENCE WITH NEIGHBORHOOD PARKING STRATEGIES

Urban transportation planning in the United States has traditionally focused on such relatively large-scale concerns as accessibility, trip generation, network configuration, and changing land use patterns. Only recently has there been any effort to examine in a systematic fashion the social, economic, and environmental impact of vehicular traffic at the local or neighborhood level (4). One of the first major policy statements concerning transportation impacts at this level is found in Buchanan's Traffic in Towns, an English report published in 1963 that advocated the creation of environmental areas in cities (5). In fact, this report went so far as to propose environmental standards that relate to levels of safety, air pollution, noise, visual effect, and pedestrian conditions.

As illustrated by the Buchanan report, European cities experimented with traffic restraint strategies long before North American planners even considered such strategies to be feasible transportation actions or demand restraint to be a relevant objective. A recent study on TSM in Europe made the same conclusion about parking policies and further stated that strategies to manage the parking supply were often adopted in European cities in lieu of more dramatic demand-restraint approaches because (6) "(i) where charges are involved, they are net earners of income for the administering locality, (ii) they are easy to implement, (iii) they are effective in holding down excessive car use in the controlled zone, and (iv) they are usually more politically expedient than more radical restraint measures."

A leading example of neighborhood parking policies and how they relate to a traffic-restraint program is found in London. The London parking policy consists of several measures aimed almost exclusively at influencing the supply of parking. The most important measures include the following (7,8):

1. Controlled parking zones (CPZs) for on-street parking,
2. Controls on the building of new public parking facilities,
3. Controls on the operation of existing temporary and permanent public parking facilities, and
4. Controls on the building of new private parking facilities.

In 1966, the Greater London Council (the transportation planning and policy agency for the metropolitan area) designated a 100-km² area of London as an inner London parking area, where on-street parking was to be stringently regulated through the use of CPZs. Parking meters were used to limit the duration of the use of parking space, and special areas were set aside for residents who had purchased and displayed a permit. Parking surveys of two CPZs in 1966 and 1969 showed that in the three-year period the number of on-street parked vehicles fell by two-thirds, and long-term parking was reduced by 80 percent and short-term parking was reduced by 44 percent. At the same time, however, London's on-street parking controls have not resulted in a reduction in street traffic comparable to the on-street parking reduction, because (9):

1. Many of the displaced on-street parkers merely switched to off-street parking facilities; in some cases (for all-day parkers) the incremental cost has been subsidized by employers;
2. Although the number of on-street spaces has declined dramatically, the numbers of public for-hire off-street spaces and, in particular, the number of private nonresidential spaces, appears to have increased, possibly in part due to the pressures created by on-street demand restraint; and
3. Through traffic has grown sharply, to replace vehicles that have downtown destinations now discouraged from parking.

In North America, a concern for neighborhood transportation problems and the subsequent planning of comprehensive neighborhood-level transportation programs did not begin until the early 1970s. For example, transportation planners in Ottawa, Ontario, initiated a series of neighborhood traffic studies in 1973 that have resulted in several changes in the provision of transportation services (10). In two of these studies, residents were only slightly concerned with parking issues; the most important issue was the provision of off-street parking to meet the demand of those who lived, worked, and shopped in the study area (11,12). In another study, however, parking problems were of considerably more concern among neighborhood residents and stimulated lengthy discussion on a number of alternative solution strategies (13):

1. Residential zoning that permitted parking for commercial uses,
2. Permit parking in commercial and mixed land use zones,
3. Metered parking along a busy residential-commercial street to increase space turnover,
4. New off-street parking areas, and
5. Strong enforcement of parking restrictions.

In the United States, comprehensive neighborhood transportation strategies were little known outside of a few cities (Berkeley, Seattle, and Madison) until the mid-1970s. The most common strategy consisted of traffic restraint schemes that employed a combination of such measures as diverters, barriers, street closures, and one-way street configurations (14). Only in recent years have parking controls become a major element of these neighborhood schemes, due to the increased concern with parking problems expressed by local residents.

The parking problem in residential neighborhoods is based on three principal issues (15):

1. Retention or restoration of on-street parking as a means of restricting the volume and speed of travel,
2. Provision of adequate and convenient parking for residents, and
3. Restriction of nonresident and commercial vehicle parking to preserve the residential character of the neighborhood.

A recent survey of 20 U.S. communities showed that the most widespread form of on-street parking strategy applied to address these issues was the residential parking permit program (RPPP) (16). The characteristics of an RPPP usually reflect perceived specific needs of the community in which it is applied. The primary characteristic that denotes RPPPs is the assignment of parking privileges within a neighborhood area, usually through some sort of permit or sticker displayed directly on the vehicle windshield or bumper. In Cambridge, Massachusetts, for example, the principal elements of the current program include the following (17):

1. Any Cambridge resident who has a valid Massachusetts registration is allowed a citywide resident parking sticker;
2. Visitors receive passes, valid for only 1 of the 13 designated neighborhoods in the city;
3. Resident parking areas include all city streets except for areas in front of commercial establishments; and
4. All permits are reissued January 1 of each year to control the use of permits by previous residents.

In San Francisco, RPPPs have been established around some Bay Area Rapid Transit (BART) stations as well as in the more densely populated downtown area. In Washington, D.C., the RPPP has been extended to 24 areas of the city to protect local residential parking space from automobile commuters attracted by universities, hospitals, transit garages, transit transfer points, and proximity to the central business district (CBD).

As can be seen from the above discussion, the RPPP concept has been used mainly to protect local residents from the encroachment of nonresident automobiles. One suspects, however, that not only do RPPPs affect the level of congestion on residential streets and provide a higher quality residential character, but they can also affect measures of accessibility, fuel consumption, air pollutant emissions, and economic development both in the neighborhood and at a much larger, regional scale (18). This comprehensive assessment of RPPPs has been lacking in the transportation literature to date.

URBAN GOALS AND RPPPS

A recent effort to place parking management within the broader context of management tools for the supply of urban transportation defined a slate of general urban goals and traced the traditional relation of each of these goals to urban transportation, in general, and parking availability and control, in particular (19). As shown in the list of urban goals related to parking strategy applications, these goal categories tend to embrace most, if not all, of the specific objectives proposed by municipalities as reason for embarking on particular transportation policies. As such, they provide a useful means of gauging the potential range of impacts of RPPPs (19):

1. Healthy economic climate, and a business community able to support local employment needs, which means the ability to attract and keep desired kinds of development and industry, a healthy retail sales climate, and a stable or growing municipal revenue base;
2. Most efficient use of existing transportation, land, and other public resources;
3. Ease of mobility and accessibility of resources for vehicles and pedestrians;
4. Equity of resource distribution and preferential allocation of some resources;
5. Environmental goals, especially reduced air pollution and the related goal of minimized energy consumption; and
6. Enhanced amenity and cultural attractiveness, preservation of a city's unique character.

Healthy Economic Climate and a Business Community Able to Support Local Employment Needs

One of the most important concerns to city officials in the consideration of parking management schemes is the possible impact on the economic climate of the area. Some preferential access strategies have the potential to alter the kinds of new development proposed for the area of control, which results in an increase in activities that serve the favored groups and a decline in other kinds of development. When favored groups are explicitly identified and provided for, the result may be an increasing homogeneity of the area, and a consequent increase in demand for parking, even among those who meet the requirement for preferential treatment.

Major office or business development is not likely to be discouraged by programs designed to give special access rights to local residents as long as (a) their own short-term customer or client parking needs are adequately provided for, (b) street access for service and delivery vehicles is not restricted, and (c) some form of alternative access (or preferential parking for carpooling commuters) exists to allow employees to get to work. In the long term, the existence of parking controls may alter land values faced by potential builders to reflect the increased desirability of locations served by reasonable transit service or within easy reach of unrestricted parking. For this reason, the extent of the area across which parking controls apply (and the perceived permanence of such controls) may be important in the locational decisions made by developers.

In addition to development-related issues, local officials are likely to be concerned about the impact of parking-restraint measures on a continuing high level of retail activity. The relation between the availability of parking and retail success has not as yet been defined adequately, although important attempts were made to formulate such a relation during the 1960s (20). However, customer parking is still regarded as an absolute necessity by most retailers. In most cases, RPPPs have been implemented to give special consideration to customers of local businesses (e.g., permitted 2-h parking in areas otherwise restricted to residents). Consequently, there is very little evidence to suggest that RPPPs have a detrimental impact on retail activity. A survey of business leaders in Alexandria, Virginia, for example, found that most business people did not perceive the RPPP as an inconvenience but reported the sentiment that more off-street parking facilities should be built (21). This suggests that, to some degree, RPPPs may crystallize merchant demands for increased public parking designed exclusively to serve retailer needs. In other cases, where the primary target group of parking controls was clearly seen to be all-day commuter parkers, the congestion-relief characteristic of strategies such as RPPPs are reported to have resulted in the attraction of more business activities to the area (22). In Washington, D.C., recent meetings between representatives of businesses located near the capitol and local transportation officials have shown near unanimous support from the business community for the local RPPP (16). The business representatives, especially those from small establishments, claim that the parking restrictions have resulted in larger numbers of customers and a healthier business climate.

In sum, where RPPPs have been implemented with special considerations given to the requirements of business establishments, there is little empirical evidence to suggest that such programs have had negative effects on development and retail concerns thus far. Of course, these sorts of impacts tend to require long gestation periods before they become manifest, so that definitive conclusions regarding a strategy that has only become popular in this country in the last 5-10 years cannot yet be reached. It seems likely, however, that as long as sufficient provision is made for customer access, such impacts will be small. Indeed, the reaction of many business people in RPPP areas seems to indicate that such parking restrictions increase business activity by providing potential customers with an increased probability of finding a parking space.

Most Efficient Use of Existing Transportation, Land, and Other Public Resources

This goal can be restated in terms of deriving the maximum level of productivity from resources, where productivity is defined according to the functions that the resource is expected to serve. The imposition of specific parking management techniques is likely to be most directly relevant to efficient or optimal use of existing transportation and land resources. With respect to a limited number of parking spaces to serve a particular area, efficient allocation of parking resources may be interpreted as the reserving of sufficient quantities of parking for users who have no reasonable alternatives, and discouraging the use of the limited parking supply by patrons who could reasonably use other modes, transit in particular. By thus reserving space for residents, RPPPs serve to enhance the accessory value of parking that is not in itself designed to be profit-making but which provides access to particular adjacent land uses.

Limited findings have been reported concerning the impact of residential parking programs on the use of street space and on changes in travel behavior adopted by restricted parkers. In Alexandria, Virginia, 12 percent of a commuter sample indicated that they had changed travel mode (to bus and carpool) as a result of the RPPP restriction. Close to 30 percent of the respondents had shifted to off-street parking facilities. In Baltimore, a previously underused parking garage in the RPPP area has become a more desirable parking location for displaced commuters. In San Francisco and Washington, D.C., parking programs resulted in dramatic decreases in on-street commuter parking (16).

Thus, to the extent that residential permit programs encourage greater use of existing off-street parking facilities or the diversion to transit of trips that can readily be served by existing services, they can be said to contribute, to some degree, to more efficient use of existing resources. This is so if, in fact, existing transit is capable of handling the diverted demand, and if control can then be maintained over the size, operation, and location of any new additions to the parking stock designed to accommodate overflow from existing facilities.

Ease of Mobility and Accessibility of Resources

In urban areas, vehicles and pedestrians compete for limited space; each in a sense impedes the other's mobility. To the extent that parking policies have been used in the past to achieve ease of mobility, a primarily vehicle-based mobility has been encouraged. The primary motivation of agencies charged with the management of street traffic has generally been the reduction of vehicle congestion and the facilitation of traffic movement on city streets. However, parking policy may be related to pedestrian mobility in two ways. First, in that pedestrian safety and directness of access are enhanced when traffic volumes are reduced or removed altogether from certain rights-of-way. A parking policy that discourages vehicular traffic from certain areas may work toward these ends. Second, a relation may be established between the amount and distribution of parking and the activity densities and lengths of walking trip of parkers and nonparkers in urban areas.

RPPPs act both to decrease mobility by adding to the perceived cost of parking for commuters and to increase ease of mobility for residents by reducing traffic levels on residential streets and by providing easier means of parking. In particular, such programs may have the following consequences.

They raise the perceived cost of parking, measured in both dollar cost and time spent searching or walking, for some or all parkers. In effect, RPPPs decrease their mobility and trip-making ease. Some parkers may be unaffected or aided by particular strategies: Employees of firms that control their own parking, for example, will benefit from the increased value of their reserved spaces. Most nonresident parkers will be mobility-disadvantaged by strategies that make parking more difficult or more expensive.

Residential parking strategies may serve to reduce traffic on residential streets and thus allow enhanced movement by remaining vehicles and pedestrians. However, this effect will result only if (a) additional through traffic is not generated to replace diverted terminating traffic, and (b) the area across which parking is limited is wide enough so that traffic diversion to the area's periphery in search of replacement parking is minimized.

If parkers displaced by these strategies are largely commuters, they will be likely to seek alternative methods of making the same trips. In addition, it may be relatively easy to offer reasonable travel alternatives to such trip makers. If, instead, displaced parkers tend to be short-term visitors or shoppers, they are likely to seek alternative destinations or to eliminate the trip altogether. The latter eventually may be regarded as a more severe mobility loss, in terms of both individual and community impacts.

As a neighborhood traffic restraint method, RPPPs are designed to serve the first purpose mentioned above (i.e., decrease the utility of parking in the residential area for nonresidents). The evidence to date indicates that the parking programs are most successful in doing this. A sample study of two neighborhoods in Cambridge, Massachusetts, showed that, one year after RPPP implementation, the number of cars parked on the street decreased by 31 percent. In San Francisco, a before-and-after study of one RPPP area indicated that the parking program had significantly reduced nonresident parking. In Washington, D.C., the decrease in the number of nonresident vehicles parked in two residential areas was 62 percent and 42 percent, respectively (23).

Equity of Resource Distribution and Preferential Allocation of Some Resources

The difficulty of establishing transportation policy intended to achieve some measure of equity in the distribution of scarce resources lies in determining what is equitable, given a host of varying affected constituencies. Equity implies fairness, which can be translated into a number of principles, not all of them consistent with one another.

Equity Implies Providing Just Compensation for Injuries Sustained or Hardship Borne

Thus, for example, residents of a town that is transversed by a new freeway should, in principle, receive some priority in terms of access to that facility, prices charged for tolls, and parking compared with residents of other unaffected towns. However, this principle does not hold to the extent that access to a regional facility should be prohibited de facto by parking restrictions or other means to persons not residents of the town in which the facility is located.

Equity Involves Nondiscrimination in the Provision of Services

If it can be demonstrated that public transportation resources are allocated in a manner that grossly favors certain neighborhoods, social classes, or sets of interests over others, a legitimate equity case can be made. This is not to say, however, that it is necessary to provide equivalent levels of service in all parts of an area for the sake of equity. Such an approach would itself represent a misallocation of resources.

Equity Requires a Fair Distribution of the Costs of Resources Consumed

This is an argument frequently advanced by proponents of congestion pricing: Such pricing represents a mechanism by which users of public resources can be charged directly for the indirect societal costs they generate. This principle is applied to some extent in differential transit fare structures that charge more for travel in peak periods than in the off-peak. However, other direct applications of congestion-pricing, including price structures for parking that follow this same model, have been rare in this country, although they have been adopted elsewhere, most notably in Singapore.

Equity issues arise with RPPPs in that they involve the establishment of hierarchies of preferred users, such as shoppers over commuters, or carpoolers over lone drivers, or residents over nonresidents, in areas where demand for parking greatly exceeds supply. Some applications are intended to reserve certain scarce privileges or resources for residents, explicitly excluding outsiders. No behavioral change is desired of outsiders, other than keeping away from the prized resource, but the privilege in question is not denied to members of the insider group who derive all the benefit from such actions. Usually, a valid case can be made for at least partial restrictions of the parking rights of outsiders on equity grounds, when such neighborhoods are genuinely threatened. In other areas, however, local autonomy over the creation of such programs may create the equivalent of snob zoning, especially when there is a valid reason for making some local parking available for outsiders (e.g., shoppers in neighborhoods that border downtowns or commuters at a park-and-ride transit or carpool facility).

Several court cases have upheld the legality of the residential parking programs and have dismissed charges that such programs are inequitable to nonresidents (24). The court concluded in a case that challenged the Arlington ordinance that local objectives of reducing air pollution and other adverse environmental effects are legitimate goals and that a "community reasonably may restrict on-street parking available to commuters, thus encouraging reliance on carpools and mass transit." In 1975, a nonresident of Cambridge, Massachusetts, brought suit against the city, arguing that the parking regulation discriminated against him in violation of his right to equal protection of the laws. The court disagreed and upheld the legality of the permit program.

Thus, residential parking programs have different levels of impact on various groups. The groups affected by RPPPs are listed below.

1. Neighborhood--residents, store owners, students, parking lot owners, and schools and churches;
2. Community, private sector--developers, employers, business people, and parking lot owners;
3. Community, public sector--police; hospitals, schools, and other attractors of high traffic; traffic engineering department; chamber of commerce; parking authority; and planning department;
4. Regional, private sector--commuters and developers' organizations; and
5. Regional, public sector--transit provider, metropolitan planning organization, air quality agency, and cities and towns that adjoin RPPPs.

The most affected group is the commuters who previously used the parking space. However, this incidence of impacts has been found acceptable by several courts throughout the country. Nevertheless, such programs should be viewed with a broad perspective on their ultimate consequences. In those cases, for example, where designated commuter parking that serves regional facilities is restricted out of concern for local amenity and yet alternative means of access to the station are likewise unacceptable to local constituencies, the access rights of legitimate customers of such facilities are very likely being abrogated. At present, no right-of-review authority exists to overrule excessively exclusionary local demands.

Environmental Goals, Especially Reduced Air Pollution and Related Goal of Minimized Energy Consumption

The idea of reducing air pollution levels through the application of parking constraints was one of the major thrusts of the U.S. Environmental Protection Agency's (EPA) transportation control plan regulations as applied to certain urban areas. That this idea failed in most applications was due largely to the political opposition generated by these constraints, which rendered them unenforceable and therefore ineffectual. Several residential parking programs, however, have been successfully advocated as means of reducing the levels of air and noise pollution. As mentioned before, the Arlington, Virginia, RPPP had been justified on the grounds of protecting the residential areas from polluted air and excessive noise. The evaluation of the London parking program concluded that it was not possible to identify any environmental effects of parking controls, although there had been a significant improvement in the street scene as a result of the reduction in on-street parking.

An environmental assessment of RPPPs must occur at two levels, the impact in the residential restricted area and the spin-off effect of displaced automobiles on the surrounding areas of the region. In both cases, the environmental impact depends to a great extent on what happens to those drivers who previously parked in the restricted area.

Within the residential area, the impact on air quality and noise levels should be favorable if large numbers of automobiles are deterred from entering the area. This seems to have been the result in San Francisco and Washington, D.C. However, as found in Arlington and to some extent in Baltimore, many of the automobiles displaced by the RPPP were diverted to nearby off-street facilities, so that areawide traffic and air pollution levels were not really reduced; they may have even been aggravated. If, in the longer term, the on-street restrictions created pressure to increase the number of off-street parking facilities in order to satisfy this new demand, the overall air quality situation could become worse than in the no-restriction case.

In addition, restricted entry for commuter parkers (who make only one trip per day per space into and out of a neighborhood) may create additional space for retail customers or people on personal business. This may mean that a single on-street space will now serve three, four, or more trips per day--an outcome regarded as beneficial by local businesses but certainly more detrimental environmentally than if primarily commuter parking is served.

From the viewpoint of regional environmental quality, another important consideration may be the displacement of previous automobile parkers to parking sites outside the zone of restriction. If a large percentage of these drivers switch to other, more efficient modes of transportation, such as carpooling or transit, then a net environmental benefit to the region would be expected. If, on the other hand, a large percentage of these drivers simply switch parking locations to areas that border the restricted zone, thereby creating congestion in these areas and increasing the amount of driver time and vehicle miles of travel spent searching for parking space, then the impact on air quality and other neighborhood environmental characteristics in the nonrestricted zone would be negative.

There are few data to support either one of these possible outcomes. However, a study for the Washington Metropolitan Council of Governments indicated that a nonresident restriction would reduce emissions by about 1 percent. This reduction corresponds to an estimated 1 percent reduction of automobile trips (12 100 trips) daily and a corresponding 1 percent increase (3900 trips) in transit trips (25).

In Cambridge, Massachusetts, a preliminary evaluation of the citywide RPPP has shown that, since the program was implemented, there has been an 18 percent decrease in the amount of traffic that enters the city on an average day. However, local officials are uncertain about how much of this decrease can be attributed to the RPPP. Both of these examples indicate that the RPPP by itself will most likely not provide significant regional improvements in air quality. However, if combined with other tactics, it could be one of the most influential components of an air quality-transportation strategy.

Enhanced Amenity and Cultural Attractiveness: Preservation of an Area's Unique Character

The influence that transportation exerts on land use can be directed toward ends that are not explicitly economic in nature, but which are more closely related to urban design and amenity objectives. Residential parking programs are perceived by many affected residents as a way of maintaining neighborhood character by limiting the intrusion of nonresidents. Polls taken of residents in restricted areas show that they overwhelmingly support the implemented programs. In San Francisco, for example, 74 percent of those who responded to a questionnaire favored the continuance of that city's permit program because they perceived that it was successfully maintaining the fabric of the neighborhood.

The specific manner in which residential parking management strategies can be applied to achieve the amenity and attractiveness goal does not lend itself to generalization as readily as do methods of structuring parking controls to achieve other ends. Moreover, parking management strategies alone will not serve as a motivational force to stimulate major changes in how urban space is used. Such changes must be motivated by social and economic forces that can be taken advantage of, rather than controlled by, parking policy.

SUMMARY AND CONCLUSIONS

Although neighborhood parking programs have been in existence in some cities for several years, few attempts have been made to analyze their impact. This is not surprising. The evaluation of such programs would be a complicated undertaking because establishment of the cause-effect relation between RPPP implementation in a complex urban environment and ensuring marginal changes in observed travel behavior is likely to be very difficult. Further, many of the impact measures that would be essential in a comprehensive analysis (e.g., impact on retail sales or development location decisions) do not evidence change immediately but require several years before the effect is noticeable. However, the data that are available and the experiences of those RPPPs already implemented provide some indication of how such a program will impact a community. A summary of these impacts is shown in Table 1.

Thus, rather than conclusions per se, this paper lends itself more appropriately to a set of summary observations regarding the interrelation of residential neighborhood parking controls and broader goals of the neighborhood itself and the urban area as a whole.

Table 1. Impact assessment of RPPPs.

RPPP	Neighborhood Impact	Regional Impact	Evidence
Healthy economic climate	+	0	Members of the local business community support of RPPPs in Washington, D.C., and Cambridge due to higher parking space turnover rate
Efficient use of public resources	+	0	Increased use of off-street parking spaces in Baltimore, Alexandria, and London
Ease of mobility	++	-	31 percent decrease in cars parked in two Cambridge neighborhoods; 62 and 42 percent decrease in nonresident parked vehicles in two Washington, D.C., neighborhoods
Equity of resource distribution	+	0	Arlington, Cambridge, and Washington, D.C., court cases
Environmental goals	+	?	Depends on behavior of displaced automobiles; preliminary finding of 18 percent decrease in automobiles entering Cambridge since RPPP implementation
Neighborhood amenities	++	0	Response of officials and residents in those communities that have RPPPs

Notes: ++ = significant positive impact, + = slight positive impact, 0 = no discernible impact, - = slight negative impact, and ? = unknown.

The efficacy of particular types of controls with respect to certain goals depends, to a large degree, on what types of parking consumers are disfavored by such controls and what alternative access modes are available or acceptable to them. Parking controls that are limited in scope may achieve only the redistribution of unwanted traffic rather than its absolute reduction. This may be regarded as acceptable or unacceptable, depending on the goals of the implementing jurisdiction, but it must be recognized that such redistribution is likely to create new problems in adjacent zones.

Reports on the limited experience thus far with RPPPs suggest that such programs probably do not create development obstacles or difficulties for existing local business establishments if designed with these considerations in mind. Also, existing programs are generally reported to have modest beneficial impacts with respect to environmental indicators and in terms of increasing use of alternative transportation facilities. These are not general or definitive conclusions, however. The direction of the effect of an RPPP on many of these objectives depends very much on the specific situation in which it is applied, and on the degree to which individual programs are tailored to fit specific needs.

With respect to other, less tangible, objectives, a set of criteria is needed for evaluating impacts of RPPPs. Also, since many of these effects tend to require a long time to develop, continued observation of and reporting on programs now firmly established for several years are called for.

As a traffic restraint measure (that is, as a method of discouraging or rerouting traffic away from specified neighborhood areas), the RPPP is a particularly effective strategy. However, such programs will also most likely affect other important aspects of neighborhood and regional life. Because of this, a closer look at existing RPPPs and, most importantly, extensive evaluation studies of future neighborhood parking programs as they are implemented are needed.

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South African Parking Standards

T.C. MACKEY, O.A.W. VAN ZYL, AND J.C. VORSTER

Certain minimum desirable parking standards were developed in the Urban Transport Branch of the South African Department of Transport during 1979-1980. This was done to provide guidance and requirements for uniform parking standards. This paper conveys these standards and some of the background to the development of the standards. The subject is dealt with in two parts: standards for parking dimension and requirements for parking provision. In the first section, the establishment of a South African design vehicle is discussed—motor cars in South Africa are generally smaller than those in the United States and slightly larger than the European cars. From the design vehicle, at present proposed to be 4.8 m in length and 1.8-m wide, the dimensions of parking bays and aisle widths are derived and certain standards proposed. For 90° parking a basic standard module width is 17.5-m wide aisles. Dimensions for angle parking and for on-street parking are also proposed as well as dimensions for certain parking garages. In the second section, the background to the development of requirements for provision of off-street parking is discussed. A questionnaire on current parking provision requirements was sent to all local authorities in the five declared metropolitan areas in South Africa. The results of this survey were compared with findings of parking demand surveys and South African and overseas proposed standards. A summary of the recommended minimum desirable standards for parking provision is then given.

Parking is a very important and integral part of the total transportation system in any metropolitan area. Because of the ever-increasing cost of land and construction of parking facilities and also because of the influence of on-street and off-street parking on traffic flow, it is necessary for all authorities to ensure compliance with adequate, realistic, and effective parking requirements and standards. The Urban Transport Branch of the Department of Transport therefore compiled a report on parking standards (1), of which this paper is a summary. The object of the report was to propose (a) standards for parking dimension and (b) requirements for parking provision to provide national guidance and requirements for uniform parking standards and also to assist the National Transport Commission in evaluating requests for subsidies for parking facilities.

The National Transport Commission accepted, in principle, the parking-dimension standards and parking-provision requirements, as laid down in the report, as the minimum desirable standards for the urban areas of South Africa. The commission further agreed that the report be distributed to all local authorities in the declared metropolitan transport areas, that it should be recommended to the core cities for possible acceptance and application in their respective transport plans, and that all local authorities should consider inclusion of the parking provision requirements in their town planning schemes, with the understanding that deviations would be possible if adequate motivation proves it necessary.

The purpose of the report was to cover only those aspects of parking that may differ from available overseas standards and requirements. The use of other literature on parking in conjunction with this report is thus recommended [e.g., (2)].

STANDARDS FOR PARKING DIMENSIONS

South African Design Vehicle

Minimum standards and desirable standards for dimensions of parking bays can be laid down. For the purpose of this report, we decided to propose only one desirable standard that will be applicable to most circumstances. Good judgment is necessary, however, in the application of these standards, and certain deviations may be necessary. These standards apply only to ordinary private vehicles such as motor cars, minibuses, and light delivery vehicles but not to trucks and buses. South African motor cars are generally smaller than those in the United States and probably slightly larger than European cars; therefore, it was necessary to develop a South African design vehicle from which dimensions of parking bays can be derived.

A number of people, including the city engineer's department of Durban (3), Olivier (4), Uys and Van der Merwe (5), and the Division of Highway Traffic Engineering of the South African Institute of Civil Engineers (6), did some work on the dimensions of a South African design vehicle. Most of the above-mentioned studies based the design vehicle on the 95 percentile value of the different dimensions. This represents a conservative working value that covers the overall majority of vehicles. Cumulative frequency diagrams were plotted for such factors as the length, width, turning circle, and height of vehicles from which the 95 percentile values can easily be determined.

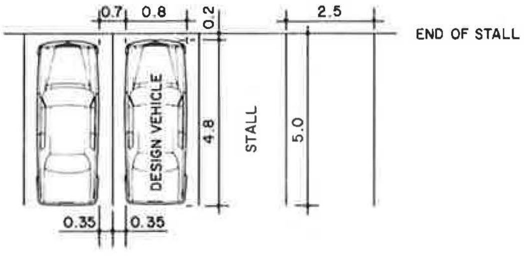
Uys and Van der Merwe (5) found a definite trend toward smaller cars in South Africa. Volkswagen South Africa (7) confirmed this after studying the change in buying habits of the South African motoring public. They found an increase of 15 percent in

Table 1. Comparison of design vehicle dimensions.

Place	Source	Length (m)	Width (m)	Turning Circle (m)
United States	Eno Foundation (8)	5.49	1.98	14.18
	Eno Foundation (9)	5.72	2.03	14.98
	Institute of Traffic Engineers (10)	5.90	2.00	
	Institute of Transportation Engineering (11)	5.80	2.05	14.60
Europe	Glanville and Seymer (12)	4.78	1.78	9.92
South Africa	Durban Corporation (3)	4.88	1.83	12.20
	South African Institution of Civil Engineers (6)	4.85	1.85	
	Olivier (4)	4.85	1.85	12.0
	Uys and Van der Merwe (5)	4.75	1.80	12.4
Proposed		4.80	1.80	12.4

Note: The following factors are generally accepted to play a role in determining dimensions of parking bays: vehicle size dimensions, operational characteristics, driving ability, and user convenience.

Figure 1. Design vehicle and 90° stall.



the number of new small cars sold in the period 1973 to May 1979 and a further increase was expected.

After the available data were compared, the following basic dimensions for the South African design vehicle were proposed:

Item	Dimension (m)
Length	4.8
Width	1.8
Turning circle	12.4

A comparison between these dimensions, as set by various sources for the United States, Europe, and South Africa, is presented in Table 1. The following additional characteristics for the South African design vehicle were then chosen (the front, rear, and side overhangs were based on limited data only):

Item	Dimension (m)
Wheel base	2.85
Front overhang	0.75
Rear overhang	1.20
Side overhang	0.2
Minimum turning radius, inside rear wheel	3.1
Minimum turning radius, outside point, front bumper	6.2
Overall height	2.0

The vehicle size dimensions will, to a certain extent, affect the bay and aisle dimensions. The most important dimensions are the following:

1. Vehicle width;
2. Vehicle length;
3. Minimum turning radius, inside rear wheel;
4. Minimum turning radius, outside front bumper; and
5. Rear overhang.

These dimensions affect the maneuverability of a vehicle directly and, therefore, the parking layout and dimensions. Another important factor is the lateral spacing between vehicles when parked or between a vehicle and a wall or other fixed objects, primarily for the opening of doors. After consideration of proposals by various authors and the variation in car positioning in the stall, a standard of 0.7 m was proposed for design purposes. Kanaan and Witheford (13) found that parkers did not, on the average, pull all the way into a parking bay. Therefore it was proposed that an additional 0.2 m should be added to the length of the design vehicle in determining stall lengths. No provision was made for vehicles parking with part of the overhang extending over curbs or sidewalks because parking like that might interfere with pedestrian activities and might also damage certain vehicles.

Off-Street Parking

If the tolerances mentioned above are added to the dimensions of the design vehicle, it results in a proposed general 90° bay size of 5.0 m in length and 2.5 m in width, as shown in Figure 1. A parking bay next to a wall should be 0.35 m wider, however, to allow for the opening of doors. This results in a bay size of 5 m in length and 2.85 m in width.

When the standard parking bay width is known, the width parallel to the end-of-stall line can be determined for different angles. The stall depth perpendicular to a wall or the end-of-stall line for different parking angles, with or without the interlocking of bays, can also be determined. A summary of these dimensions is given in Table 2.

Ricker (14) derived a formula for determining the aisle width between a row of parked cars and a wall or obstruction. This formula produces rather wide aisle widths, and, therefore, parking maneuvers were also simulated graphically to determine the proposed aisle widths given in Table 2. The proposed aisle width for 90° parking is 7.5 m. A parking module, which represents two rows of parking bays together with the aisle in between, is a standard dimension in planning and designing a specific parking lay-out configuration. For 90° parking, the proposed module width is 17.5 m.

On-Street Parking

There are basically two types of on-street parking--parking at an angle and parallel parking. Parking at an angle on-street is generally viewed as unsafe and should be avoided. There are three basic types of curb stalls--end stall, interior stall, and paired parking, which are shown in Figures 2 and 3.

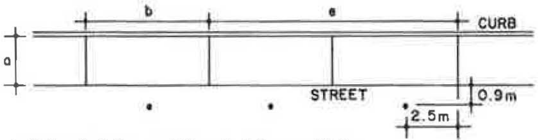
Paired parking is preferred to the interior stall layout in South Africa. The widths of curb stalls are prescribed in the different road traffic ordinances of the provinces as 2.2 m. To allow the driver and occupants of the vehicle to safely enter or leave the vehicle, the width of the traffic lane adjacent to curb parking should be increased, where

Table 2. Summary of proposed parking dimensions.

Interlocking Bays	Parking Angle (degrees)	Stall Width (m)	Stall Depth (m)	Aisle Width (m) Two-Way	Aisle Width (m) One-Way	Module Width (m) Two-Way	Module Width (m) One-Way
None	90^a	2.4	5.0	8.0	8.0	18.0	18.0
		2.5	5.0	7.5	7.5	17.5	17.5
		2.5	5.0	7.0	7.0	17.0	17.0
	60	2.5	5.3	5.4	4.4	16.0	15.0
	45	2.5	4.9	5.2	4.2	15.0	14.0
On one side	60	2.5	4.8	5.4	4.4	15.5	14.5
	45	2.5	4.2	5.2	4.2	14.3	13.3
On both sides	60	2.5	4.8	5.4	4.4	15.0	14.0
	45	2.5	4.2	5.2	4.2	13.6	12.6

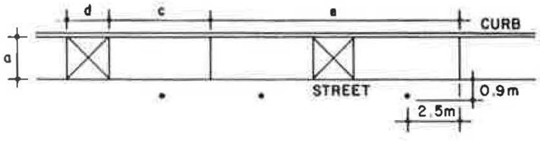
^{a}Basic proposed standard.

Figure 2. The interior stall.



a=2.2m, b=6.0m, c=5.0m, d=2.0m, e=12.0m

Figure 3. Paired parking.



possible. The proposed dimensions for on-street parking are shown in Figures 2 and 3.

Parking Garages

Although parking garages or structural parking is a comprehensive subject on its own, vertical clearance, slope of floors, and certain ramp characteristics are discussed briefly. A minimum vertical clearance of 2.1 m is proposed for parking garages, which implies careful placement of lighting fixtures and overhead signs. However, the vertical clearance on the ground floor or part thereof of any parking garage should conform to the maximum vertical height laid down in the ordinance (i.e., 4.1 m). The slope of floors should not exceed 3 percent in directions longitudinal to parking stalls or 5 percent for cross slopes or aisles (2). The preferable maximum grade for sloping floor self-park garages is 4 percent (15).

Ramps should be skid-free and the maximum proposed grade is 15 percent (15). A 10 percent grade is preferred for high-volume ramps. The width of a straight one-way ramp without a sidewalk and curbs should not be less than 3.5 m and with sidewalk and curbs not less than 3.0 m. A two-lane straight ramp with sidewalk and curbs should have a width of not less than 6.0 m for one-way operation and 7.0 m for two-way operation. The width of a circular ramp should not be less than 4.5 m.

PARKING PROVISION REQUIREMENTS

Off-Street Parking Requirements

In order to safeguard traffic flow on adjacent arterials, ensure effective access, and protect the transportation system's general functioning, a sufficient number of off-street parking spaces must be provided at all the different types of development in urban areas. Requirements for such parking provision are normally contained in the town planning scheme for a particular area. Where it is the purpose of this report to develop and recommend such desirable minimum standards, these standards should be applied with the necessary care. The following factors may require these standards to be adjusted in a specific case:

1. Size and nature of the development;
2. Urban character, socioeconomic structure of the population, and residential density in the market or influence area;
3. Availability of public transport;
4. Availability of other on-street or off-street parking in the vicinity; and
5. Certain combinations of land uses, such as offices or theaters in shopping centers that may reduce the total combined parking requirement where the peak parking demand for the different land uses do not occur at the same time.

In the central areas of major cities different situations exist from those in the outlying areas of central business districts (CBDs) of smaller cities and towns. Factors such as the high density of development, available public transport, major pedestrian flows, and scarcity and cost of land, may prohibit or limit the provision of parking in relation to outlying areas or smaller town centers. Therefore, a separate parking policy normally exists for the CBD of a large city.

Data Collection

Questionnaires on requirements for provision of off-street parking were distributed during June 1979, with the assistance of the relevant provincial administrations, to all the local authorities within the five metropolitan areas of Johannesburg, Pretoria, Cape Town, Port Elizabeth, and Durban. Most local authorities and provincial administrations responded, and an excellent return of 44 completed questionnaires was achieved.

Analysis of the completed questionnaires showed that there is a great diversity in the standards for off-street-parking-provision requirements as applied by the local authorities. For example, among the 44 cities and towns there are no less than 26 different parking requirements for general offices. This great diversity indicates the need for guidelines on the uniformity of parking standards.

In the analyses of the completed questionnaires we also endeavoured to determine whether there is any relation between the size of the city or town and the parking demand or requirement for the various land uses. The local authorities were divided into three groups, depending on population size and the parking-provision requirements compared within each of these three groups. No trend or special

Table 3. Summary of recommended minimum standards for off-street parking.

Land Use	Buildings	Standard[a]
Residential	Single and attached dwelling units	
	One habitable room	1.0 space/unit
	Two habitable rooms	1.0 space/unit
	Three habitable rooms	1.25 spaces/unit
	Four or more habitable rooms	1.5 spaces/unit
	Visitors	0.5 additional space/unit
	Hotel and motel	1 space/habitable room + 10 spaces per 100 m^2 PAA
	Residential hotel and boarding house	0.6 spaces/habitable room
	Old-age home and orphanage	0.3 spaces/habitable room
Office	General office	2 spaces/100 m^2 PFS
	Bank, building society, and other public trade office	4 spaces/100 m^2 PFS
Business	Shopping center	
	Neighborhood (<5000 m^2)	7 spaces/100 m^2 PFS
	Community (5000-15 000 m^2)	6 spaces/100 m^2 PFS
	Regional (>15 000 m^2)	5 spaces/100 m^2 PFS
	Hypermarket[b]	7 spaces/100 m^2 PFS
	Single shop, excluding car showroom and plant nursery	6 spaces/100 m^2 PFS
Medical	Consulting room	6 spaces/100 m^2 PFS
	Small private hospital and clinic	1 space/bed
	General hospital	1 space/bed
Industrial and commercial	Manufacturing	1 space/100 m^2 PFS
	Warehousing	1 space/100 m^2 PFS
	Dairy, bakery, and laundry	1 space/100 m^2 PFS
	Storage yard	1 space/100 m^2 PFS
Public garage		4 spaces/working bay + 2 spaces/100 m^2 spaces and sales area
Place of public worship		0.15 space/seat
Educational	Nursery school	1 space/classroom or office
	Primary school	1 space/classroom or office
	Secondary school	1 space/classroom or office
	College	0.25 space/student
	University	0.4 space/student
Recreation, sport, and entertainment	Community center	2 spaces/100 m^2 PFS
	Hall	0.25 space/seat or 20 spaces/100 m^2 PFS
	Movie and theater	
	Within shopping center	0.1 space/seat
	Isolated	0.2 space/seat
	Sport stadium	0.25 space/seat
	Swimming pool	0.25 space/seat
	Library and museum	2 spaces/100 m^2 PFS

Note: PAA = public accessibility area, PFS = permissible floor space.

[a]Not applicable in CBD of large cities. [b]A hypermarket is a large discount store that sells many items, including food, clothing, and furniture.

relation within the groups or differences among the groups was noticed, and we therefore concluded that, at this stage, there is no noticeable or specific difference in parking demand for different sizes of local authorities.

The requirements and proposals obtained from the questionnaires were also compared with other surveys of parking demand made in South Africa. Kruger, Van Zyl, and Du Plessis (16) used the results of their own surveys and surveys done by University of Pretoria students to propose parking indices for certain land uses. Jordaan and Switala (17) also compared results of a large number of surveys done by students of the University of Pretoria. Guidelines were also prepared by the South African Institute of Civil Engineers (18) for off-street parking provision. Cognizance was also taken of other South African surveys and proposals for parking-provision requirements.

Off-Street Parking Requirements for Different Land Uses

The existing parking requirements, as applied by the different local authorities, were compared with South African and overseas recommendations in order to derive a minimum standard that can be applied under existing conditions to the average South African city or town. A summary of the recommended minimum standards is shown in Table 3. The complete comparison of parking requirements for different land uses, as well as definitions of the most important descriptive units, is discussed in detail in the original report (1).

CBD Off-Street Parking Requirements

As mentioned before, parking requirements for central areas of large cities are generally substantially less than the requirements shown in Table 3. In some cases no parking is required or the provision thereof prohibited. This may be due to good public transport access, the high density and high cost of land, and the pedestrian flow, which should not be interrupted by vehicle entrances. Parking provision can also be limited in order to limit the influx of traffic into the CBD.

On the other hand it may be necessary to provide sufficient parking to combat decentralization and deterioration of the CBD. Specific policies in relation to on-street parking as well as core parking for short-term shoppers and fringe parking for long-term workers should be adopted.

The large South African cities reported that they have specific requirements for their central areas. Some smaller cities and towns indicated that, although there is no difference in their parking requirements for their CBDs compared with their outlying areas, they do allow, with the consent of the administrator, that a sum of money shall be used for the provision of the required number of parking spaces as a public-parking facility in the vicinity of the site in question. This is paid in their CBD payment, in lieu of the provision of the number of parking spaces.

Pretoria divided its CBD into two zones. Zone A, which is the core, is about 25 street blocks in extent and no parking is allowed. In zone B, which is a fringe area around zone A, the parking must be provided as is the case for the remainder of Pretoria, except in the case of shops where 1 space/116 m² GFA (±0.9 space/100 m²) must be provided.

In Johannesburg the central area is divided into four zones (A, B, C, and D). Except in certain special cases, no parking may be provided for any building in the core (i.e., zone A). In zones B and C it may only be provided for sites of 1480 m² or greater in extent and in zone D on sites of 900 m² or larger. If parking is provided in these zones, it may not exceed a certain number of spaces, as specified in the town planning scheme. These requirements are much less than those for the remainder of Johannesburg.

It is not possible to recommend minimum standards for the central areas of large cities as they depend on the local circumstances and also on the parking policy adopted by the local authority. The above summary of the requirements for the central areas of Pretoria and Johannesburg do, however, give some indication of what such requirements could be and the principle of precluding the provision of parking in highly pedestrianized areas is supported in these circumstances.

CONCLUSION

We hope that the minimum desirable standards for parking dimensions and parking provision requirements developed in the report and summarized in this paper will provide guidance in South Africa and also contribute to some uniformity in parking standards in other countries. These are standards to be applied with the necessary care and understanding; properly motivated deviations will be necessary from time to time. It will also be necessary to revise and update the report from time to time. Comments on the report will thus be welcome.

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Implementation of a Regional Parking Policy: Institutional and Political Considerations

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Parking policy in most U.S. cities consists of the independent actions of a large number of transportation and parking agencies, each implementing different parking management strategies to achieve a wide variety of urban goals. However, the use of the provision of parking as a policy lever for attaining urban objectives in a comprehensive and consistent manner requires the formulation and implementation of a regional parking policy. This paper examines the in-

stitutional issues that affect the formulation of such a policy. Case studies of Alexandria, Virginia; Baltimore; Boston; Evanston, Illinois; Hartford, Connecticut; and Seattle are used to illustrate the complexity of the institutional structure for parking policy. These case studies showed that formulation and implementation of parking policy are influenced by the capability of the lead agencies to adopt and implement parking strategies, the diversity of objectives and constituencies that correspond to these lead agencies, the degree of consensus on the policy objectives, the level of communication among these agencies, and the state of the economy in the metropolitan area. A set of implementation guidelines is provided for formulating a regional parking policy. We conclude that a regional parking policy is essential if parking is to be used as a means of influencing urban objectives. Major effort has to be exerted in two areas to develop such a policy: (a) establishment of the institutional base to support a regional parking policy and (b) identification of a means of measuring the effect of parking management strategies (and combinations thereof) on urban objectives. We recommend that the latter task be the focus of future research in the area of parking policy.

The provision of adequate parking in urban areas has long been an important item on the agenda of public officials. Parking policy has been traditionally associated with public policy toward the automobile and its concomitant impacts. Before 1970, when the objective of most transportation policy was the accommodation of the automobile through highway construction, parking policy was simply focused on where sufficient space could be found to provide the needed storage for all of the automobiles that use these new highways. During the early 1970s, however, as the emphasis in transportation policy shifted away from a highway-oriented program, the role of parking in the transportation system, and perhaps its more important role in the larger economic and social urban environment, began to receive closer scrutiny (1). The purpose of this paper is to examine this expanded role for parking in the urban system and to identify the institutional characteristics of the existing structure of parking policy formulation and implementation (2).

INSTITUTIONAL STRUCTURE OF PARKING MANAGEMENT

Parking availability has traditionally been considered a necessary component of the trip-making sequence and thus a basic element of automobile accessibility and mobility. Until recently, however, the development of a coordinated approach to parking management has been either nonexistent or has focused solely on the objective of congestion relief. Such an approach has also not yet totally been accepted in principle by agencies traditionally associated with the provision, management, and regulation of parking supply. The findings of a recent research study have indicated that "this restrictive perception of parking management is only one aspect of such tactics and, in fact, is not consistent with the application of parking management tactics by many jurisdictions" (3). The institutional structure (i.e., the agencies and their interrelationships) for formulation and implementation of parking policy is very complex and often hinders the development of a coordinated parking management program. The various legal, financial, and operational aspects of the parking sector involve numerous organizations such as development agencies, police departments, building and zoning commissions, real property boards, or public works departments.

One of the major identifying characteristics of the parking sector at the local level is its separation into public and private providers of parking space. In spite of functional complementarity, the public and private components of parking supply tend to exist independently of each other. However, the private sector is mainly interested in profits, and the public sector agencies have a multitude of different objectives that they are trying to achieve through the use of parking and other transportation strategies. The private sector is mainly active in commercial off-street parking facilities (e.g., open-lots or garages) and also provides a substantial number of parking spaces for business and private development not available for general use.

The public sector is different in that a larger set of agencies and organizations and a more expansive set of objectives is involved. Indeed, the service represented by parking falls within various functional lines of many public sector organizations, and each one has its own particular conception of the role of parking. Traffic departments are largely responsible for the on-street supply and, in some cases, the off-street supply as well. Their primary responsibility is with traffic flow and safety, and, consequently, parking is viewed in light of its effect on vehicular movement. Transit authorities and sometimes state and county transportation departments often provide park-and-ride lots. The main objective here is to provide an adequate supply of spaces in order to facilitate the use of the transit system.

Many cities also have a municipal agency responsible for the provision of off-street parking. In smaller cities, this agency is usually found within the traffic engineering department and is generally concerned with how off-street parking can alleviate a perceived deficiency of available on-street parking spaces. In most cases, off-street parking policies are based on the belief that an adequate aggregate supply of parking is a prerequisite for sound downtown economic development. Consequently, if the perceived level of on-street parking is inadequate, downtown business people will often advocate the provision of more off-street parking spaces.

This institutional fragmentation in the parking sector often leads to a site- or action-specific approach to planning. As particular needs or local problems arise, they are generally dealt with on a piecemeal basis without full consideration of the impacts of proposed solutions on other elements of the parking sector or on the transportation network. For example, when residents in urban areas complain about the parking situation in their neighborhood, the common approach has been to solve the particular problem at the scale of the residential area concerned. Often, the adopted solutions at this scale solve the residents' problems; however, they also create greater difficulties for larger numbers of people. A good example of this is when large numbers of drivers who usually park near rapid transit stations are no longer able to park and ride the transit line; thus, the transit system is hurt and substantial numbers of people are inconvenienced (4).

The resolution of a problem at the subregional level can result in considerable negative impacts at the regional level. For this reason in particular, the consideration of a parking policy, defined here as a set of parking strategies to achieve broader urban objectives, can provide a basis for solving parking problems at both levels.

The institutional fragmentation at the local level is generally matched by a parallel fragmentation of federal mechanisms for intervening in or influencing parking-related decisions. The Federal Highway Administration (FHWA) can fund two types of parking facilities under the federal-aid highway program: (a) fringe and transportation corridor parking and (b) replacement parking. In the first case, only public-transportation-related parking projects outside of the central business district (CBD) can be funded (5). In the second case, federal-aid funds can be used to construct off-street replacement parking facilities when the implementation of a federal-aid project requires the removal of on-street parking in an area that has a critical shortage of parking spaces (6).

The Urban Mass Transportation Administration (UMTA) capital grant program funds parking projects if they can be related to transit services. Although under present guidelines for the urban initiatives program parking facilities can be funded if they are found essential to the project and enhance proposed mass transit services, UMTA is currently considering stricter guidelines that would severely limit the type of parking project funded with UMTA funds. In fact, some UMTA regional offices seem to be already following a policy of not funding parking projects.

The Federal Railroad Administration (FRA), as part of its Northeast Corridor Improvement Program (NECIP), will spend about $35 million for parking in the renovation of several railroad stations. The FRA estimates that, in all, 8000 spaces will be provided through its program.

In some cases, federal funding for parking projects can be at cross-purposes with the objectives of other federal programs. For example, while the U.S. Environmental Protection Agency (EPA) and UMTA, through various programs, focus on decreasing the use of automobiles in downtown areas and fostering the competitiveness of alternative modes of access, funds from the U.S. Department of Housing and Urban Development (HUD) continue to provide incentives for urban areas to plan (largely in isolation from other transportation decision making) large downtown parking developments.

In summary, the parking sector is characterized by a high degree of complexity and fragmentation, both in terms of the variety of organizations responsible for managing each of its components as well as in terms of the variety of objectives that motivate the involvement of these organizations in the parking sector. Perceived local parking problems tend to be dealt with as they arise (i.e., a specific action is chosen and tailored to address a particular problem). Thus, parking supply in the aggregate is managed by a large variety of individual actions that attempt to deal with a set of specific problems. This isolated use of parking actions is also associated with a general lack of concern for secondary impacts of local problem solutions, particularly in locations adjacent to the geographic area of immediate concern. As has been found in the implementation of neighborhood parking strategies, the problem has often just been transferred to adjacent areas (see paper by Meyer and McShane in this Record).

The use of a specific strategy to deal with a particular problem might address only one aspect of the global parking allocation problem. Indeed, parking problems cited by different localities might be considered as variations on the more basic problem of allocating a restricted supply of parking to a variety of competing uses, such as residential parking, retail and business-related parking, entertainment and other off-peak parking uses, and communication. The definition of a strategy related to a specific local problem might, therefore, result in increasing the tensions in the allocative process among the other competing uses.

One solution to the problems identified above is the articulation of a regional parking policy that consists of parking management packages. Not only is the notion of parking policy a prerequisite to the creation of a structure able to reduce the impacts of negative spillover effects, but it is also a prerequisite for addressing problems at the scale of the urban area. Because a comprehensive parking policy constitutes an action at the level of the urban area, it is a particularly appropriate way of addressing urban objectives. A coordinated parking policy approach thus constitutes a prerequisite to the serious linking of parking policy and urban objectives.

The failure to reconcile the fragmented nature of the parking sector with the necessity for formulating and implementing a comprehensive parking management program leads to a tenuous link between action in the parking sector and the ability to deal with larger urban issues through parking. From this point of view, issues that surround policy implementation and the analysis of such issues become a prerequisite to the formulation of parking policy. The following analysis is therefore not aimed at the implementation of specific parking management strategies but at the more basic analysis of the possible configurations in which parking policy might be conceived within the existing institutional environment of the parking sector.

ANALYSIS OF PARKING POLICY FORMULATION AND IMPLEMENTATION

The objective of the methodology used in this research was to provide an analytical framework for understanding the institutional functioning of the parking sector. Such an understanding was necessary in order to define institutional preconditions that lead to the formulation and implementation of parking policy. The tool of analysis used in the following methodology is institutional analysis. It is defined as the analysis of a group of organizations that interact in the pursuit of a particular task, and the resulting problems that arise from the nature of these interrelations at any stage of the policy process, by using elements of organization and political theory. As such, institutional analysis is normative since it is aimed at improving the policymaking process and policy content. It is also decision-oriented in the sense that it is used to produce an input to the decision-making process. And it is anticipatory in that it structures in a logical taxonomy the uncertainty that surrounds the pursuit of a particular task.

A telephone survey of transportation, parking, and local elected officials in selected case-study cities was the primary method of data collection. The selection of the case-study cities was based on three sources of information that provided data on the characteristics of different cities in relation to their parking management activities: (a) the Virginia Highway and Transportation Research Council survey of 1977 (7), (b) the 1979 Public Technology, Inc. survey, and (c) the 1979 Peat, Marwick, and Mitchell study (3,8).

Three criteria were used in selecting the case-study cities for this research:

1. Together, the cities should have implemented a wide variety of parking management actions;
2. Individually, they should have implemented a variety of strategies; and
3. There should be a common set of implemented strategies among the cities.

By using these criteria, the following set of cities was chosen for study: a set of large cities, which consists of Baltimore, Boston, and Seattle, and a set of medium cities, which consists of Alexandria, Virginia; Evanston, Illinois; and Hartford, Connecticut.

Baltimore

Three major organizations are concerned with parking in Baltimore. The Baltimore Department of Transit and Traffic plays a central role in the planning and implementation of several parking management strategies within the city limits. A carpool preferential parking program, which is part of the general policy to improve air quality in the Baltimore region by reducing the use of the automobile, and a residential parking program, which is aimed at solving the local parking problems of residential neighborhoods adjacent to large traffic generators, are examples of two such strategies. These two strategies, however, present some contrasting institutional characteristics.

The carpool preferential parking program is developed within the administrative structure of the department. In contrast, the residential parking-permit program requires, over an area of 10 blocks, signatures from 60 percent of the households (one signature per household) in order to support an application. Additional field work is then necessary before implementation. The acceptance by key actors of the residential parking program has also been controversial. Many of the businesses and other establishments that attract nonresident automobiles have opposed such a program, thus the environment of program implementation is somewhat turbulent.

Another major agency involved in the parking sector of Baltimore is the Off-Street Parking Commission, whose main role has been to provide funds for the building of off-street parking facilities. The main objective of the commission is to support the development of the city with an adequate supply of off-street parking, an objective that is substantially different from that of the Baltimore Department of Traffic and Transit.

The Baltimore Department of Traffic and Transit is more concerned about using parking management strategies to improve air quality and decrease the use of the automobile by commuters; however, the Off-Street Parking Commission has operated on the precept that the development of Baltimore depends on its accessibility to automobiles, particularly in terms of parking. Even though there is interaction between the Off-Street Parking Commission and other city agencies, it does not seem to affect the dual focus in Baltimore's approach to parking.

The third major actor in Baltimore's parking program is the Greater Baltimore Committee, which is associated with the Baltimore Chamber of Commerce. The committee has established a task force that will examine the existing parking situation in Baltimore and recommend both short- and long-term solutions. An underlying attitude among committee members is that there is a strong need for a more coordinated approach to the parking sector.

The parking sector in Baltimore thus operates on the basis of a parking policy that is not clearly enunciated and reflects the dual concern of the city to improve air quality and maximize the redevelopment of the downtown area. Consequently, in spite of executive intervention in such strategies as the preferential carpool program, there is a conspicuous lack of cohesiveness in the orientation of parking policy in Baltimore. The initiative of the Greater Baltimore Committee could possibly provide the catalyst for development of such an orientation.

Seattle

Seattle's parking program originated with the EPA state implementation plan (SIP) regulations aimed at improving air quality in the nonattainment area of the Seattle air quality control region. Even after the subsequent relaxation of EPA's enforcement, the concern and interest of the city to manage its parking supply in a consistent manner has remained. Other transportation-related objectives, such as the reduction of peak-hour traffic or the increased use of transit, have also emerged as strong objectives underlying the parking program. The mayor's office, the Seattle Office of Planning and Evaluation, the City Council, and the Seattle Department of Community Development continue to maintain a positive attitude toward a structured and consistent parking management policy.

A clear commitment for coordination exists in Seattle. Coordination is currently practiced in two ways: the definition of responsibilities within the parking sector and the creation of a task force on parking. In terms of role definition, Seattle presents a clear operational structure based primarily on the guidance provided by the Office of Policy and Evaluation, the City Planning Commission, and the Department of Community Development. This guidance is predominantly oriented toward environmental objectives, and no other parking policy guidelines are followed by other agencies within the city administration. This consensus allows for the development of adequate supporting strategies for parking management and the derivation of maximum benefit out of the success of complementary activities such as transit and carpool. It then becomes possible to develop around the policy core accessory parking management strategies aimed at more localized problems, such as a residential parking permit program or a growth-constraint program.

This consensus on environmental objectives is, in addition, reinforced by actions aimed at maintaining a working relationship among parties who could easily be antagonistic. A good illustration of such a relationship is a collaborative effort between the city's Office of Downtown Development and the Downtown Seattle Development Association in regard to a proposed downtown transit mall and the provision of additional parking. Although such collaborations are not a panacea, they provide valuable channels of communication and constitute useful conflict-avoidance mechanisms.

The definition of responsibilities also involves the Building Department, which overlooks the application of the zoning ordinance, mainly from the point of view of a strict environmental interpretation of the code. This role within a single organization allows for increased procedural efficiency and clearer decision making. It also provides for a better environment of policy guidance at the Office of Policy and Evaluation on particular development issues related to zoning in that it does not need to deal with a complex set of different agencies.

A task force on parking, which constitutes a second mechanism of coordination, has been involved in two main areas of work. The first area concerns the development of means to alleviate the parking problems associated with the zoning ordinance. For example, a ban on demolition of any building for transformation into an open lot and, even stronger, a ban on new open parking lot facilities have contributed to a decreased supply of available commercial off-street parking. Among transportation strategies considered by the task force to provide alternatives to downtown parking have been vanpools or subsidies to transit users.

Another function of the task force has been to examine the short-term parking supply in the retail core of the CBD. As the amount of spaces open to the general public has decreased and the private supply has increased substantially due to significant downtown development, the task force is searching for new regulatory tools able to provide an adequate supply of short-term parking within the retail zone.

Recent judicial decisions have put new regulatory and intervention powers at the disposal of the city agencies for use in the parking sector. For many years, private operators succeeded in lobbying the state so that the city had a limited ability to build or acquire municipal lots and no taxation power at all, because the city had to keep the parking tax aligned with that of other operators. Recent state legislation has given the cities the option to use their new development or taxation powers in the parking sector. Thus, the regulatory environment of commercial parking in the core area is substantially transformed and the public has increased control over the supply of parking. However, the city is still unsure about how to use these new powers because of the pressure exerted by private operators and because it is still unsure about the technical consequences of such measures.

Boston

The policy orientation of Boston relative to parking has not changed substantially since 1972. The city continues to encourage the use of mass transit to downtown and to discourage the use of the automobile. In spite of some equipment problems, the transit network is efficient, extensive, and provides the support for such a policy. In addition, the recent economic upsurge of downtown Boston has also indirectly protected the development of such a policy because clear indication of the negative economic implications of the freeze on parking spaces can be made. The transportation and economic environments provide, therefore, a favorable setting for the development of a parking policy aimed at discouraging automobile commuter traffic and one that reflects a commitment to air quality improvement objectives.

The fringe parking and park-and-ride programs operated by the Massachusetts Department of Public Works and the Massachusetts Bay Transportation Authority (MBTA), along with the freeze on commercial parking supply, are consistent with the objective of decreasing automobile use in the downtown area. Similarly, residential parking-permit programs and increased enforcement are aimed at protecting neighborhoods and congested areas of the city from high levels of inconvenience generated mostly by commuter parking.

Even with a general consensus on these guidelines for parking policy (the only significant opposition to these guidelines, and the freeze in particular, was voiced by the Chamber of Commerce), some problems at the administrative level arise due to the relative independence of the agencies involved. In the case of the freeze implementation, for example, a lack of coordination between the Boston Air Pollution Control Commission and the Building Department produced procedural delays that could be avoided by the definition of a clearly expressed process that involves all concerned agencies. Similarly, in the case of parking spaces leased to private operators by the Real Property Department or of private commercial parking operations, consistency in implementation is impossible. First, leases tend to be very long term, so that renegotiation of leases does not occur frequently and the inclusion of special pricing clauses is rare. In addition, in the case of private ownership and operation, it is very difficult to obtain unanimous cooperation of the operators on particular adjustments to the rate structure.

In the absence of a clearly defined parking policy, informal channels of communication operate within the Boston administrative structure. In particular, informal communication operates among the Boston Redevelopment Authority, the Traffic and Parking Department, and the Boston Air Pollution Control Commission. In addition, the Traffic and Parking Department has shown, particularly in its residential parking-permit programs, a particular concern for interaction with community organizations at all levels of the policy process.

Boston presents, therefore, the case of a city that has a latent, unified set of purposes in relation to parking policy and a fragmented administrative structure with partial channels of informal communication operating within it.

Medium-Sized Cities

The institutional structure for parking programs in medium-sized cities is generally fragmented and emphasizes a specific objective in agency actions. Indeed, all cities tend to be characterized by a major policy emphasis on growth. This emphasis varies in intensity among cities, depending on the particular economic environment. For example, Hartford's emphasis on development is strong due to the strong impact it has suffered from suburbanization, but Evanston is mainly concerned about growth at the site-specific level due to the relatively high level of development within the city.

Parking has become a major topic for debate in Alexandria, as evidenced by the following statement from the city of Alexandria Annual Report (9, p. 14):

> The continuing revitalization of downtown Alexandria has increased demand for residential, shopper, and employee parking. Concurrently, new development has replaced some facilities.... A number of strategies have been applied or are under consideration to ease the situation. First, the city government is attempting to maintain the current supply of public parking. Second, all practical actions are being taken to place portions of the courthouse parking garage in operation before courthouse construction is completed. Third, City Council approved the residential parking permit system.... Fourth, the city government is supporting programs to reduce employee parking demand in the downtown area.... Finally, city staff is preparing a feasibility study for possible parking garages.

The major actors in the Alexandria parking program include the Traffic Engineering Department, which undertook much of the analysis and recommended implementation of specific strategies; the City Council, which actively debated and finally adopted a permit-parking program; and the Chamber of Commerce, which perceived the permit program as a hindrance to shopper convenience.

The Chamber of Commerce has also played an activist role in establishing parking policy in Evanston. For 10 years, the chamber has been sponsoring a merchant's parking coupon system that provides attractive parking rates to customers in the downtown area. Evanston has also been unwilling to allow open areas to be used for parking lots and, given the high level of transit accessibility, the City Council has changed the zoning law to reduce by 50 percent the minimum level of parking spaces needed in development projects. The City Council has also created a residential parking-permit program for a neighborhood adjacent to a major hospital. The Evanston parking policy is thus heavily oriented toward economic issues and in solving on a microscale basis problems that arise in specific neighborhoods or subareas.

A similar focus on urban economic development can be found in Hartford, where city officials and business groups have actively promoted downtown development through marketing, urban planning, and artistic design. In the process of defining the problems of the downtown area, these groups found that a major reason for shoppers not coming to the center city was transportation. Accessibility to shopping centers and availability of parking were perceived as clearly superior in suburban areas. To combat this, the downtown council, a government-business joint action group, has been active in promoting parking facilities in the downtown area, and the Hartford Development Commission also includes parking availability as part of its promotional strategy to attract development. In particular, it puts businesses directly in contact with private operators of parking facilities in areas where parking is scarce. The Zoning Commission enforces the effort to increase the parking supply by putting no ceiling on parking construction and by requiring relatively high minimum parking requirements for office buildings (one space per 500 ft^2). In addition, substantial areas of redevelopment lots are presently devoted to surface parking.

To compete economically with the suburbs, the downtown council has developed, in conjunction with Connecticut Transit, Inc., and the Connecticut Department of Transportation, an instant-repay program aimed at making the downtown retail shops subsidize use of transit or parking in downtown for the customer. Special coins, sold by a major bank to merchants at $26/100 coins, can be used either on buses or in parking lots by a customer who receives them from the merchant or professional office visited. A coin is given to the customer on presentation of an instant-repay coupon, which is distributed in buses or parking lots. The number of coins given is left to the discretion of each business, although a standard practice has been to give one coin for a $5.00 purchase, two coins for a $10.00 purchase, or a maximum of four coins per transaction (8).

Due to a high level of suburbanization, Hartford's daytime population is three times larger than that at night. Following the decision by Governor Thomas Meskill to minimize the effects of the anticipated gasoline shortage, a three-point program to reduce fuel consumption, traffic congestion, and air pollution was initiated by the Connecticut Department of Transportation. This program consisted of fostering carpooling and buspooling in private industry through computer ridematching, construction of additional interchange parking facilities for carpools, and development of additional express commuter bus service between suburban areas and the CBDs of Connecticut cities (12). The program has, therefore, a strong fringe parking component aimed both at increasing the use of carpools and transit to downtown Hartford. The program has developed in an impressive way; 121 commuter lots, which offer a capacity of more than 9000 spaces, were provided statewide by the end of 1978, but only 434 spaces in four lots were offered in 1970.

In summary, the types of parking management strategies implemented in medium-sized cities analyzed in this research reveal an ability to deal with particular, well-defined problems. The instant-repay program in Hartford or the merchant's coupon program in Evanston are aimed at one particular segment of the parking problem. Similarly, the residential parking problems of Alexandria and Evanston are site-specific actions in response to particular parking problems that arise from growth and congestion. From an institutional perspective, the small-scale nature of the parking actions taken in these cities implies a smaller level of interaction needed among agencies. Also, the business community seems to play a dominant role in the direction of parking policy for these cities.

Analysis of these case studies indicates that five institutional variables seem to influence the process of parking policy formulation and implementation. These are as follows:

1. The capability of the lead parking agencies in the adoption, planning, and implementation of parking management strategies;
2. The diversity of objectives and constituencies that correspond to these lead agencies;
3. The degree of consensus among the agencies on the objectives of the parking management program;
4. The level of communication between these agencies; and
5. The state of the economic environment of the metropolitan area.

The identity of the different agencies involved in the adoption, planning, and implementation of parking management strategies used within a city provides a first indication of the level of concentration of effort in the parking sector. The range of effort includes a single agency to plan and implement all parking strategies to a variety of different agencies that are involved at each stage in the development of each parking management strategy. Initial inquiry about the nature of these agencies, therefore, constitutes a necessary preliminary step to assess the level of diversity that exists among the set of agencies involved in parking management.

Throughout the case studies, both the economic environment and the urban transportation context had a substantial impact on the nature of the set of parking management strategies implemented. The state of the economic environment affects the substantive goals of a city. In a city attempting to induce redevelopment in its downtown area, priorities are set relative to the necessity of attracting developers downtown. Alternatively, in a city enjoying a stable and consistent rate of growth, the management of growth, rather than seeking it, becomes the predominant notion. In the sense that parking tends to be perceived as an important component of downtown revitalization through its positive impact on accessibility, parking policy itself becomes affected by the nature of the economic environment. As the state of the economy improves and stabilizes at a consistent rate of growth, consideration of other objectives, such as environmental quality or residential amenities, becomes an essential guiding element in the determination of the set of objectives that supports the selection of parking management strategies.

The diversity of objectives and constituencies that correspond to this variety of parking strategies leads to the other important characteristics of the institutional structure for parking--the level of consensus and communication among the relevant agencies. The level of consensus on the objectives to be reached through the implementation of parking management strategies reflects the overall coordination and integration of parking policy within the metropolitan area. The degree of communication among the different agencies also affects the level of integration that can be reached within the existing institutional framework.

IMPLEMENTATION GUIDELINES FOR A REGIONAL PARKING POLICY

The analysis of the case studies described in the previous section provides useful input into the formulation of a strategy for developing a comprehensive, regional parking policy and, most importantly, for identifying the roles of transportation agencies at all levels of government in encouraging such a policy. The following guidelines are offered for an individual or group of individuals who wish to set up the necessary institutional structure and to establish the foundation for a comprehensive policy.

Identify Relevant Participants and Their Capabilities for Active Participation in a Parking Policy Formulation Process

As was seen in the case studies, each metropolitan area has a different institutional structure for parking management. In some cases, city agencies are the most important actors; in others, the chamber of commerce or other business group plays a prominent role. The first step in developing a metropolitan parking policy is, therefore, the identification of organizations and individuals that play an important role in the provision of and policy guidance on public and private parking availability. An important task in this identification is also to determine the capability of each actor to actively participate in a policy formulation process. Some questions that need be asked here are, What staff capabilities do these groups have? What are the political and financial constraints under which these groups operate? What specifically can these groups contribute to a comprehensive parking policy? Over what component of the parking system do these groups have control?

Establish an Institutional Base for the Formulation of a Parking Policy

Once these groups have been identified, it is necessary to establish some means of continuous interaction and a forum for discussion on, and resolution of, conflicts that surround the directions of parking policy in a metropolitan area. A wide variety of actions could be taken, ranging from the creation of a new agency responsible for coordinating the operations of the parking sector to reliance on the entrepreneurial skills of agency staff to coordinate the process. In those cities where a sense of a regional parking policy has already been established, a task force or subcommittee has been the most used mechanism for providing the needed forum. The task of establishing this institutional base, however, is not necessarily an easy one in that agencies that have different objectives and capabilities are often hesitant to discuss issues aimed at creating a mutually satisfactory position on parking policy. This is especially true when both private and public interests are important actors in developing an integrated policy. However difficult it might be, the creation of such an institutional base is a prerequisite for efforts to develop a parking policy.

Develop Awareness of the Different Objectives for Which Parking Strategies Can Be Used

Because such a wide variety of agencies are involved with parking, there will generally be little consensus on one major objective that should guide the development of a parking policy. To try and reach a consensus on such an objective, given the different agency mandates and constituencies, would be most difficult. Instead, each participant in the process should be made aware that parking management strategies affect a large number of urban objectives and that they can thus be used as a policy lever for achieving a diverse set of purposes, such as the following (1):

1. Healthy economic climate and a business community able to support local employment needs, which means the ability to attract and keep desired kinds of development and industry, a healthy retail sales climate, and a stable or growing municipal revenue base;
2. Most efficient use of existing transportation, land, and other public resources;
3. Ease of mobility and accessibility of resources for vehicles and pedestrians;
4. Equity of resource distribution and preferential allocation of some resources;
5. Environmental goals, especially reduced air pollution and the related goal of minimized energy consumption; and
6. Enhanced amenity and cultural attractiveness, or the preservation of a city's unique character.

As shown in Table 1, officials from different agencies in the case-study cities viewed the implemented strategies as helpful in attaining several objectives. As was also found in the case studies, however, many agency officials considered parking strategies solely from the perspective of their own agency's mandate and did not necessarily understand the relationship between their actions and the actions of other parking-related agencies. It is thus essential that a general awareness of what parking management strategies can and cannot do be developed among the participants of the parking policy process so that an internally consistent and multiobjective policy will be produced.

Identify and Analyze the Types of Parking Management Strategies Available for the Parking Policy

The range of impacts of a parking policy can be evaluated through the scope of the parking management strategies of which it consists. Based on the case studies, three levels of application may be defined (see Table 2). The areawide level corresponds to the broadest range of impacts and reflects that many strategies affect not only a particular area of the city but also the urban area as a whole. Park-and-ride programs, for example, are typical strategies that are not bound to specific geographical subareas of the region. The next level corresponds to strategies that have an impact at the level of the neighborhood. Residential parking programs fall mostly within this category. Finally, some actions are typically implemented at the site-specific level. This means, for example, that a particular set of parking management actions is applied at a local site in order to reduce the level of demand for site parking.

Each of the parking management strategies should be related to the objectives of the parking policy and estimates should be made, where possible, of the impact the strategies have on the attainment of these objectives. In most cases, the conclusions regarding feasible combinations of parking strategies and urban goals will be based largely on the likely effects of different market forces imposed on different parking-supply-demand scenarios and on implications of past experiences. No obvious metric exists, or has been used, to judge the absolute or relative effects of various parking management techniques on the goals being examined. Although preliminary efforts have been made in this direction, the analysis of parking management strategies must necessarily be based on experience and judgment (12).

Table 1. Perceived objectives of implemented parking management strategies in the case-study cities.

	Preceived Objective				
Strategy	Improve Air Quality	Improve Residential Areas	Encourage Retail Activity	Encourage Downtown Development	Produce Congestion Relief
Parking freeze and zoning	X				X
Park-and-ride	X				X
Preferential carpool parking	X				X
Parking enforcement		X	X	X	X
Residential parking permit programs		X			
On-street parking restrictions			X		X
Local constraints and pricing					X
Preferential parking for retail shopping			X	X	

Table 2. Perceived scope of parking management strategies in the case-study cities.

	Scope		
Strategy	Areawide	Neighborhood	Site Specific
Parking freeze and zoning	X		
Park-and-ride	X		
Preferential carpool parking	X		
Parking enforcement		X	
Residential parking permit programs	X	X	
On-street parking restrictions	X	X	X
Local constraints and pricing			X
Preferential parking for retail shopping			X

Formulate a Strategy for Implementing the Parking Policy

In a recent book on policy implementation, Nakamura and Smallwood state (15), "The policy implementation process is characterized by a complex series of diverse linkages among policymakers, implementers, and evaluators, and a high degree of political judgment and leadership is required to tie this system into an integrated whole." The institutional structure for parking policy is clearly characterized by such diverse linkages and thus susceptible to obstructions and delays throughout the parking policy formulation and implementation process. As such, it is extremely important that a strategy for policy implementation, where organizational responsibilities are clearly spelled out, where the lead agency or agencies have introduced features into the policy (e.g., incentives, mandates, or sanctions) to deal with resistance, and where efforts have been made to establish a feasible coalition of parking policy proponents, be developed and used.

CONCLUSIONS

The case studies of parking policy illustrate the fragmented nature of the institutional structure of parking policy in American cities. A large number of organizations, both in the public and private sectors, have a major role to play in establishing a comprehensive and coordinated parking policy. Currently, most parking policy in American cities consists of the independent actions of several agencies, each of which has a different mandate and a different set of constituencies. Each uses a variety of parking management actions to achieve objectives that often conflict. As is argued in this paper, however, a coordinated parking policy constitutes a prerequisite to the serious linking of parking policy and urban objectives.

The development of such a parking policy requires a close examination of the institutional relations that exist in the parking sector and the formulation of a strategy for establishing an institutional base for a regional parking policy. Given the large number of agencies often involved with parking, one could expect significant obstacles in developing a policy aimed at achieving one or two objectives. It is therefore recommended that a major purpose of the policy formulation process should be to make the participants aware of the impact parking management strategies have on a large number of urban objectives.

Finally, a major obstacle to the development of a comprehensive parking policy is the lack of data on the impact of various parking management techniques on urban goals and objectives. The identification of such impacts and the formulation of a consistent set of effectiveness measures are research items that should receive top priority.

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Role of Law Enforcement in Transportation Planning

JAMES E. SMITH

The operational expertise that law enforcement has gained in carrying out its traffic safety mandate is seldom voiced, considered, or even sought as a part of the transportation planning process. This is partly a result of a lack of understanding of the complexities of transportation planning among the law enforcement community and others who share responsibility for the implementation of public policy. It also stems from the fact that the traditional law enforcement focus has been on problems of expediency, and law enforcement agencies are reluctant to become involved in planning. The obvious result of this situation can be (and often is) that society receives a suboptimal return for the capital improvements made to the transportation system in both operational efficiency and the prevention of economic loss from accidents. In the era of plentiful funding, the effects of incomplete or misdirected planning could be overcome through trial and error. Today, however, such luxury can no longer be afforded. A framework is needed so that all parties who have an interest or expertise in transportation can contribute toward a determination of the most desirable alternatives to meet transportation needs. Within such a framework, the operational expertise of law enforcement can provide vital assistance to transportation planners in the attainment of a broad range of transportation goals.

As this nation's highway system developed, certain tasks associated with highway operations were inevitably assigned to or assumed by law enforcement agencies. Typical of those tasks are traffic law enforcement, congestion relief, parking control, and accident investigation. This operational orientation has continued to the present. Consistent with this traditionally operational role, enforcement agencies have seldom contributed their expertise to the development of local, regional, or statewide transportation plans. The philosophy has been that enforcement agencies need not be involved with transportation projects until after facilities have been constructed. And then, their involvement is generally limited to expressing safety and operational concerns in an effort to bring about engineering corrections or to acquire additional resources to handle problems not anticipated during plan development.

This relationship between transportation planners and law enforcement has not been altogether unsuccessful. Despite the absence of police participation during the planning process, safety and other law enforcement concerns have not been totally ignored. Modern highways reflect lessons learned in the past, and the existence of state highway patrols and traffic divisions within local police departments is an indication of an awareness of transportation-related enforcement needs.

Unfortunately, for enforcement agencies to maintain their traditional reactive stance with respect to transportation planning is no longer feasible or responsible. One reason for this is the expansion of transportation purposes, or goals, and the strategies that have been adopted to achieve those purposes. Where transportation was once viewed simply as a means of mobility, it is increasingly being accepted as a means to achieve other social, economic, and environmental objectives. These objectives would include, for example, rational growth, enhancement of existing urban areas, conservation of fiscal and natural resources, minimization of environmental degradation, and achievement of social equity.

CASE FOR PLANNING IN TRANSPORTATION SYSTEM MANAGEMENT PROJECTS

With respect to this new direction of transportation, and of particular interest to law enforcement, is the emphasis being placed on the application of transportation system management (TSM) strategies. Many TSM strategies are dependent on enforcement for their success. High-occupancy-vehicle (HOV) lanes on freeways and metered-ramp bypass lanes are examples of this dependence. An HOV facility that is overcrowded with vehicles that carry fewer than the required number of passengers provides little or no time-saving advantage or incentive for carpools and vanpools. Appropriate enforcement of TSM-related traffic regulations can help to maintain the incentive needed to ensure that the purposes of such facilities (e.g., decreased congestion and fuel conservation) are achieved.

Conversely, the lack of law enforcement involvement during planning for TSM facilities can result in situations where enforcement agencies are unable to provide an adequate level of service. Recent experience with TSM projects provides several pertinent examples. In Miami, during the three-person carpool phase on the Interstate 95 preferential lane, minimal enforcement resulted in a violation rate of 75 percent. Likewise, in Boston, a self-enforcing voluntary diamond lane experienced a violation rate of greater than 80 percent. Both of these projects had a specific characteristic that precluded the application of traditional traffic law enforcement tactics: Neither project had a median shoulder to permit the immediate stopping of a violator. Consequently, if any enforcement action was to be taken, the officer would have to follow the violator to the terminus of the project. A slightly different situation occurred in California. Enforcement of the Santa Monica diamond lane regulations kept the violation rate between 10 and 20 percent; however, absence of any physical separation between the diamond lane and the general traffic lanes, coupled with the speed differential between the two types of lanes, created a situation in which accident rates increased by as much as 150 percent.

Another situation that illustrates dramatically the need for law enforcement involvement in the initial planning of a high-cost project is the proposed I-105, Century Freeway, in Los Angeles. This 17-mile freeway project will incorporate several TSM strategies and cost approximately $1.7 billion. The freeway is being designed to accommodate mass transit facilities within a 64-ft-wide median. The long-range plan calls for a light rail system; however, the freeway will be served initially by buses that use the rail bed. In addition, HOV lanes, transfer facilities, and park-and-ride lots will be strategically situated along the project corridor.

This enormous investment of public funds for the I-105 project dictates that consideration for the ultimate success of the project not be limited to the aesthetic, environmental, and basic transportation issues. It is imperative that the entire facility fulfill the purposes for which it is being built. Therefore, project planning must include comprehensive consideration of enforcement needs, not only in terms of personnel but also with respect to facility design. First, without engineering for enforcement and provision for a level of service sufficient to ensure a minimum violation rate, the HOV lanes can be expected to be less than effective. Consequently, the incentive for motorists to carpool or use mass transit would be lost and the entire corridor would suffer from the increased congestion and air pollution that result from the breakdown of the system.

Another concern that law enforcement input should be used to address is that of crimes against persons and property that occur in or about the transfer stations and park-and-ride facilities. These locations, by virtue of the large number of people and vehicles and predictable traffic patterns, are an attractive setting for the criminal element. Activities such as vandalism, pickpocketing, automobile theft, and assault must be discouraged if the motoring public is to consider mass transit an attractive transportation alternative. Law enforcement expertise during the planning for transit-related facilities will help to ensure that safety and security needs are adequately addressed, and thereby contribute to the ultimate attainment of transportation goals.

LAW ENFORCEMENT PARTICIPATION

To provide adequate enforcement under circumstances such as those described in the preceding examples requires a substantial redeployment of available resources. The alternatives are to either abandon the projects or attempt to alter design configurations. This suggests a second reason for law enforcement participation in the transportation planning process--cost. Project abandonment, redesign, and redeployment all involve costs that are reflected in either additional resource requirements or a decreased overall level of service. In many cases, law enforcement involvement in the transportation planning process could help to avoid or minimize those costs since operational problems are less expensive to solve prior to the pouring of concrete. Finally, from an enforcement resource point of view, it will usually cost less to maintain acceptable violation rates if enforcement needs are recognized during the planning stages and personnel and procedures are made available on implementation rather than allowing high violation rates to become an established practice. In a similar sense, competition for public funds is increasing and it is no longer realistic to expect law enforcement agencies to justify budget increases for transportation projects that have already been built.

These observations are indicative of only a few of the problems and opportunities that surround law enforcement involvement in the transportation planning process. Clearly, effective operations, cost-efficient use of resources, and both economic and social concerns for traffic safety are within the purview of law enforcement responsibility. The conclusion that there is a need for greater law enforcement involvement in transportation planning is no guarantee, however, that such involvement will occur. Resistance both within and without the law enforcement and transportation planning communities is inevitable. Even when there is general support, there will be obstacles to overcome. A significant problem is that few transportation planners have any substantive ideas about how to best use the expertise of law enforcement during the planning process. Therefore, the responsibility for initiating participation will largely be borne by enforcement agencies. This may also be of concern to law enforcement because many agencies do not have personnel who are sufficiently familiar with the transportation planning process to design and implement an effective program for involvement.

FRAMEWORK FOR INVOLVEMENT

The California Highway Patrol has developed a program or framework for involvement in the transportation planning process. This program is called Transportation Planning for Operations, Resources, and Traffic Safety (TRANSPORTS). Applications outside California would naturally require modification to fit the particular transportation planning environment in question.

Concerning the transportation planning environment, transportation planning in California is governed by statute and is designed to facilitate planning on a regional basis. Every other year the regional transportation planning agencies (there are 43 regional agencies) prepare individual regional transportation plans (RTPs). The California Department of Transportation (Caltrans) uses these RTPs as input in preparing its annual proposed State Transportation Improvement Program (STIP). The proposed STIP is transmitted to the regional planning agencies, and those agencies that represent urban areas that have populations of 50 000 or more prepare and adopt a Regional Transportation Improvement Plan, (RTIP), which can differ from the proposed STIP. Regional planning agencies that do not represent urban areas of 50 000 or more review the portion of the proposed STIP that concerns their respective region and develop comments. Disagreements raised by comments on the proposed STIP or RTIP differences are resolved by the California Transportation Commission, which has ultimate responsibility for developing and adopting the STIP.

The California Highway Patrol is responsible for providing enforcement services on all highways within unincorporated areas of the state and all freeways, wherever they are located. The patrol's headquarters is in Sacramento and eight field divisions are located throughout the state. Divisions are divided into area commands, and there are 96 such areas.

It is within these transportation planning and operational environments that the California Highway Patrol is attempting to establish its TRANSPORTS program.

TRANSPORTS

The main thrust of TRANSPORTS is departmentally oriented; however, the program is intended to contribute to improved transportation system effectiveness and the ability to deal with change, externally as well as internally. The overall objectives of the TRANSPORTS program are as follows:

1. To promote traffic safety and departmental objectives in the transportation planning process and
2. To facilitate the coordination of departmental planning (strategic, resource, and operational) and the transportation planning process at all government levels (local, state, and federal).

The basic approach to achieving these objectives will be to develop and implement a departmentwide program of internal education, research, planning, and representation. These functions are the four elements of the TRANSPORTS program.

Program Concept and Framework

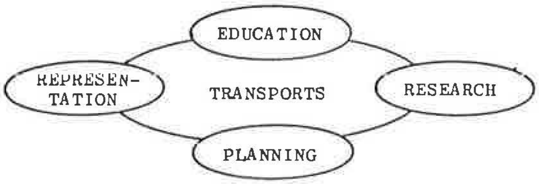
Figure 1 is a general model of the major elements of the TRANSPORTS program and their interactions. As can be seen, all program elements are interrelated and contribute not only to the TRANSPORTS purposes and objectives but also to the support and operation of each individual element.

Inasmuch as Figure 1 describes graphically the element relationships, the model is mainly a broad, functional description of the TRANSPORTS program. In order for the model to have working value, direction must be provided to coordinate and balance each element with respect to three program dimensions: level of participation, subjects of emphasis, and areas of involvement.

Program Dimensions

The level of participation is, in essence, a recognition that participation in transportation systems planning may be accomplished in several interactive ways with varying intensities. Ideally, interaction among agencies, public officials, and private groups should take place throughout the entire system planning process. The desirable characteristics of such interaction are that all participants should feel that their interests are adequately represented. Informal as well as formal ties should be developed, and each participant should make the choice as to how deeply involved in the process he or she could and should be. Levels of participation are applicable to the other two program dimensions in terms of actions taken or degree of activity. Interaction at any participation level cannot be self-serving but must contribute to improving the decision-making process if the program is to be successful.

Figure 1. TRANSPORTS model.



The subjects of emphasis are defined as enforcement operations, resources, and traffic safety. These areas reflect, in general, the purposes of law enforcement's involvement in the transportation systems planning process.

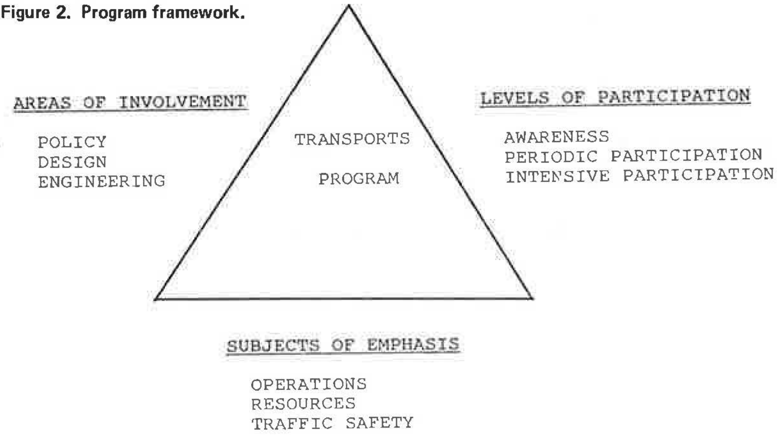
Areas of involvement, the last dimension of the program, provide the direction for participation in the transportation systems planning process. Three areas of involvement have been established:

1. Systems policy includes those decision-making activities associated with broad economic, social, and environmental factors; typical policy areas would include level of service, funding, mode selection, and needs assessment;
2. System facility design includes those decision-making activities that address facility configurations, locations, operations, and implementation of transportation facility projects;
3. Systems engineering includes those decision-making activities that relate predominately to traffic safety.

Taken together, these three dimensions provide the framework for law enforcement's participation in the transportation systems planning process. As shown in Figure 2, the levels of participation provide the how of involvement, the subjects of emphasis provide the why, and the areas of involvement describe what to be involved in. Within this framework, for a given area of involvement and subject of emphasis, levels of participation may vary, depending on location or other circumstances. Thus, a basic principle of this program is the recognition of diversity in transportation planning. Law enforcement involvement in the process should be commensurate with the scope and implications of the planning being performed.

The conceptual framework and the principles of commensurable involvement are not only significant to the development of the program elements that fol-

Figure 2. Program framework.



low but also to the implementation of the program. This is perhaps best illustrated through the education element where, for example, a system of courses in transportation planning may be developed that range from basic awareness to intensive coverage. The basic awareness course would then be conducted for all management personnel, but only those management personnel (or their staff) that have the need (e.g., managers of commands located in major regional planning areas) would be given the advanced course. Other parallel examples could be given for the other program elements; however, the basic principle is the same--involvement in the process should be commensurate with need.

Program Elements

The TRANSPORTS program consists of four elements: education, research, planning, and representation.

Education

The purpose of education is to increase awareness and interest in the transportation systems planning process as it impacts or affects the law enforcement agency's missions, goals, and objectives. In addition, it is intended that, through this element, individual skills necessary to work with transportation planning will be developed in varying degrees, based on need.

Research

The purpose of research is to (a) develop concepts, methods, and information concerning transportation and transportation systems that will be useful to the management and operation of the law enforcement agency; (b) contribute to the other TRANSPORTS program elements; and (c) expand the knowledge of the law enforcement-transportation planning communities. The scope of this element is constrained by the enforcement agency's goals and objectives, the subjects of emphasis, and the areas of involvement presented in the program framework.

Planning

The purpose of planning is to transfer the information gained through the program elements research and representation to the agency's routine planning processes. Through this activity it is intended that proactive agency plans will be developed to provide the overall direction needed

1. To assist the organization to more effectively fulfill its public responsibilities and
2. To identify opportunities for the organization to make even greater contributions to the goals of effective transportation systems.

Representation

Representation is externally oriented and is vital to the success of the program. The purpose of this element is directly related to the overall program objective of promoting traffic safety and the objectives of the law enforcement agency in the transportation planning process. Representation will help the law enforcement agency to identify and deal with problems directly related to the responsibilities of other entities. Likewise, the agency will become a resource for the planning community by being able to contribute another dimension in the analysis of problems and the development of alternative solutions.

Many representation strategies could be devised to achieve the TRANSPORTS objectives. A sampling of these potential strategies would include the following:

1. Initiation and maintenance of staff contacts with other appropriate and involved governmental agencies,
2. Development of existing and new contacts with nongovernmental agencies involved in the planning process (e.g., automobile club, highway users federation, environmental organizations, and citizens' groups),
3. Development of federal transportation agency contacts,
4. Development of local and regional planning contacts, and
5. Enhancement of liaison activities with the state department of transportation.

Anticipated Benefits

The ultimate benefits of law enforcement participation in transportation planning include a reduction in the number and severity of traffic accidents, alleviation of traffic congestion, and improved enforcement operations. These benefits will not, however, be achieved as a direct result of establishing a TRANSPORTS program. The primary role of such a program will be one of ensuring that enforcement concerns are considered in the transportation systems planning process and that enforcement personnel are properly equipped to contribute to the process. The decisions that result from law enforcement involvement in the transportation planning process will lead to achievement of the higher-order benefits.

From a practical or operational point of view, implementation of a law enforcement transportation planning program can be expected to provide many additional tangible and intangible benefits. Examples of these anticipated benefits include the following:

1. Improved resource utilization and needs assessment. This occurs through participation in project development where operating strategies can be developed and resource requirements determined. Research activities also contribute in this area.
2. Increased awareness of the role transportation plays in the socioeconomic environment and the contribution enforcement efforts make to this setting. This occurs primarily as an educational-training activity both internal and external to the enforcement agency. Externally, the role of law enforcement is enhanced. Internally, the insight gained contributes to opportunity identification and expansion of the agency's overall value.
3. Improved service to the public. This benefit affects not only safety, security, and other emergency services but also extends to fiscal responsibility and information delivery concerning the highway system.
4. Increased contribution to the field of transportation, traffic safety, and traffic law enforcement. This occurs primarily through research but also through representation in the transportation systems planning process.

SUMMARY

The TRANSPORTS program, or any similar program, should not put law enforcement agencies in the business of transportation planning. The primary concerns of law enforcement with respect to the transportation system must continue to be safety, security, and enforcement operations. The law enforcement perspective, however, is a resource that is available to the transportation planning community, not only for its safety expertise, but for improving the effectiveness and efficiency of the transportation system and ensuring that the goals and objectives for individual projects are met. Awareness of that perspective and using it for the public good are the sole purpose and intent of TRANSPORTS. The transportation planning and law enforcement communities must share the responsibility for bringing that perspective into focus.

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Enforcement of TSM Projects

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Transportation system management (TSM) strategies introduced on California freeways in recent years have included ramp metering, preferential lanes for high-occupancy vehicles, and bypass lanes for buses and carpools at metered ramps. Several factors have frustrated efforts to enforce the traffic laws that accompany these strategies; these include personnel limitations, enforcement priorities, public hostility, confusion, and physical constraints imposed by the geometry and design of specific projects. As a consequence, violations have increased on several projects. This paper covers the first six months of an ongoing two-year study designed to measure and evaluate the effect of different enforcement options, engineering features, and educational programs on violation rates for various TSM freeway strategies and to trace the resulting impact of these violation rates on safety, freeway performance, and public attitudes. During this six-month period, statistics were assembled to describe violation rates, enforcement levels, and operating performance on current and past California projects; drivers were surveyed; and different levels and combinations of routine and special enforcement activities were tested on a variety of TSM projects. Violation rates were measured before, during, and after the assignment of highway patrol officers to enforce specific projects. This paper documents current violation rates, sketches profiles of violator behavior prior to special enforcement activities, outlines the preliminary results of the first wave of special enforcement, and documents the results of surveys designed to test the attitudes of drivers toward violators, enforcement, and the TSM projects themselves.

Adequate control of violation rates on preferential lanes for high-occupancy vehicles (HOVs) and other transportation system management (TSM) projects requires an effective mixture of enforcement, engineering design changes, and public education. Although past experience with similar projects has given the California State Department of Transportation (Caltrans) and the California Highway Patrol (CHP) a number of insights regarding the potential effectiveness of different enforcement strategies, engineering changes, and education programs, this experience has not been documented with the quantitative precision necessary to identify the appropriate levels and mixture of these factors needed to obtain adequate motorist compliance. The purpose of the study described in this paper is to provide a detailed, quantitative, and objective assessment of the effect of different enforcement options, engineering features, and educational programs on violation rates for various TSM freeway strategies and to trace the resulting impact of these violation rates on safety, freeway performance, and public attitudes.

STUDY OVERVIEW

As a first step in accomplishing the study objectives, SYSTAN Inc., developed a detailed study design (1) that itemizes project objectives, specifies measures of effectiveness, outlines procedures for data collection and analysis, and provides a structured statistical framework for assessing the effectiveness of different enforcement options, engineering features, and educational programs.

Projects to be Evaluated

Mainline HOV Lanes

In the case of mainline HOV lanes, the different engineering options to be evaluated are limited to the major projects currently in place on California freeways. These projects include the nonseparated right-of-way on Marin RT-101 north of the San Francisco Bay Area; the preferential lane of Interstate 580 in Alameda County, which is separated from regular traffic by a buffer lane; and the 11-mile San Bernardino Busway east of Los Angeles, where the preferential lane is separated from general traffic by concrete barriers on the western end of the freeway and by a buffer shoulder and pylons on the easternmost 7 miles of the project. Detailed descriptions of each of these projects may be found in the study design (1).

Ramp Bypass Lanes

The full range of characteristics of bypass lanes represented on California freeway ramps are being tested to determine their impact on enforcement and violations. More than 130 ramp bypass lanes currently provide preferential access to carpoolers and buses that use Los Angeles freeways; San Diego has 7 such lanes, 3 of which have been installed on freeway-to-freeway connectors. Existing bypass lanes have been classified in groups according to a number of important geometric features, design choices, and performance characteristics, including the visibility of the enforcing officer and the current violation rate. In developing a sampling framework, three levels of officer visibility and ramp violation rates were defined:

Officer visibility--not visible, queue-dependent, and visible.

Ramp violation rates--high, more than 12 percent; medium, 12-6.5 percent; and low, less than 6.5 percent.

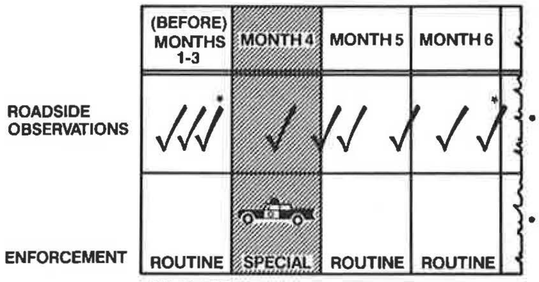
The visibility of the enforcing officer is rated from the driver's point of view as he or she enters the ramp. If the enforcing officer can be seen as soon as the driver is on the ramp, enforcement is classified as visible; if the officer cannot be seen until a violator passes the meter, enforcement is classified as not visible; if the visibility of the officer depends on the position of the driver in the queue on the ramp, enforcement is classified as queue-dependent. In addition to ramp violation rates and officer visibility, other classification concerns include the characteristics of the area served by the ramp (i.e., residential or industrial), ramp geometry (i.e., diamond or loop), availability of a refuge area for enforcement, length of time a ramp has been operating, relative percentage of regular users, freeway performance in the vicinity of the ramp, and existence of any special engineering problems (i.e., turning lanes that can trap single-occupant vehicles in the carpool lanes).

Data Collection

A typical pattern for field observations for a specific TSM project is shown in Figure 1. This pattern calls for observation of violation rates for 2 or 3 days prior to the introduction of special enforcement activities, followed by as many as five observations during the 2 months following these activities. This series of observations focuses attention on the behavior of the motorist after special enforcement activities have ceased. The need for the last observation in each sequence is determined by applying prespecified testing procedures to earlier observations in the sequence (1). Experiments with different enforcement levels have been scheduled sequentially over a period of nearly 2 years, so that the results of ongoing analysis and the observations of enforcement personnel can be used to direct future testing.

This paper summarizes the results observed during the first six months of the ongoing 2-year study. During this 6-month period, statistics were assembled that describe violation rates, enforcement levels, and operating performance on current and past TSM projects in California; drivers were surveyed; and an initial wave of enforcement was launched in which different levels and combinations of routine and special enforcement activities were tested on a variety of TSM projects. Violation rates were measured before, during, and after the assignment of CHP officers to enforce specific HOV lanes and metered freeway ramps. This paper documents current violation rates, sketches a profile of violator behavior on each TSM project prior to special enforcement activities, outlines the preliminary results of the first wave of special enforcement, and documents the results of surveys designed to test the attitudes of drivers toward violators, enforcement, and the TSM projects themselves. Additional details on each of these topics may be found in the first interim report on the project (2).

Figure 1. Typical pattern of field observations.



*AS NEEDED

VIOLATION CHARACTERISTICS

Table 1 summarizes violation statistics on key California TSM projects during the study implementation phase, prior to the introduction of any special enforcement programs. This table shows that the percentage of vehicles that used California mainline HOV lanes illegally during the preenforcement phase of the study ranged from 8.8 percent on the San Bernardino Busway to 30.5 percent on the controversial Alameda I-580 diamond lanes. Occupancy violations on the shoulder-separated right-of-way of the San Bernardino Busway averaged 7.3 percent of all vehicles in the lane during the morning peak and 10.5 percent of all vehicles in the afternoon. These violation rates were lower still (estimated at 3 to 4 percent) on the portion of the busway where a physical barrier makes lane-switching impossible. Although violation rates on the San Bernardino Busway and Alameda-580 had not increased appreciably over prior measurements, the 21.5 percent violation rates recorded on Marin-101 represented an increase over the violation rates of 5-15 percent reported roughly 1 year earlier.

The average lane violation rate for a sampling of 39 metered ramps that have HOV bypass lanes in the Los Angeles area was 37.7 percent, which is appreciably higher than the comparable violation rate on any mainline HOV project in California. This rate appears to be increasing on most ramps, and bypass lanes that have been operational for several years have significantly higher ramp violation rates than do newly opened lanes. The relative number of vehicles that use bypass lanes illegally ranged from a low of 13 percent to over two-thirds of all vehicles in the bypass lane. (In terms of the total number of vehicles on the ramp itself, these percentages range from a low ramp violation rate of 2.4 percent to a high rate of 39 percent.)

Table 1. TSM project violation rates and historical enforcement levels.

		Violation Data		Enforcement Data		
Type of Roadway	Project	Lane Violation Rate (%)	Ramp or Freeway Violation Rate (%)	Past Citation Rates	Apprehension Rate (%)	Average HOV Time Savings (min during peak hour)
Mainline HOV lanes						
Nonseparated lanes	Marin-101	21.5		11.6/day	2.6	Negligible[a]
	Santa Monica[b]	15.1	1.0	55/day		5-6
Separated lanes	Alameda I-580	30.5		2.5/day	0.8	Negligible[a]
	San Bernardino	8.8		10.8/day	3.3	5-7
Metered ramps						
Without bypass lanes		3.8[c]	3.8[c]	NA	NA	NA
With bypass lane	Los Angeles	37.7	12.8	0.27/ramp/day	0.18	1.3
	San Diego	19.5	3.0	0.07/ramp/day	0.24	0.4
Exclusive HOV bridge lane	San Francisco-Oakland Bay Bridge	5.4	0.7	2.4/day	1.1	4-5

[a] Average time savings is under 20 s.

[b] Project discontinued.

[c] Meter violation rate.

HOV lane violation rates were found to be considerably lower (averaging 19.5 percent on a sampling of seven HOV bypass lanes) in San Diego, where the peak traffic periods are shorter, meters are traffic-responsive, and the HOV lanes themselves are meter-controlled. The lowest lane violation rate recorded on any HOV project in California was the 5.4 percent violation rate on the San Francisco-Oakland Bay Bridge, which consistently offers carpoolers substantial time savings of 4-5 min, in addition to a toll-free trip across the San Francisco Bay.

The number of drivers who ignore meter restrictions by running the red light is relatively low, and is not considered to be a major problem by either Caltrans or the CHP, particularly because such violations tend to occur when traffic volumes are low and ramp queues are short or nonexistent. In Los Angeles, the level of meter violations is significantly higher on ramps without bypass lanes than on ramps with such lanes (3.8 versus 0.99 percent of all vehicles on the ramp), as the bypass lane itself provides a convenient pathway for those potential violators who might otherwise simply run the red light.

VIOLATOR BEHAVIOR

Violations by Time of Day

On Marin-101, violations tend to cluster on the fringes of the morning and evening operating hours. A high proportion occur just after restrictions come into play at 6:00 a.m., again at 4:00 p.m., and just before restrictions are removed at 9:00 a.m. and 7:00 p.m. (see Figure 2). A similar phenomenon was observed during morning and evening operating hours on the ill-fated Santa Monica Freeway diamond lanes (3). In the case of Alameda-580, preferential lane restrictions begin officially on Monday at 6:00 a.m. and are legally in force until Friday at 6:00 p.m. However, an unusually high proportion of violations occur between 6:00 p.m. and 7:00 p.m. every weekday (see Figure 3), which suggests that a large number of drivers wrongly interpret the operating hours to be 6:00 a.m. to 6:00 p.m., Monday through Friday. In this case, then, a significant proportion of peak-period violations could presumably be eliminated by redesigning either the signs or the operating hours.

On the separated right-of-way of the San Bernardino Busway, violations during the evening peak coincide with peak traffic volumes, but violations during the morning peak are concentrated during the first hour of lane operations, when darkness and CHP shift changes combine to create a lull in enforcement activities. Violations on Los Angeles bypass ramps also tend to be slightly higher at the beginning of the morning metering period and at the end of the evening period, when darkness makes the lanes difficult to observe and enforce. Ramp violation rates in San Diego tend to coincide with periods of heavy morning traffic and peak on the hour, just before 7:00 a.m. and just before 8:00 a.m.

Impacts of Delays

Little correlation was found between ramp violation rates and the time saved by bypassing the queue in the metered lane (see Figure 4). Although ramp violation rates increase slightly with the delay in the queue (rising to an average of 19 percent for delays of 2 min), the average violation rate recorded for delays under 20 s was a still-formidable 12 percent. The majority of the delays recorded by roadside observers were under 20 s.

Figure 2. Mean violation rate by time of day (Marin).

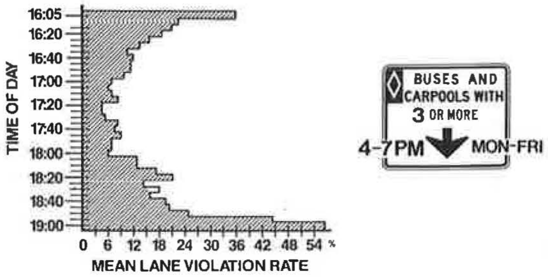


Figure 3. Mean violation rate by time of day (Alameda).

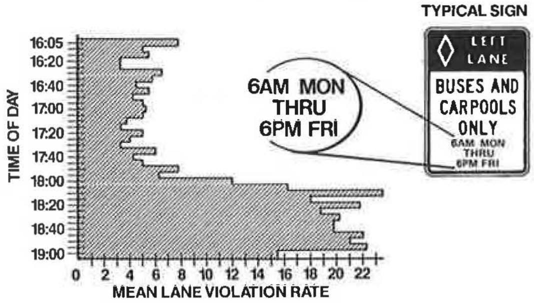
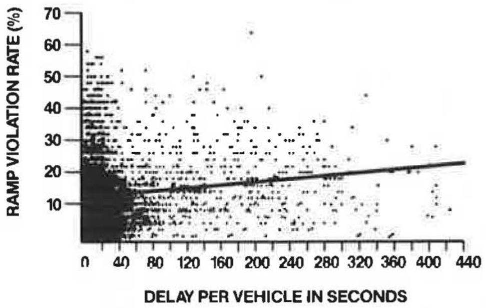


Figure 4. Ramp violation rate versus delay.



Observers reported that some single-occupant vehicles in Los Angeles used the HOV lane illegally even when the non-HOV lane had no cars at all. Drivers of those vehicles apparently simply wanted to avoid stopping for the signal, and felt that running a red signal light was a more serious violation (or potentially more hazardous to their health) than was illegal use of a HOV lane.

Although violation rates varied widely and unpredictably with ramp conditions, some evidence suggests that drivers' perceptions of delay stem not so much from the queue length as from the meter rate. Given the same delay, drivers appear more willing to stay in a long queue that is moving relatively fast than in a short queue that is moving very slowly because of a long meter cycle time. Figure 5 plots the mean ramp violation rate as a function of the meter cycle time for a sampling of 29 Los Angeles ramps.

Repeat Violations

Relatively few instances of repeat violations were observed on any TSM project. Preliminary findings suggest that HOV lane violation rates tend to reflect the actions of a large number of drivers who

Figure 5. Impact of meter rate on ramp violations.

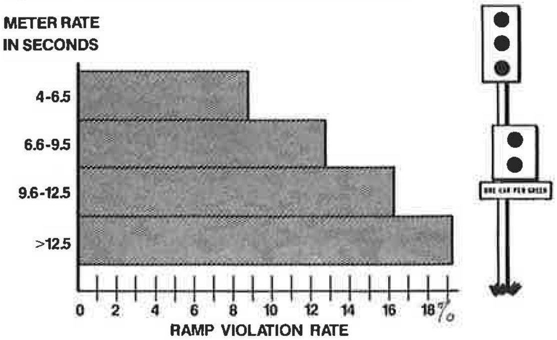
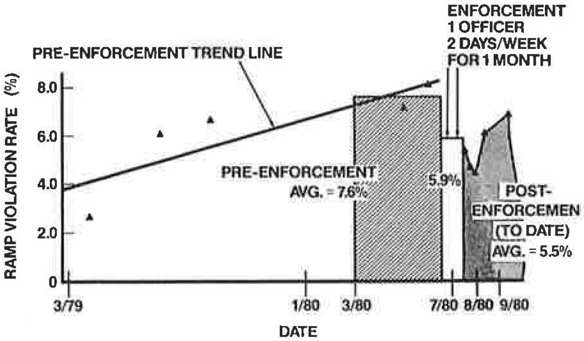


Figure 6. Ramp violation rate over time for Orangethorpe ramp in the morning.



transgress at infrequent intervals, rather than the day-to-day actions of a small group of repeaters. This indication is supported by the responses to numerous survey questions, which suggest that observed violators are not markedly different from ordinary drivers.

ENFORCEMENT IMPACTS

Past Enforcement Levels

In the past, the CHP has applied a policy of relatively low-priority, routine enforcement to ramp bypass lanes. Available personnel have enforced the lane restrictions in addition to performing regular patrol duties. As the number of bypass lanes in Los Angeles has exceeded 130, however, the supply of bypass lanes in some CHP command areas has actually outnumbered the supply of officers available for all patrol duties during the peak traffic periods. As a result, a ramp-by-ramp survey of seven command areas in Los Angeles and two in San Diego showed that the average number of occupancy citations issued per bypass lane was slightly more than one per week at the start of this study.

Past citation rates on mainline HOV lanes have been considerably higher than those for bypass ramps, and range from a low of 4 tickets/weekday on Alameda-580 to 14 tickets/weekday on the San Bernardino Busway. Additional officers are routinely assigned to patrol the freeways adjacent to the mainline HOV lanes in order to enforce the preferential lane restrictions.

Special Ramp Enforcement Activities

The first wave of special enforcement activities on ramp bypass lanes in Los Angeles and San Diego was scheduled over the 4-month period between June and September 1980. Officers were assigned to particular projects for a specific number of days each week for periods of 1-3 months. These special assignments were applied randomly and interspersed with periods of routine enforcement.

Enforcement tactics employed on the ramp bypass lanes varied from officer to officer and ramp to ramp. The most popular and effective tactic on ramps with ample refuge areas entailed parking the patrol car or motorcycle beyond the meter and standing in place in the refuge area to wave violators over. On ramps that have scanty refuge areas, officers positioned themselves and their vehicles either ahead of the meter or behind it, and pursued suspected violators along the freeway until they could be pulled over. Since this tactic leaves the officer at some distance from the ramp being enforced, it is less efficient than in-place enforcement, both in producing citations and in providing an example to other ramp users.

Typical Violation Patterns

The interim report (2) contains detailed accounts of observed violation rates before, during, and after the first wave of special enforcement activities on each sample ramp in Los Angeles and San Diego. Figure 6 charts the typical behavior of ramp violation rates over this period, by using as an example the Orangethorpe ramp leading to westbound CA-91 in Orange County. This graph reflects the general tendencies observed on most Los Angeles ramps. Historical counts collected prior to the current project are typically lower than the preenforcement counts collected in May and June 1980, which indicate a general trend of increasing violations. The average preenforcement ramp violation rate was 7.6 percent, which reflects an average of 121 violations/peak period. The violation rate dips to 5.9 percent during the special enforcement period, which covered a one-month period between mid-June and mid-July. During this period a motorcycle officer was stationed at the head of the Orangethorpe ramp 2 days each week for the entire period of meter operation. The officer issued 59 citations during this period, for an average of 8.4 on each day of special enforcement, or 3.0 on each weekday during the month. This citation rate was far higher than the average of 0.23/ramp/day turned in on all ramps within the cognizant CHP area during the early months of 1980.

Following the one-month enforcement period, the violation rate dipped still further and reached a low of 4.3 percent (73 violations) during the third week following enforcement. The violation rate then began to climb and rose to 6.1 percent four weeks after the special enforcement period eased and 6.7 percent eight weeks following enforcement. Statistical tests showed that the difference between the four week level and the preenforcement level was not statistically significant (at the 0.05 level), so a conservative assumption was made that the impact of special enforcement was no longer felt at this point.

Different Enforcement Levels

During the first wave of ramp enforcement activities, several different levels of special enforcement were tested on ramps that have different geometric characteristics and violation histories. At this time broad conclusions about the overall impact of this activity can be drawn, but data are still being assembled regarding the details of citation rates and enforcement tactics. Figures 7 through 10 chart the broad impacts of four different levels of special enforcement:

Figure 7. Composite enforcement impacts for eight-ramp sample.

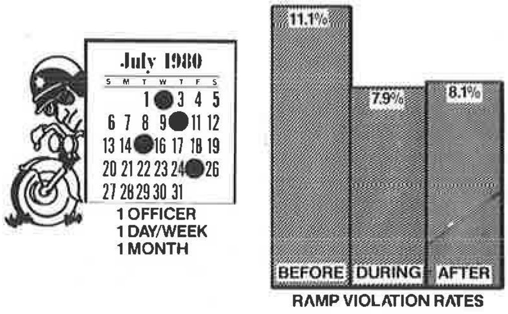


Figure 8. Composite enforcement impacts for five-ramp sample.

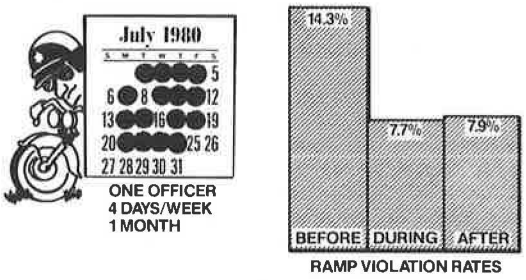


Figure 9. Composite enforcement impacts for four-ramp sample.

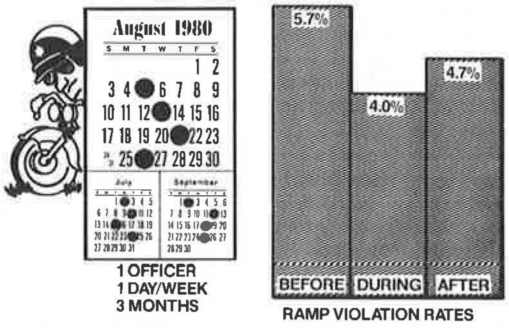
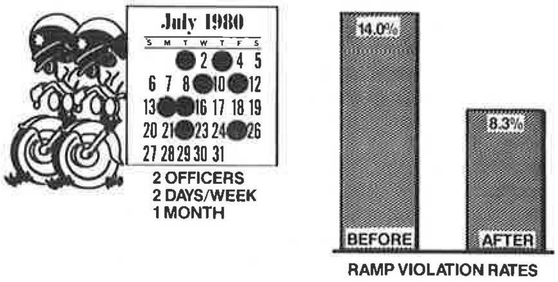


Figure 10. Typical enforcement impacts for one-ramp sample.



1. One officer, 1 day/week for 1 month (Figure 7);
2. One officer, 4 days/week for 1 month (Figure 8);
3. One officer, 1 day/week for 3 months (Figure 9); and
4. Two officers, 2 days/week for 1 month (Figure 10).

The results of these enforcement levels are plotted for composite ramps constructed by averaging the violation rates on appropriate ramps before, during, and after the indicated levels of enforcement were applied. This method of aggregating results contains several inherent statistical flaws:

1. All postenforcement measurements are averaged together, which masks upward trends as the impact of enforcement wears off. For this reason, the after percentages in Figures 7-10 actually represent a conservative upper bound on the impact of enforcement.
2. The results are biased by the nature of the ramps selected to receive each level of enforcement. Ramps that have a history of low-violation rates tended to receive lower levels of enforcement and did not respond as dramatically to these levels as did ramps that had a history of higher enforcement levels. The heavy presence of these low-violation ramps in the composite statistics for low levels of enforcement activity biases these results.
3. The composites depicted in Figures 7-10 tend to obscure the results obtained on individual ramps, which will be the focal point of future analyses. The ramp-by-ramp response of violators to special enforcement activities can be found in the interim report (2).

In spite of all these drawbacks, the composite results depicted in Figures 7-10 summarize the central outcome of the first wave of enforcement activities with a minimum amount of distortion. That is, even the lowest level of special enforcement activity (one officer, 1 day/week, for 1 month) reduced ramp violation rates significantly. Moreover, violation rates tended to remain low for as long as four to eight weeks following the cessation of special enforcement activities. Extension of the period of special enforcement from 1 to 3 months did not produce a corresponding reduction in ramp violations, which suggests that the marginal impact of special enforcement activity diminishes with time. Future study activities will further explore this relationship.

Because of the longer time spans involved, the impacts of 3-month periods of special enforcement were not available for analysis at this time.

Effect of Past Violation Patterns

Special enforcement appeared to be most effective on ramps where violation rates were previously medium or high (see Table 2).

On ramps where ramp violation rates were already low (i.e., under 6.5 percent), special enforcement seems to have less impact in reducing occupancy violations further, and violation rates returned to preenforcement conditions much faster. This suggests that there is a practical limit on the reductions that can be brought about by enforcement, and, consequently, special enforcement efforts should not be expended in an attempt to make tolerably low violation rates lower still.

Enforcement on Newly Opened Ramps

Start-up enforcement strategies were tested by selecting matched pairs of newly opened ramp bypass lanes similar in geometric configuration and enforcement visibility, initiating special enforcement activities on one ramp of each pair, and restricting the other ramp to low-priority routine enforcement.

After one month of special enforcement activities, all ramps that received special enforcement had significantly lower violation rates than did their opposite numbers. In general, the heavier the ramp enforcement activity, the wider the spread

Table 2. Effect of enforcement on ramps that have different historical violation rates.

Preenforcement Violation Category	Ramp Violation Rates Avg Preenforcement Level	Avg Level During Enforcement	Drop (%)	Avg Post-enforcement Level	Drop (%)
High violations, 14 ramps	19.9	12.8	35.7	13.2	33.7
Medium violations, 10 ramps	9.0	5.9	34.4	5.7	36.7
Low violations, 9 ramps	3.8	3.3	13.2	2.9	23.7

Table 3. Lane violation rates before, during, and after enforcement for mainline HOV lanes.

	Marin-101		Alameda-580		San Bernardino Busway	
Item	Morning	Evening	Morning	Evening	Morning	Evening
No. of violations						
Before enforcement	14.1	29.0	28.5	32.7	7.3	10.5
During enforcement	9.9	17.4	25.9	21.3	6.0	7.0
After enforcement						
Week 1	9.7	21.2	11.5	19.8	5.4	6.5
Week 2	9.9	23.6	25.0	20.5	4.1	5.4
Weeks 3 and 4	18.2		24.8	19.0	3.7	4.8
Week 5	19.1	25.2	16.4	21.1	2.6	4.7
Weeks 7 and 8		33.3		25.2		
No. of additional officers	0	2	2	2	6	4
Days per week		4	2	3	2	2
No. of weeks		2	2	2	2	2

between violation rates on the enforced ramps and their unenforced counterparts. Violation rates on the unenforced ramps rose relatively rapidly and exceeded 15 percent within 6 weeks of the opening date on two of four control ramps. This rapid rise suggests that Los Angeles drivers who use the new lanes have had enough past experience with bypass lanes in other areas to have formed opinions regarding the relatively low levels of CHP enforcement and the correspondingly low probability of violator apprehension.

Special Mainline Enforcement Activities

The first wave of special enforcement activities took place on mainline HOV lanes early in May 1980. Periods of special enforcement were shortened to 2 weeks so that postenforcement measurements could be made in advance of summer vacation. Between two and four additional officers were assigned to each project for 2-4 days/week during each 2-week enforcement period.

Preferential lane restrictions on Marin-101 are generally enforced by using motorcycles because of the lack of a median lane and the limited amount of shoulder space. Enforcement officers need to guide violators across three lanes of traffic to a narrow 8-ft shoulder. During the winter rains, when motorcycle use is hazardous, a patrol car is parked in a highly visible position on the freeway shoulder to discourage violators, slow down traffic, and respond to accident calls. In recent months, preferential lane enforcement activities have been concentrated during the evening peak. These evening activities have evidently had a chastening impact on morning drivers as well, since the average lane violation rate is lower in the morning than in the evening (14.1 percent during the morning peak versus 29.0 percent during the evening peak).

Alameda-580 is most often enforced by patrol cars. Officers on Alameda-580 pull violators over to a fairly wide shoulder that has a dirt median. The San Bernardino Busway is enforced by a combination of patrol cars and motorcycles. Occupancy violations are detected by assuming a position on the buffer lane that separates the eastern section of the busway from the general flow of traffic, and citations are issued either on the shoulder or on the buffer lane itself. Enforcement of the physically separated western section of the busway is minimal because violation rates are low, and the limited access makes it difficult to patrol efficiently.

Table 3 lists lane violation rates before, during, and after enforcement for the three mainline HOV lanes. On each project, the special enforcement activity had a significant impact in reducing violation rates. Projects differed primarily in the residual impacts of enforcement. Violation rates on both Alameda-580 and the San Bernardino Busway remained lower than preenforcement levels for at least 8 weeks, until the summer vacation period began. Marin-101 experienced large reductions during both the morning and evening peak periods, even though special enforcement activities were only scheduled during the evening commute hours. The percentage reduction, however, was smaller in the morning, and conditions returned to normal faster. The relative decline in violation rates was not so great on the San Bernardino Busway as on the other two mainline lanes, primarily because the busway violations were relatively low to begin with.

DRIVER ATTITUDES

Before special enforcement activities were initiated, surveys were mailed to a sample of single drivers, carpoolers, and carpool-lane violators on three mainline HOV lanes, six ramp bypass lanes in Los Angeles, and two bypass lanes on freeway-to-freeway connectors in San Diego.

The populations surveyed on each project were contacted by sampling the license plates of vehicles that use the carpool lane and adjacent lanes, by using department of motor vehicles records to obtain the addresses of vehicle owners, and then mailing the surveys to the owners' homes. To ensure the anonymnity of respondents, no attempt was made to link the surveys to a particular driver. Surveys were printed separately for each project and color-coded so that the responses of violators, carpoolers, and general drivers could be analyzed independently. Copies of the basic survey form and a summary of the response rate from each project group can be found elsewhere (2). The overall response rate for all projects averaged 22.5 percent; the highest response rate was from general drivers (24.4 percent), followed by carpoolers (20.9 percent), and violators (18.8 percent).

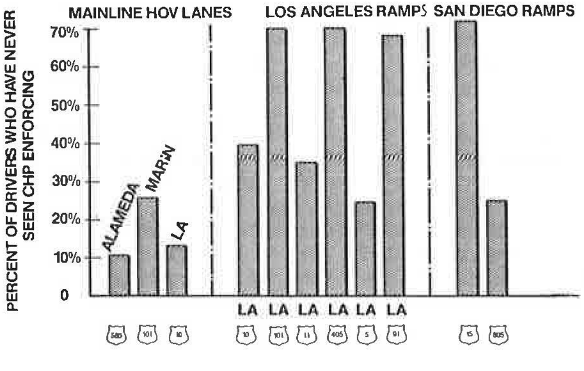
Findings

In general, the tabulated survey responses seem to indicate that, although the differences among violators, carpoolers, and general users on a particular project are few and generally predictable, major differences separate the attitudes and perceptions of users of individual projects. This was especially true on the mainline HOV lanes. All classes of drivers on the controversial Alameda-580 project viewed the preferential lanes unfavorably; however, drivers who use Marin-101 and the San Berndadino Busway were generally more tolerant of HOV projects. Relatively few drivers on these two projects opposed the idea of more freeway lanes for carpools. Among the users of ramp bypass lanes, San Diego drivers viewed the idea of dedicated freeway lanes more favorably than did Los Angeles drivers. Some of the Los Angeles opposition seemed to reflect the much-publicized controversy that surrounded the ill-fated Santa Monica Freeway diamond lanes in 1976 (3).

Perceptions of Enforcement

One of the major differences among the projects themselves may be found in the perceived enforcement level reported by drivers. Drivers on mainline HOV lanes were much more aware of CHP enforcement activities than were drivers who use the survey ramps in Los Angeles and San Diego (see Figure 11). Only 14 percent of the mainline HOV-lane users said that they had never seen CHP enforcement of occupancy violations, but 38 percent of the San Diego ramp users and half of the Los Angeles ramp users responded that way. Although these differences in awareness certainly reflect the relative emphasis on enforcement on the different projects, they also provide insights into the impression made by different enforcement techniques. On the San Bernardino Busway, where violators are usually apprehended and ticketed in the buffer lane in full view of passing motorists, only 13 percent of all respondents said they had never seen the CHP ticketing violators. On Marin-101, however, where the CHP must escort violators to the side of the freeway before a ticket is issued, 26 percent of all respondents reported that they had never seen an occupancy citation issued. On one San Diego ramp that has a scanty refuge area that forces officers to pursue violators and issue tickets some distance from the ramp itself, 70 percent of all respondents reported they had never seen a citation issued for illegal use of the carpool lane. On a nearby ramp that has an ample refuge area where CHP officers could stand and wave over violators in full fiew of other drivers, the corresponding percentage was 25 percent.

Figure 11. Perceptions of enforcement levels.



Only about 10 percent of the drivers on all projects, except Alameda-580, thought that current enforcement levels were sufficient. On Alameda-580, however, 33 percent of the respondents thought that there was no need for the CHP to enforce more often.

Perceptions of Violations

The violation levels perceived by drivers also vary from project to project. When asked, "What percentage of the drivers in the bus-carpool lane would you estimate use the lane illegally?" drivers on mainline HOV lanes consistently overestimated the actual violation rates. Los Angeles drivers asked to estimate the relative number of bypass lane violators tended to underestimate, and San Diego drivers guessed that the lane violation rates on the I-15 and I-805 interchanges were higher than the actual rate computed from roadside observations. Driver estimates of violation rates cover a narrower range than do roadside observations, which indicates that drivers may tend to overestimate low violation rates and underestimate high rates.

Drivers on Alameda-580 were less concerned than other drivers about the presence of violators, which is presumably a reflection, again, of the adverse media publicity and public hostility directed toward the project. Of the Alameda-580 respondents, 43 percent thought that lane violations are no problem. Similar attitudes from drivers on other projects typically constituted only 15-20 percent of the responses received.

Attitudes Toward Ramp Metering

Overall, survey responses seem to indicate that ramp users have mixed feelings about the benefits of ramp metering. Although 70 percent of Los Angeles ramp users and 66 percent of San Diego ramp users agree that metering has improved freeway flow, only 14 percent of all Los Angeles respondents and 21 percent of their counterparts in San Diego thought that metering has shortened their overall trip time. Over half of all ramp users thought that ramp metering has no effect on their overall travel time and one-third of them believed that it has actually increased their travel time.

Perceived Time Savings

Drivers on both mainline HOV lanes and sample ramps that have bypass lanes were asked how much time they save by using the preferential carpool lanes. Tabulations of results show that drivers who respond to this question wildly overestimate the amount of time saved by using the carpool lanes (see Table 4). In each case, violators, carpoolers, and general drivers alike greatly overestimated the average time savings available to carpoolers.

One interpretation for the wide discrepancy between perceived time savings and actual time saved may be that differences tend to be amplified when one lane (i.e., the carpool lane) is moving while the other is not. In addition, the survey drivers may tend to cite the time savings available driving the worst freeway congestion (or longest meter delay) that they remember. This tendency to perceive greater time savings in the carpool lane, however, undoubtedly makes the carpool lanes appear more attractive to drivers than to statisticians and

Table 4. Driver estimates of HOV-lane time savings.

	Time Savings (min)	
Lane	Perceived	Measured
Ramp bypass		
National, LA-10	5.4	2.4
Woodman, LA-101	2.5	0.7
Vernon, LA-11	5.1	2.0
Olympic-Pico, LA-405	2.4	0.3
Colorado, LA-5	4.4	0.2
Orangethorpe, LA-91	3.1	0.4
Mainline HOV		
San Bernardino Busway	13.9	5-7
Alameda-580	6.9	<0.3
Marin-101	6.6	<0.3

indicates that there may be a psychological advantage in providing a carpool lane, even when the available time savings appear minimal. The illusion of greater time savings also helps to explain the relatively high violation rates observed on ramps in the face of negligible delays.

PRELIMINARY FINDINGS

Key findings with respect to violator behavior, enforcement effectiveness, and driver attitudes are summarized below.

Violator Behavior

On mainline HOV lanes that do not have barriers to separate the preferential lanes from the general flow of traffic, violations are heaviest at the fringes of the morning and evening operating hours.

Little correlation was found between violation rates on ramps and the time saved by bypassing the queue in the metered lane. Although violation rates increase slightly with the delay in the queue, and rose to an average of 19 percent for delays of 2 min, the violation rate recorded for delays under 20 s was a still-formidable 12 percent, and many violations were observed when there was no queue at all. Given the same total delay, drivers appear to be more willing to stay in a long queue that is moving relatively fast than in a short queue that is moving very slowly because of a long meter cycle time.

The number of drivers who fail to stop at the red signal light on a metered ramp is relatively low (less than 4 percent of all drivers on ramps without bypass lanes) and does not pose a major problem, particularly because such violations tend to occur when traffic volumes are low and ramp queues are short or nonexistent.

Enforcement Impacts

Even the lowest levels of special enforcement tested to date (one officer, 1 day/week, for 1 month) have had a significant impact in reducing violation rates on most HOV projects. Moreover, the residual effects of special enforcement actions have kept violation rates from returning to normal for at least 4-8 weeks after the actions have ceased.

Special enforcement appeared to be most effective on ramps where violation rates were previously high. On ramps where ramp violation rates were already low (i.e., under 4 percent), special enforcement seems to have less impact on reducing occupancy violations further, and violation rates returned to preenforcement conditions much faster. In the absence of enforcement, ramp violation rates can be expected to increase over time to the point at which meter effectiveness is minimized.

Driver Attitudes

Although the attitudinal differences that separate violators, carpoolers, and general drivers on a particular project are few and generally predictable, major differences separate the attitudes and perceptions of drivers on different HOV projects. Drivers are much more aware of in-place enforcement actions conducted in refuge areas near the HOV facility than of citations issued on freeway shoulders some distance from the facility.

More than two-thirds of the drivers on metered freeways feel that metering has improved freeway flow; however, less than 21 percent feel that it has shortened their individual trip times. Violators, carpoolers, and general drivers alike greatly overestimated the average time savings available to carpoolers from using HOV lanes, which indicates that there may be a psychological advantage in providing carpool lanes even when the available time savings appear minimal.

FUTURE DIRECTIONS

The findings of this paper must necessarily be regarded as preliminary, because data are still being assembled on citation rates and enforcement tactics, and a second wave of special enforcement activities has been scheduled on each sample TSM project. The impacts of these activities will be monitored to gain further insights into the relation between enforcement and violation rates. In addition, the effects of enforcement on freeway performance will be investigated, accident rates before and after the introduction of TSM projects will be analyzed, and the effects of increasing routine enforcement levels in the absence of special enforcement will be tested in two CHP command areas.

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Abridgment

Enforcement of Parking Management Strategies: A Critical Element in Program-Project Implementation

JAMES SHELDON-DEAN AND MICHAEL D. MEYER

Parking management strategies have become an important component of urban transportation programs. However, the implementation of such strategies and their eventual success is heavily influenced by the degree to which their new requirements are enforced. This paper examines the enforcement component of parking management strategies and identifies some of the key enforcement characteristics of successful strategies and programs. Case studies of a towing and booting program and a residential parking permit program in Boston are used to illustrate the important role that enforcement has in project implementation. The enforcement and adjudication process established should consider not only the types of tactics that can be used but also the capability of the agencies involved in the process to handle their responsibility. This is especially true in the adjudication component when the responsible actors are the courts. Finally, the U.S. Department of Transportation should take appropriate action to incorporate the start-up costs of parking enforcement programs into existing federal-aid programs.

Transportation professionals have become increasingly interested in parking management strategies as a means of restricting urban and neighborhood automobile use, encouraging public transit use, improving the urban economic base through better access to shopping establishments, and developing a source of revenue from parking fines (1). Several studies have shown that such strategies as residential parking permit programs (RPPPs), preferential parking for high-occupancy vehicles, differential pricing, and provision of off-street parking are effective ways of achieving these and other objectives (2,3). To succeed, however, a strategy must have public compliance, and that compliance is heavily influenced by effective enforcement, particularly during the initial stages of project implementation. This paper examines the role of enforcement in the implementation of parking management strategies and identifies some of the characteristics of successfully implemented enforcement programs. Case studies of two parking enforcement programs in Boston (a RPPP and a tow and hold-booting program) illustrate the importance of enforcement and the role of enforcement agencies in the project development process.

PARKING ENFORCEMENT IN THE UNITED STATES

Transportation planners and engineers have long recognized that enforcement was a critical component of project implementation, especially as it related to the success of parking strategies. As the following statements reveal, effective enforcement of parking regulations is an important and complex component of parking management strategies.

> The practical difficulties of initiating and operating a restraint scheme must be addressed. Administration and enforcement of present day parking controls has proved to be costly and difficult. (4)

> Strict enforcement, particularly in well-traveled areas, is generally required in order to achieve maximum benefit from parking controls.... Thus full enforcement of existing parking restrictions might preclude further restriction or removal of on-street parking. (5)

Although transportation planners recognize the importance of enforcement strategies in the overall transportation program (6), a number of factors make it difficult to define, in a general way, enforcement's role and effectiveness. For example, the objectives of an enforcement strategy will vary from case to case. In Louisville, Kentucky, parking enforcement is used to improve traffic flow along specific roadways; in Arlington, Virginia, and Palo Alto and San Francisco, California, enforcement programs are the key elements of residential parking programs (7,8). Washington, D.C.'s parking enforcement program, one of the most extensive and all encompassing in the nation, grew out of the district's problems with high numbers of illegally parked automobiles (see paper by Meyer and McShane in this Record). Another difficulty in defining the effectiveness of enforcement is distinguishing between the effects of a strategy and the effects of its enforcement. Clearly, enforcement will influence the success or failure of a parking management strategy, but its specific contribution is almost impossible to isolate. This determination is also hampered because enforcement has not been considered an important component of project implementation in recent years; therefore, data on its use are limited.

Despite these difficulties, enforcement programs are starting to receive closer attention along several dimensions. A sample study of two RPPP neighborhoods in Cambridge, Massachusetts, showed that, 1 year after RPPP implementation, the number of cars parked on the street decreased by 31 percent. As shown in the table below (2), enforcement has also had a major impact on parking patterns in Washington, D.C. (9).

Item	Prior to Enforcement Program	After Enforcement Program
Legal hours parked (%)	13	56
Illegal hours parked (%)	84	31
Vacant hours (%)	3	13
Turnover	1.2	2.9

Perhaps of more importance to local officials concerned with municipal finance, more data are available on the impact of enforcement programs on revenue generation. Washington, D.C.'s enforcement program netted an impressive $14 million in 1979; initial start-up costs were $776 000. Cambridge, Massachusetts, tripled its enforcement revenues, and in Portland, Oregon, the budget for the traffic engineering department is covered by enforcement program revenues. Thus, enforcement programs serve not only as effective means of achieving transportation and environmental objectives but also produce revenue for the implementing municipalities. However, as will be seen in the following discussion of parking enforcement in Boston, these programs are often difficult to implement and maintain.

PARKING ENFORCEMENT IN THE BOSTON AREA

Although Boston has a reputation for motorists who show little respect for traffic (and especially parking) regulations, the Boston area uses some of the more innovative parking control and enforcement techniques in use in the country today (13). In recent years, citywide and neighborhood RPPPs, a center-city automobile-restricted zone, an enhanced ticketing program, towing programs, and the Denver Boot have all been used with varying success to control the use of the automobile in the metropolitan area.

Towing and Booting Program in Boston

Boston began its Tow and Hold operation in the early 1970s. Tow and Hold was a minor program until Boston's 1976 fiscal crisis. Then, by using a list of scofflaws, Tow and Hold became a means of collecting millions of dollars of unpaid parking fines for the city. In 1977, to improve the campaign's effectiveness, the city began use of the Denver Boot, a mechanical device that locks the axle of the automobile, and thus immobilizes it. The advantages of booting over towing were numerous: Damage claims and thefts from impounded cars were eliminated, the number of impoundment lots needed was minimized, cars parked in difficult locations for towing could still be immobilized, traffic jams caused by towing operations were eliminated, booting was faster (five boots can be placed in the time it takes to tow one car), equipment was less expensive, and, perhaps most importantly, boots, visible on a scofflaw's car for hours while he or she pays tickets, demonstrated vividly to motorists the consequences of illegal parking and nonpayment of tickets.

The process of booting a vehicle and securing back payment for fines outstanding is quite simple. Meter maids from the Traffic and Parking Department and police officers issue violations. After 21 days, unpaid tickets are turned over to the courts for collection. The courts, after warnings and summonses have been issued and ignored, turn the lists of violators who have five or more tickets over to the city for Tow and Hold immobilization. Scofflaws must pay all outstanding tickets before their cars are released and, in doing so, must often visit several court districts. The time and annoyance involved have become well known and are a deterrent in themselves.

The city averages 140 cars booted per day, at a cost of $150-$160/car. Initially, the program averaged $300/car and yielded about $2 million for the city during the first year. No detailed evaluation of the program has been undertaken, but city officials feel the program is a great success. One city official estimated that the number of tickets paid today is twice the number paid in 1976. Parking lots in Boston also appear to be more heavily used since the introduction of booting, because motorists have come to learn that illegal parking is more risky than it once was. The impact of booting has thus reached far beyond the scofflaws who owe back tickets.

RPPPs

The first RPPP in the Boston area was instituted as a portion of the Boston transportation control plan (TCP) and consisted of a 2-h parking limit and a peak-hour parking ban on nonresident parking throughout Boston. Stickers were issued to city residents that exempted them from these parking restrictions. Enforcement of the peak-hour, nonresident restrictions was straightforward because violations are easily recognized by the absence of a resident sticker. However, enforcement of the 2-h limit was problematic in that the identification of violations requires multiple sightings of a nonresident vehicle in the same location at least 2-h apart. Given limited resources, the police department was unable to enforce this 2-h limitation and thus the program rapidly became ineffective.

Cambridge, across the Charles River from Boston, instituted the first neighborhood RPPP in the Boston area in response to parking congestion created primarily by the city's proximity to Boston. In response to neighborhood requests, Boston soon followed Cambridge in implementing neighborhood RPPPs that are in force 24 h/day, 7 days/week, to provide neighborhood residents with spaces reserved exclusively for them. Resident support (15 percent minimum) and precise neighborhood boundary definition were crucial to the successful enforcement of these programs.

Institutional Considerations

Although enforcement can contribute a great deal to the successful implementation of parking management strategies, the enforcement process itself is subject to both financial constraints (in the form of start-up costs) and institutional conflict.

The Boston criminal courts play a critical role in the enforcement process, but often they cannot give top priority to parking violations. A slow rate of fine collection has created some tension between the court system and city agencies, as has the courts' reluctance to allocate adequate resources for ticketing. To correct this situation, the city has proposed removing the process from the courts and the creation of a Parking Violations Bureau. Several cities, most notably New York and Washington, D.C., have adopted such a system of administrative adjudication to handle parking violations, but such an approach often encounters many legal, institutional, and political obstacles.

Ticketing agencies are also critical actors in the enforcement process. In most cases, police officials do not consider parking enforcement to be a major task of their agency. Because of this perception, Boston placed enforcement responsibility in the hands of a new Traffic and Parking Department, which used meter maids to distribute tickets. The police still participate in ticketing violations, particularly at night when union rules prevent meter maids from working, but their role is peripheral to the program's operation.

In summary, implemention and enforcement of a new parking management strategy require cooperation, often between several agencies at different levels of government. Police departments; traffic engineering and planning departments; city, county, and state offices and agencies; courts; and community interest groups all have a potential interest and role in parking enforcement programs. Success depends on the participation of all major actors in the planning process and on their subsequent willingness and capability to handle their responsibilities in the program.

CONCLUSIONS

Parking management experiences from several U.S. cities have shown the importance of enforcement in the implementation of such strategies. The case studies of parking enforcement programs in Boston have illustrated some of the important characteristics of enforcement strategies.

1. Enforcement of the parking strategy was provided at the beginning of project implementation and applied periodically to reinforce the public perception of serious enforcement commitment to the project.
2. Enforcement strategies have been developed in cooperation with community groups and local offi-

cials so that a constituency for such a program is developed at the local level.

3. The adjudication component of the enforcement process is often a barrier to the overall effectiveness of the program. The courts have other responsibilities that decrease the amount of resources they devote to parking enforcement.
4. Police departments also have other responsibilities that they consider more important than parking enforcement; meter maids can be used effectively in their place to distribute tickets.
5. Revenues from parking enforcement can often be quite substantial, many times more than paying for the costs incurred for program operation.
6. A major obstacle in establishing a parking enforcement program is in obtaining the funds to initiate the program. Currently, the U.S. Department of Transportation provides funds for such a purpose.

In summary, parking management programs are of increasing interest to transportation officials concerned with economic development, congestion, neighborhood amenity, and city finances. The effectiveness of these programs, however, is directly related to the level of enforcement provided during the initial stages and throughout the project's life. To formulate an effective enforcement strategy requires the participation of the police department, local officials, the courts, community groups, and the business community. This process can often be very controversial. However, each of these actors has an important role to play if the enforcement program is to be successful.

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Enforcement Requirements for High-Occupancy Vehicle Facilities

CRAIG MILLER AND ROBERT DEUSER

Enforcement of high-occupancy vehicle (HOV) traffic restrictions forms an integral and sometimes critical element of HOV preferential treatment projects. This paper summarizes the findings of a research study conducted for the Federal Highway Administration. This research (a) reviewed enforcement on HOV facilities, (b) identified effective HOV enforcement techniques, (c) developed model legislation for effective HOV enforcement, and (d) prepared HOV enforcement guidelines. Sixteen projects in the United States, representative of each type of freeway and arterial treatment, were visited to gain in-depth operational and enforcement data on each project. These projects exhibited varying enforcement programs, deficiencies, and performance levels. Enforcement guidelines have been prepared for each type of freeway and arterial priority treatment of HOVs. In order to improve enforcement of HOV facilities, innovative techniques, involving photographic instrumentation, mailing of citations, tandem (team) patrol, and paraprofessional officers, have been identified within the context of this research. For these innovative techniques to be effective, a compatible legal environment is necessary. This research conducted a legal review of six prominent legal issues posed by these techniques. Model legislation is drafted to provide the proper legal environment for effective HOV enforcement.

A number of high-occupancy vehicle (HOV) projects have suboptimal levels of enforcement. This is due in part to a lack of engineering concern with enforcement, even though the enforcement issue has a considerable impact on the operational and safety characteristics of HOV projects. As diversification in the design of HOV preferential treatment projects continues, the issue of enforcement of HOV facilities takes on greater importance and the need for developing enforcement strategies becomes essential.

ENFORCEMENT PLANNING PROCESS

In selecting a final HOV design strategy for implementation, the enforceability of that concept should be taken into consideration. For each HOV design strategy, the project planning and design team should ask, "How difficult will it be to enforce the restrictions associated with each of these strategies?" Possible modifications to the HOV design strategies should be explored to alleviate as many potential enforcement problems as possible.

Traffic law enforcement personnel should be intimately involved in the planning effort so that their valuable insight into the nature of possible enforcement problems may be encountered and also to gain their support for and sensitivity to the constraints within which the transportation engineer has to work. In many cases, compromises may have to be made in terms of the final design concept or the desired enforcement program.

Once the HOV design concept has been selected from a number of candidate strategies, a comprehensive enforcement program should be developed. Several enforcement strategies may be applicable to the realistic enforcement objectives of an HOV project. A careful review of the local legal environment and state statutory requirements should be made, particularly if innovative enforcement practices are under consideration. There are two basic criteria that can be used to judge the performance of the various enforcement options. These are (a) the projected violation rate and (b) the projected cost of the enforcement program. The selection of the alternative that produces the best results per dollar invested can be made in a straightforward manner. Unfortunately, detailed statistical information is lacking to forecast the violation rate.

In view of the lack of precise data on which to base the design of the final enforcement program, an evaluation plan should be developed to ensure a continuous flow of empirical data and feedback for program optimization. Specific areas related to HOV lane and enforcement operations that should be quantified include the following:

1. Relation between the number of citations issued and the number of violations that occur;
2. Interrelations among the violation rate, apprehension rate, and the travel time savings of the HOV lane; and
3. Changes in the violation rate due to changes in the quantitative, qualitative, or substantive aspects of the enforcement program.

A detailed enforcement manual is recommended for effective management of a complex HOV program. This manual should provide descriptions of the HOV project, system operations, enforcement procedures, and reference information.

Public awareness is essential for any new enforcement program. If the public understands the HOV operating strategy and its restrictions, the tendency to violate may be reduced. Furthermore, enforcement agencies concur that a public awareness program that notifies the public of enforcement activities increases the effectiveness of the enforcement effort. Inexpensive public education techniques available include news releases and conferences, public service advertising, transit advertising, speakers' bureaus, pamphlets or handouts, and banners over the roadway. More expensive techniques include paid television, radio, and newspaper advertising, as well as roadside billboards. The primary message that should be transmitted about HOV enforcement should be a simple statement of (a) what the law states and what is prohibited, (b) what will be done if a violation of that law occurs, and (c) what the consequences are if a violator is apprehended or cited.

HOV ENFORCEMENT PROGRAMS

A number of interrelated elements may comprise the HOV enforcement program. These elements are

1. Enforcement strategies,
2. Enforcement procedures,
3. Objectives of the enforcement program,
4. Priority assigned to the HOV enforcement program,
5. Assignment of enforcement personnel,
6. Enforcement equipment,
7. Enforcement budget and funding,
8. Enforcement planning, and
9. Legal and judicial environment.

Enforcement strategies related to HOV projects can be organized into three broad categories: routine, special, or selective. Routine enforcements are those enforcement activities that are randomly conducted in concert with the normal assortment of a uniformed police officer's duties. Special enforcement involves police activities planned and applied specifically to the HOV project on a continuing basis. Selective enforcement is a combination of both routine and special approaches, to the extent that special enforcement is applied periodically by officers in conjunction with a routine enforcement program. Routine enforcement can be an effective approach if the HOV project's geometric or operational features result in an acceptable (or tolerable) violation rate. If it does not, then special or selective enforcement would be required, provided funds are available.

Enforcement procedures may vary among HOV projects because accepted traffic law enforcement practices consist of a myriad of procedures. HOV enforcement programs consist of procedures for

1. Surveillance and detection, such as foot patrol, mobile patrol, stationary patrol, and hidden patrol;
2. Apprehension and citation, such as standard pursuit, stationary apprehension, wave-off, mail-out warnings, and team approach; and
3. Management approach, such as interagency approach, public information campaign, and enforcement manual.

The enforcement objective, whether stated formally or informally, is generally described as maintenance of the integrity of the HOV project. Once the HOV project gains operating experience, some enforcement programs establish a specific enforcement objective by defining a tolerable violation rate.

The level of relative priority assigned by the enforcement agency to the HOV enforcement program is usually indicated by the type of enforcement program selected for deployment. Special enforcement indicates relatively high priority because additional resources are required to execute such strategies. The extra enforcement personnel associated with a special enforcement program are assigned to detect, apprehend, and cite the violators of the HOV restrictions.

The number of personnel assigned to each HOV project is dependent on many factors, the most significant of which include the following:

1. Project length,
2. Project operation,
3. Project restrictions,
4. Enforcement strategy, and
5. Availability of enforcement personnel and funds.

The number of enforcement personnel assigned to cover an HOV project can vary greatly between similar projects. The motor vehicle is the primary equipment item.

HOV enforcement programs are usually funded through the enforcement agency's existing budget. This is especially true for enforcement programs that involve routine patrol and selective patrol strategies. The enforcement agency may be unable to allocate special funds for special or selective enforcement of an HOV project, and thus the HOV project must operate with routine enforcement. HOV enforcement should not necessarily be considered a drain on public funds. Each time a traffic citation is issued for an HOV violation, a fine is usually paid. The dollar amount of these fines is then allocated in some manner to the local or state treasury. The dollar amount of fines collected for HOV citations could exceed the costs of enforcement for the HOV project.

One of the most-significant factors in achieving a succesful enforcement program is the early involvement in the planning process by representatives of the enforcement agencies affected. This is especially true for HOV projects that will require either special or selective enforcement. The advantages of the early involvement of the enforcement agency in the planning process of an HOV project centers on these areas:

1. Provision of technical advice,
2. Promotion of cooperative relations, and
3. Personnel planning and budgeting.

In general, the HOV violation is cited either as a failure to obey a traffic control device if the project is based on general legislation or as a specific offense of the HOV designation if the legal statute or ordinance is more specific. The fine is dependent on the fine schedule established within the jurisdiction responsible for the project.

A good enforcement program can be undermined by the judicial branch of government if the judicial branch does not uphold the citations issued. An HOV project is susceptible to misinterpretation by the judicial branch. Briefings for traffic court judges regarding the HOV project can have an important influence on court attitudes. Judicial appreciation of the project's merits helps develop the proper judicial support for the project. Specifically, the judges should be informed of

1. Objectives of the HOV project,
2. Traffic regulations applied to achieve the objectives,
3. Enforcement approach,
4. Previous court rulings on similar projects, and
5. Legal basis for the restrictions and enforcement procedure.

Problems and Deficiencies

A number of HOV enforcement problems and deficiencies are created by geometric, operational, or institutional factors. The problems are as follows:

1. The lack of a safe and easily accessible refuge area bordering the HOV lane that can be used to apprehend and cite HOV violators;
2. The absence of any vantage point from which enforcement can observe the HOV facility while keeping out of view may cause enforcement to be inefficient and too visible,
3. Some concurrent-flow HOV projects do not have the HOV lane physically separated by barriers, traffic posts, or other implements from the general traffic lanes and thereby provide the motorist with an infinite number of locations to violate the HOV regulation;
4. If an HOV facility does not have a paved surface, clear of obstructions, for passing, then apprehension maneuvers can be difficult because general traffic lanes, especially on freeways, are usually congested;
5. On HOV systems where carpools are permitted, the determination of the number of occupants in a vehicle is made difficult by young children, vans and mobile homes, mirrored glass, hours of darkness, and inclement weather;
6. Most HOV projects have a speed differential between the HOV lane and the general traffic lanes, which presents a significant safety concern for all traffic and especially enforcement;
7. For HOV projects where refuge areas are not adjacent to the HOV lane, the citing of HOV violators is less visible to the motorists;
8. Certain HOV restrictions require judgment decisions on the part of the enforcement personnel; the primary judgment situation faced by enforcement personnel focuses on curb bus lanes and the use of the bus lane by vehicles turning right;
9. A good enforcement program for an HOV project requires proper coordination and cooperation between project management, enforcement, and judicial interests; if the cooperation between any two participants deteriorates, for whatever reason, then the enforcement program will suffer;
10. Traffic law may limit the effectiveness of potential HOV enforcement programs; because of geometric or operational problems associated with an HOV project, it may be extremely difficult for the officer who witnesses the offense to be the officer who apprehends the offender;
11. Many enforcement agencies have personnel constraints that hinder the traffic enforcement requirements imposed on the agency; and
12. A low probability of being cited, especially when combined with a low fine, offers little incentive toward compliance with HOV restrictions.

Program Performance

The primary measure of effectiveness of an HOV enforcement program is the violation rate achieved. On most projects, and for the purposes of this report, the violation rate is defined as the percentage of the total number of vehicles that use the HOV lane that fail to meet eligibility criteria for the HOV lane. The violation rates for the HOV projects encompass a wide range of percentages--from a nearly 0 percent violation rate to a violation rate of greater than 50 percent. The latter percentage means that the majority of vehicles that use the HOV lane are violators.

That an HOV project experiences a relatively high violation rate may not necessarily indicate failure of the objectives of the HOV project. The intent of employing a certain enforcement strategy is, in part, to achieve a violation rate that is considered tolerable to project management, enforcement personnel, motorists, or the general public. A high violation rate could very well be considered to be tolerable by the determinant group.

A number of factors affect the violation rate. These include the following:

1. HOV lane signing,
2. Bus versus carpool HOV lane restriction,
3. Travel time benefits,
4. Probability of apprehension,
5. Accessibility to the HOV lane,
6. Operating period,
7. Occupancy restriction,
8. Visibility, and
9. Weather conditions.

One of the objectives of HOV projects is to improve traffic flow on the particular facility; however, enforcement of the HOV projects often disrupts traffic flow. The directly related traffic flow problems are mainly associated with an apprehension procedure that results in hazardous weaving maneuvers performed by the enforcement vehicle alone or the enforcement-violator tandem. Once an HOV violator is escorted to a refuge area, the enforcement effort can be indirectly involved in disrupting traffic flow and contributing to traffic accidents through the phenomenon known as rubber-necking, which is associated with the curiosity of motorists and the presence of enforcement of any kind.

ENFORCEMENT OF HOV PRIORITY TREATMENT PROJECTS ON FREEWAYS

Certain recommendations for enforcement of HOV priority treatment projects are common to all freeway applications:

1. Enforcement requirements should be included in the earliest stages of project planning, and enforcement personnel should be active members of the planning team;
2. To the maximum extent possible, HOV priority projects should be designed, constructed, or modified in strict conformance to American Association of State Highway and Transportation Officials (AASHTO) and Manual of Uniform Traffic Control Devices (MUTCD) standards;
3. Officials of the traffic court system should be briefed prior to the project start-up about the project's operational goals, traffic restrictions, enforcement program, and legal basis;
4. On a project that has as its operational goal travel time savings, the HOV restrictions should be imposed only during those time periods when these savings can be achieved;
5. The entire project should be opened at one time;
6. Enforcement should be supported by extensive public education and publicity of the seriousness of the HOV restrictions; and
7. Aggressive enforcement should begin immediately to instill a degree of respect for the HOV restrictions.

Separate Facilities

Separate freeway facilities for HOVs include separate roadways and exclusive ramps. These facilities are designated for exclusive use by specified HOVs and all other vehicles are expressly prohibited. Separate facilities possess many of the operational characteristics of tunnel facilities, one of which is an irrevocable commitment to using the facility. This attribute makes separate facilities generally easy to enforce.

Separate HOV roadways characteristically have low violation rates, which vary from 0 to 6 percent where separation is permanent and from 5 to 10 percent where violators can gain access or egress by crossing partial separations.

The following specific recommendations are offered for separated HOV facilities:

1. The facility should have full right and left shoulders;
2. On partly separated facilities that have common shoulders, the shoulders should be flush and easily accessible by disabled vehicles but they should also be well delineated to discourage crossing the median shoulder;
3. On reversible facilities, access control must be positive; use of lane control signals is suggested by MUTCD and AASHTO, and gates or barricades should also be provided; and
4. Access locations should be designed to meet the traffic demand but should also be upstream of bottleneck locations if possible.

Except for some project-specific reason, the enforcement strategy should involve mobile patrol of the general traffic lanes with officers also conscious of the HOV facility. When the incidence of violations appears to be increasing, patrols should be stationed at strategic points on the shoulder of the HOV roadway. This surveillance should vary by timing and should use inconspicuous locations. Apprehension should generally be made on the HOV lane shoulder, unless a convenient exit can be safely reached.

Concurrent-Flow Lanes

Concurrent-flow HOV lane-priority projects on freeways generally involve the designation of the median lanes for use by buses alone or by buses and carpools. Access to the restricted lane is most often continuous; that is, there is no physical separation or other barrier between the HOV lane and general lanes. This feature makes concurrent-flow lanes among the most difficult HOV treatment to enforce. Concurrent-flow HOV lanes can be created by either reserving an existing lane for HOVs or, more commonly, by constructing new lanes in the median. These two approaches have differing effects from an enforcement point of view. First, the addition of lanes often eliminates or reduces median shoulders or refuge areas that otherwise might be used as vantage points for police patrols and for issuance of citations. Second, the taking of a lane for HOVs most likely will increase the congestion in the general travel lanes, thus making it more desirable for a motorist to violate. The public acceptance of this type of HOV treatment has been much better when new lanes are constructed for the HOVs.

Violation rates among concurrent-flow-lane projects can vary dramatically, ranging from 10 to 60 percent. The following specific recommendations are offered for concurrent-flow HOV lane projects:

1. The facility should have median shoulders and refuge areas; these are needed both for public safety and to provide an area for officers to monitor HOV operations effectively;
2. On projects that operate in both directions during the same hour, median barrier cuts should be provided (if there is a median barrier) to enable motorcycle officers to enforce in both directions; and
3. Signing and markings should conform rigidly to MUTCD standards, and special supplemental signs should be used as needed; limits of the HOV priority section should be clearly defined [special demarcation between the HOV lane and general traffic lanes can be provided by wider skip lines (8 in) or by a continuous row of mountable buttons].

The enforcement strategy should involve monitoring by motorcycle officers in the median. If not possible, mobile patrols in adjacent general lanes should then be used. Apprehension and detention should not generally be made in the median. Offenders should be pursued to the outside of the freeway and then off the facility in order to minimize disruption to traffic flow. If congestion is heavy in general lanes, extreme care should be exercised in escorting violators off the freeway. Where left-hand exits exist downstream, violators should be escorted in the HOV lane to these exits.

Contraflow Lanes

The common application of contraflow HOV lanes is to assign the inside (median) lane in the opposing (off-peak) direction to a special class of vehicles. The contraflow lane is separated from the other travel lanes by insertable plastic posts. If sufficient capacity remains in the off-peak direction, an additional lane can be taken for use as a buffer lane. The vehicles qualified to use the contraflow lane are usually buses. Buses (and other vehicles if permitted) enter the lane via a median crossover or by a special ramp and proceed in the peak direction against the flow of off-peak-direction general traffic, and thereby bypass congested traffic in the peak direction. The output terminal depends on the site and may be a crossover merge with the general freeway or it may terminate at a bridge, tunnel, or toll facility.

Violation rates on contraflow HOV lane projects approach 0 percent.

The following specific recommendations are offered for contraflow HOV lane projects:

1. Delineation of the HOV lane should include removable safety posts and barricades, changeable message signs at access points, and lane control signals (red X and green arrows) over the contraflow, buffer, and adjacent general lanes;
2. Spacing of lane control devices should have at least one, and preferably more, devices in view of opposing traffic; spacing of delineators should be close enough to discourage lane changes and a 40-ft maximum spacing is recommended;
3. A buffer lane should be provided if possible;
4. Full right and left shoulders should exist for emergency stops in both the contraflow lane (median shoulder) and opposing general traffic (right shoulder);
5. If the output terminal is not inherently suitable for detaining violators (such as a toll plaza), a refuge area should be provided, preferably in the median;
6. Speed limits on both HOV and opposing general lanes should be lowered as necessary to reduce relative speeds; and
7. Quick-reaction incident detection and removal systems should be incorporated into the project; if possible, median cuts should be provided if there is no buffer lane so emergency vehicles can approach in the proper direction.

The most-effective enforcement strategy is to have officers stationed at the access point to divert nonqualified vehicles from using the lane. Depending on the site-specific requirements of the project, the preferred strategy can be selective or continuous special enforcement. Routine freeway patrols should be extremely observant for violators and, more importantly, for incidents. Even accidents in the opposing general lanes can cause swerves into the contraflow lane by vehicles trying to avoid rear-end collisions. Violators detected in the contraflow lane should be apprehended in the terminal area if possible.

Ramp-Metering Bypass

Ramp metering has been used for nearly two decades to improve general operations on freeways by limiting access onto the mainline of the freeway. As an incentive to HOVs, bypass lanes have been constructed that allow these vehicles free access to the freeway without the delays encountered by low-occupancy vehicles at the ramp signal. The ramp-metering-bypass (RMB) technique can be used at isolated ramps or can be incorporated into a series of ramps that collectively form an RMB-HOV priority system. RMB lanes are generally constructed by widening existing ramps or redesignating one lane of existing multilane ramps.

Violation rates among RMB projects can vary dramatically and range from 0 to 40 percent.

The following specific recommendations are offered for RMB projects:

1. Provide a physical separation between the RMB lane and the general ramp lane, if space and funding resources permit; if there is no physical separation, then there should be a solid white-line demarcation between the lanes, supported by raised pavement buttons for additional emphasis;
2. A vantage point should be provided for a stationary officer to monitor the RMB lane out of view of the motorists; adequate shoulders should be provided for the apprehension and ticketing of violators; and
3. The selection of right or left lanes as the HOV lanes is important, particularly on nonseparated RMB ramps; consideration should be given to access to the ramp, position of signals, relation to the stopped queue, and how the two lanes will merge.

Because of the isolated nature of this priority treatment, continuous enforcement is impractical, particularly if a large number of ramps is involved. Bus-only RMB ramps are less prone to violations but still require periodic attention. A selective enforcement system should be established so that each ramp is targeted on a periodic, but random, pattern. The enforcement assignment should be dependent on violation levels, which requires some type of data-collection scheme.

Patrols, preferably motorcycle mounted, should station themselves where they can observe the HOV lane and the ramp signal and observe for violators. Preferably, the position is hidden from view. Once a violator is detected, he or she should be pursued or (if possible) waved over to the shoulder. Tickets should be issued in view of the ramp traffic for maximum effect because the disruption to ramp traffic is not as detrimental as it is on the mainline.

Exclusive Toll Plaza Lanes

A toll plaza is inherently a bottleneck on a freeway. Exclusive toll plaza lanes serve several purposes. They allow HOVs to (a) bypass queues on the approach, (b) move through the toll station with minimal delay, and (c) gain preferential access to the toll facility itself.

Exclusive toll plaza lanes for HOVs can operate efficiently and with relatively few violations. Selective enforcement, when used periodically, can maintain a sustained violation rate that is lower than 10 percent.

The following specific recommendations are offered for exclusive toll plaza lanes:

1. Provide special areas, such as a refuge area or shoulder, adjacent to the HOV lanes in order for officers to monitor the HOV lane and conduct the enforcement operations;
2. Provide a physical separation, such as a barrier wall or raised curb, between the HOV lanes and general lanes so long as such a barrier does not pose safety hazards itself; and
3. Where the facility is not metered, the capability of informing toll attendants to halt traffic should be included (this would clear the downstream

roadway and allow police vehicles to pursue violators and, more importantly, allow emergency vehicles to travel unimpeded).

Mobile patrols should provide routine enforcement by monitoring the HOV lane operations from stationary positions, preferably adjacent to the lanes. The toll booths are an excellent location for detection, but apprehension is disruptive. When warranted by increasing violation rates, selective enforcement teams should be called in to set up shunt lanes (if refuge areas do not exist) in which to store violators while they are being ticketed.

ENFORCEMENT OF HOV PRIORITY TREATMENT PROJECTS ON ARTERIALS

The nine recommendations for enforcement of HOV priority treatment projects, which are presented as being common to all freeway applications, are also common to all arterial street and highway applications.

Separate Facility

Separate facilities on an arterial street system are commonly referred to as transitways because the transit coach is often the only type of vehicle that is permitted to travel on such a facility. A transitway may serve as a major transit collection-distribution route and provide benefits of transit accessibility and separation of different classes of vehicles. Also, a transitway may serve the line-haul portion of transit service and provide the more traditional HOV benefits of travel time savings and increased total person throughput.

Transitways tend to be easily enforced and violations of the restrictions are virtually nonexistent.

The following specific recommendations are offered for separate facility HOV lane projects:

1. Appropriate pedestrian controls should be instituted if pedestrian crossing is considered to be a safety problem (these controls include pedestrian cross-walks, pedestrian signals, and strict enforcement of jay-walking);
2. Procedures regarding bus operations on the transitway should include reduced bus speeds and increased driver awareness and courtesy;
3. Cross-streets across the transitway should be eliminated whenever possible; when the elimination of cross-streets is impossible, the turning movements between the transitway and the cross-streets should be restricted; and
4. Terminal areas and any other access areas should be well signed and marked and the traffic appropriately channeled.

The use of routine enforcement in either mobile or pedestrian modes should be satisfactory for HOV enforcement purposes.

Concurrent-Flow Lane

Concurrent-flow priority applications on arterial highways involve reservation of either the curbside lane or the median lane for HOVs. Curbside lanes have historically been installed to provide better transit circulation in the central business district (CBD) or to improve downtown traffic flow through the segregation of buses and automobiles. A second objective may be to provide a travel time improvement (not advantage) for buses. Taxicabs, other vehicles that load and unload passengers, vehicles turning right, motorcycles, and bicycles may also be permitted to travel in the curb HOV lane. Enforcement requirements on the curbside concurrent-flow lanes address illegal stopping, parking, or ineligible vehicular travel in this lane. Median lanes are generally intended to provide HOVs with travel time advantages by bypassing traffic congestion in the general traffic lanes. Enforcement requirements address the illegal travel in the lane as well as possible illegal turning movements across the median HOV lane.

Concurrent-flow lane projects can be operated effectively with reasonably few violations; however, this may require a special enforcement program. Without special enforcement, the number of violations may interfere with the operations of the HOV lane. The following specific recommendations are offered for concurrent-flow HOV lane projects:

1. Enforcement of HOV lanes may have an additional concern with parking and turning restrictions; these restrictions may require more enforcement attention than will violations of the HOV lane itself;
2. For a median lane HOV treatment, use of bays for left turns (closed off due to left-turn restriction) have proved to be an effective area for enforcement vantage points and detention areas, when coupled with a special enforcement program;
3. Signing and markings should conform rigidly to standards, but special supplemental signs should be used as needed; limits of the HOV priority section should be clearly defined;
4. For a median lane HOV treatment, cones or safety posts should not be employed to separate the HOV lane and general travel lanes (these implements can pose safety problems and do not favorably affect the violation rate);
5. For a curbside lane HOV treatment, locations should be available or provided where officers can apprehend and issue citations to violators without encroaching onto the main roadway; the use of cross-streets may be an appropriate detention area; and
6. For a curbside lane HOV treatment, the signing to permit right turns should specifically state the point at which a vehicle that is turning right may enter the priority lane.

Median lane HOV treatments should be enforced by selective or special enforcement efforts. On curbside HOV lane treatments, routine patrols (mobile or foot) could be justified as capable of producing a tolerable violation environment.

Contraflow Lanes

A contraflow HOV lane is commonly a lane in the off-peak direction reserved for HOV vehicles traveling in the peak direction. It can incorporate the median lane or the curb lane of a highway facility. A contraflow HOV lane that operates in the median lane is commonly associated with express-bus service that operates in a through mode or on a line-haul trip. A contraflow HOV lane that operates in the curb lane occurs on a facility that otherwise serves one-way traffic. This type of operation is commonly associated with local bus service that makes periodic stops for loading and unloading passengers.

Enforcement of both types of contraflow-lane treatments are concerned with (a) violators of the HOV restrictions and (b) violators of the supplemental traffic restrictions necessary to operate the contraflow lane. The violators of the supplemental traffic restrictions are frequently of much greater concern to enforcement officials. Supplemental traffic restrictions may involve turning movements across the HOV lane and parking or stopping in the HOV lane.

Violations of the bus-only restriction are uncommon because bus volumes in the contraflow lane can be high and this provides a self-enforcing feature. Also, a non-bus vehicle in the contraflow lane is very conspicuous to police officers. Another deterrent is that the general lane traffic is moving in the opposite direction of the contraflow lane. With a bus-carpool contraflow lane, violations may be more prevalent because a violating vehicle is no longer as conspicuous as in the case with a bus-only restriction.

The following specific recommendations are offered for contraflow HOV lane projects:

1. In addition to HOV lane violations, enforcement also needs to focus on turning and parking restrictions; these restrictions may pose greater responsibilities for enforcement;
2. Geometric and traffic control techniques intended to eliminate or physically impede access-egress at intermediate intersections greatly enhances enforcement on contraflow facilities and should be deployed where possible;
3. Overhead lane-use signals and signs should be used, especially where extensive visual clutter decreases the effectiveness of roadside signing;
4. The use of temporary traffic control devices (such as cones, gates, and signs on stanchions) has proved to be effective in eliminating illegal turns across the contraflow lanes on projects that have physical medians; the elimination of illegal crossing turns on projects that do not have physical medians will require site-specific enforcement;
5. If possible, curbside contraflow lanes should be wide enough for a bus to pass a disabled bus safely; wide lanes enhance enforcement by providing an enforcement vantage point, a passing lane for violator apprehension, and a detention-citation area; and
6. If possible, median contraflow lanes should have a median from which enforcement officers can monitor the project's operation; without this median, enforcement will be increasingly difficult and police will be required to cross the general traffic lanes.

Routine line patrols should be adequate for enforcing many contraflow HOV projects. However, extensive turning restrictions when coupled with very little geometric or physical control of such restrictions can produce a significant amount of illegal and hazardous turning maneuvers. Therefore, selective and special enforcement strategies should be considered in such situations. Specific selective or special enforcement may include stationary or mobile patrols.

INNOVATIVE ENFORCEMENT TECHNIQUES

Readily available innovative techniques that could benefit HOV enforcement include the following:

1. Use of photographic systems and instrumentation to detect HOV violations and identify the violators,
2. Use of law enforcement paraprofessionals to detect HOV violations and identify the violators,
3. Mailing of traffic citations and warning letters to the registered owner (identified through the license plate) of a vehicle that violates the HOV facility, and
4. Mass screening of license tags to identify habitual violators.

Two separate research projects sponsored by the U.S. Department of Transportation have studied photographic instrumentation for enforcement purposes. These projects are the Mobile ORBIS III speed enforcement demonstration project in Arlington, Texas, and a photographic system for obtaining automobile occupancy counts. The Federal Highway Administration is extending this latter research, in part to produce a photographic system specifically for the various needs associated with enforcement of HOV facilities. This photographic system consists of a camera, a stroboscopic light source, and a vehicle-actuated triggering mechanism.

The use of paraprofessionals removes the enforcement responsibility from a valuable resource in short supply--the law enforcement officer. The use of such personnel or civilian observers for non-arresting activities, such as development of a data base, could enhance the efficiency of the enforcement process.

The legal environment required to mail HOV citations to the owner of a vehicle that violates the HOV facility would exist if two legal concepts, decriminalization and presumption, are included in the jurisdiction's statutes or ordinances. Inclusion of these two legal concepts should preclude challenges made against citations mailed to the registered owner.

A mass screening technique for license tags uses a small portable computer that stores information on vehicles that have been involved in certain types of unlawful activity. The data base is used by entering the license tag number of each vehicle encountered at an apprehension point. The system responds by indicating whether or not the driver should be detained. This concept could be adapted to HOV enforcement by defining the data base to include only those vehicles identified as repeat (but unapprehended) violators of HOV regulations.

LEGAL ISSUES

For many of the HOV projects that were surveyed, changes in law are necessary prior to the incorporation into the enforcement process of any innovative techniques. Certainly, a better understanding of the capabilities of traffic enforcement to execute such techniques within the existing legal environment is highly desirable. This research has identified five key legal issues associated with the innovative enforcement techniques.

Admissibility of Photographic Evidence

Courts recognize that photographs may be relevant to the issues and so they may be introduced as evidence to establish identities. It is highly unlikely that photographic evidence would be denied by the courts because of invasion of privacy, right to equal protection, or freedom of association. Use of photographs for other than HOV enforcement may constitute illegal surveillance. Destruction of HOV photographs may also hinge on whether they are considered an exception to the public record statutes or ordinances.

Instrumentation and Certification Requirements

An HOV photographic instrumentation technique would undoubtedly need to undergo the process of securing judicial acceptance of the technique. Credentials of a judicially unestablished scientific device must be proved by expert witness testimony. Given sufficient training, police officers and paraprofessionals could be trained as experts in the workings of the HOV equipment so that their testimony would satisfy the expert witness requirement. After judicial acceptance, the need for repetitious expert verification will no longer be necessary.

Visibility of Occupants

The basis for the visibility of occupants issue is that fulfillment of the requirement for number of occupants in a vehicle in the HOV lane will be related solely to their visibility. It would be necessary to write into the legislation a presumption clause that, unless the required number of persons is visible, the vehicle is in violation. This visibility presumption may be a rebuttable presumption so that the driver of the vehicle could present proof of the existence of the required number of occupants. The importance of this statutory language is that the burden of proof is initially on the motorist not the citing officer.

Mailing of Citations to Owner of Vehicle

HOV citations may be mailed to the owner of a vehicle in violation of the HOV facility if two legal concepts, decriminalization and presumption, are included in the jurisdiction's statutes or ordinances. Inclusion of these two legal concepts should preclude challenges made against citations mailed to the registered owner. Most states have established prima facie evidence presumptions in municipal parking ordinances whereby the registered owner is presumed to be the violator. These prima facie presumptions have been found to be valid and constitutional. Where moving violations are treated as noncriminal infractions, they may be considered no different from parking violations. This is especially true where no points are assessed against a driver's record for the violation and the only penalty is a fine.

Citation Issued by Nonwitnessing Officer

Speed devices such as radar and air surveillance have been used extensively to allow nonwitnessing officers to cite the violator. Where the appropriate statutes or ordinances have been passed or judicial precedent has allowed, such citations issued by nonwitnessing officers have been consistently upheld by the courts.

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Transit Lane Enforcement in the Central City

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Transit lanes in crowded urban core streets are potentially effective for improving transit operations when they are available to transit vehicles. Concurrent-flow transit lanes are susceptible to violation by motorists. Police enforcement is often costly and inconsistent. A 2-year demonstration grant, from the Urban Mass Transportation Administration to San Francisco, tested the concept of self-enforcing lanes by using improved lane markings to heighten motorist's awareness and, hence, voluntary compliance. A separate study of nontraditional enforcement techniques was included within the grant funding. The results of the test showed negligible change in motorist's behavior, but the research uncovered valuable information about more significant contributors to transit delay, namely, double-parked vehicles and a spotty parking enforcement program. Subsequent implementation of new transit lanes on a downtown San Francisco street reflected the lessons learned on design techniques and enforcement priorities.

Enforcement has always been cited as a key factor in the design and operation of transit priority treatments. In the central city, enforcement of transit lanes, malls, and other transit preferential features is both important and difficult. In San Francisco, effective enforcement of transit lanes in the central city poses a problem of unique complexity.

The central city area of San Francisco was originally laid out during California's gold rush era. As a result, the area is characterized by short blocks and narrow streets that are well suited for pedestrians. Today, however, transit vehicles, trucks and commercial vehicles, private automobiles, and bicycles all compete with the pedestrian for use of the streetscape. In this environment, the curb has become a valuable commodity. The central city largely lacks alleys and serviceways, and as a result, most of the movement of goods and service deliveries occur at the curb. At the same time that transit vehicles require use of the curb to load and unload, private automobile drivers similarly desire to use the curb for quick business and shopping stops.

The result of this intense competition for use of the curb space in central San Francisco is frequent double parking and general abuse of curb parking and loading restrictions. These conditions contribute to a congested street environment, particularly during the midday when trucks and service vehicles are most prevalent. The general level of street congestion that prevails in the central area also encourages drivers to violate transit lanes. At the same time the San Francisco Police Department has been constrained by (a) limited resources, (b) a general public attitude that places a low priority on enforcement of traffic and parking, and (c) a need to ensure that the movement of goods and service operations is not unduly hampered.

These factors have combined to result in relatively poor operating conditions for vehicles in central San Francisco. Transit vehicle speeds of 4-8 mph are common on many street sections. Transit drivers often avoid use of transit lanes to stay clear of curb activity and avoid being trapped behind a double-parked vehicle.

BACKGROUND

In 1977, a formal study program, designed to directly address the problem of transit lane design and enforcement in central San Francisco, received an Urban Mass Transportation Administration (UMTA) grant. The 2-year demonstration project would focus on practical means to improve transit lane enforcement and performance. Ultimately, the findings of the demonstration project would be applied to the design of new transit preferential treatments on the narrowest portion of four downtown streets. The demonstration project was just one of a continuing series of study, design, and implementation efforts undertaken as part of San Francisco's transit preferential streets program.

In 1972, in order to improve the overall efficiency of transit vehicles, the city adopted a transit-first policy. The transit preferential streets program was initiated to implement that policy. San Francisco now provides an extensive system of transit preferential treatments. For the most part, however, these treatments have met with mixed success and public acceptance. Two related problems have clearly emerged to limit the success of the transit preferential treatments, particularly the central area transit lanes:

1. The lanes were subject to continuous violations by motorists and repeated blockage by double-parked vehicles and
2. The lane markings and signing lacked high visibility and were confusing to motorists.

These problems resulted in a general lack of acceptance of the value of the lanes by the public, the transit drivers, downtown merchants and businesses, and the police. If not resolved, it was feared that the ongoing efforts to fully implement the transit priority street program would be halted and that already implemented treatments would be eliminated.

Two elements of the UMTA project were designed to deal directly with the enforcement problems:

1. A self-enforcing transit lane demonstration project and
2. A review and evaluation of nontraditional enforcement techniques.

The goal of the self-enforcing transit lane demonstration project was to test the belief that improved transit lane markings and signing could improve enforcement characteristics. The improvements would be designed to reduce violations and also to facilitate existing police efforts to enforce the lanes. The study involved a before evaluation of the performance of the transit lanes, the design and implementation of the signing and pavement marking improvements, and then the after evaluation of the self-enforcing capabilities of the lanes.

This study involved the identification and the evaluation of innovative techniques of transit lane enforcement. These techniques were to avoid the costly traditional approach of improved enforcement by allocating additional efforts by police officers assigned to traffic patrol and were to emphasize cost efficiency, public acceptance, and ease of implementation. A particular concern of implementation was the legality of any proposed technique.

SELF-ENFORCING TRANSIT LANE DEMONSTRATION

San Francisco adopted an official policy of transit first by resolution of the board of supervisors in 1973. It states,

> Declaring that municipal railway vehicles and other transit vehicles be given priority over other vehicles on San Francisco streets; that the Department of City Planning and the Public Utilities Commission develop a preferential transit street system within six months; suggesting methods of expediting transit service on duly designated "transit" streets.

A report was published by three city departments later in 1973, and several concurrent-flow transit lanes were installed on Mission Street, the Sutter-Post one-way pair, and later on the Geary-O'Farrell one-way pair. The experience with these lanes has been mixed. They have had some impact on motorists' driving behavior and have shifted traffic volumes from the bus-only lane to the remaining general traffic lanes. However, the violation rate remained high and active police enforcement was required in excess of that deemed desirable by the police department.

Problem

The concurrent-flow transit lanes in San Francisco are generally designed as 18-ft right-hand lanes and permit parking and goods delivery (curbside loading and unloading) at all times except during peak hours, when no stopping is permitted and towaway is in effect. Since right turns are also permitted from the transit lane, the mere presence of a motorist in the lane does not constitute a violation of the transit lane. To provide traditional enforcement, a police officer must observe the motorist driving in the lane for some distance and continuing across an intersection. Then, having established that a violation of the transit lane has occurred, the officer must stop the motorist to give the citation. This stopping of the motorist for enforcement purposes can result in a more serious blockage of the transit lane than the original violation. Even during the peak hour, when curb towaway is in effect, the stopping of motorists by police can create a blockage of the lane (see Figure 1). Finally, the traditional enforcement only catches a percentage of violators when it is actively pursued, and it is not feasible to maintain active enforcement full time. An additional element present was the reluctance of police officers to enforce these lanes because of a high incidence of motorists claiming they were unaware that they were driving in a bus-only lane.

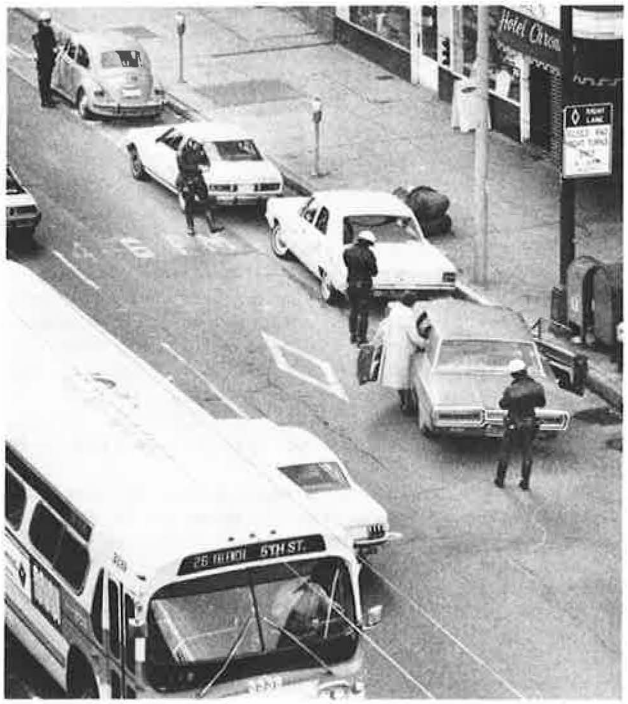
Although some traditional enforcement is necessary to keep teeth in the laws and to create a credible image to the motorist's mind that the lane is, in fact, reserved for transit use only, some other means of improving the effectiveness of these lanes was needed.

Assumptions

It was assumed that (a) a more clearly identified transit lane would result in a reduced rate of violation, (b) fewer police would be required to enforce the lanes, and (c) fewer motorists in the lane would increase the effectiveness of the transit lane and result in improved transit speed and reliability. The concept of designing a self-enforcing lane developed after several years of experience with the initial lane design. A formal demonstration was proposed to the Office of Service and Methods Demonstration, UMTA. A grant was awarded in 1977 for a 2-year study that included three principal elements:

1. A before-and-after measurement of the effect of improved lane markings on the violation rate and transit operational experience,

Figure 1. Enforcement procedures block transit lane.



2. A study of nontraditional enforcement techniques that might be used, and
3. Design of new all-day transit-only lanes for the narrower portions of four downtown streets.

All three elements are essentially complete.

Methodology

The research methodology for the self-enforcing lane demonstration was devised by UMTA's Transportation Systems Center in Cambridge, Massachusetts, and the local evaluation consultant, Systan, Inc., of Palo Alto, California. An extensive before data base was compiled in July 1979. The statistics were gathered for three streets where the original lane marking and signing was in place and traditional enforcement had been employed periodically for several years. The three streets included the one-way pair of Sutter and Post and a six-block, two-way segment of Mission Street.

The data collection included time-lapse movie films, speed and delay runs on board buses over the length of the test segments, and a postcard survey of both motorists and bus passengers relative to their awareness of the transit lanes and their feelings concerning the utility of the lanes.

An experimental lane marking was developed by Wilbur Smith and Associates in conjunction with the multidepartmental committee that monitored the project. Bio-Technology, Inc., of Falls Church, Virginia, also made valuable inputs into the design of the markings; they were under contract to the Federal Highway Administration (FHWA) to test and evaluate several kinds of experimental highway lane markings. The adopted test design was a bold lane buffer or striping that included two parallel solid white lines, 8 in apart, with small diamond symbols 10 ft on center between the lines. The transit lane was further defined by large painted diamonds in the lane, diagonal stripes at the beginning of each block, and overhead signs over the lane that clearly state BUS ONLY. These overhead signs were to supplement the existing roadside post-mounted signs.

The after data were collected in July 1980 in a manner essentially identical to the before data.

Results

Table 1 (1) shows little change in the motorists' rate of violations, and no measurable improvement in bus operating performance can be seen in the data below (1).

	Post Card Survey (%)		
Bus Lane Awareness	Post Street	Sutter Street	Mission Street
Before new markings	94.4	90.4	90.6
After new markings	94.0	91.4	94.1

Overall, 41 percent were not aware of overhead signs and 6 percent were not aware of the street pavement markings.

Bus speeds showed no significant decrease in travel time. Data were not available on how well buses adhered to the schedule on Post-Sutter Streets. On Mission Street, no difference could be detected in mean headways between buses and the standard deviation of buses on schedule.

Bio-Technology gathered independent data on two of the three test streets. Their methodology, which relied primarily on time-lapse films and some questionnaires, compared before-and-after data on the Post-Sutter one-way pair against similar data for a control sample of an adjacent one-way pair, Geary-O'Farrell. The control sample one-way street couplet has the older design, less-elaborate, transit-only lane markings [see Table 2 (2)].

What We Really Learned

As with many experiments, what we learned was not necessarily what we set out to discover. The intensive daily scrutiny of the lanes resulted in a clearer picture of what were the true inadequacies of the lanes.

The problem was not one of moving violations by motorists driving in the lane nearly so much as it was one of parked vehicles and fixed obstructions in the transit lane. The vehicles legally in the lane to make right turns or to maneuver into a parking space were one source of delay. These vehicles most often result in the buses moving from the transit-only lane to the general traffic lane to pass. This is a minimum delay factor in light-traffic situations but can become significant if the general traffic lanes are in heavy use. The most serious factor in delay to transit is caused by double-parked trucks, tour buses, and, to a lesser extent, taxicabs and automobiles. Double parking can become so prevalent that, in some blocks, it is more common for a bus to be out of the transit lane than within it. The double parking stems from problems with commercial loading zones (yellow), passenger loading zones (white and green), and special truck loading zones. In short, delay of transit vehicles is primarily the result of inadequate use and enforcement of curb parking restrictions.

Some of these difficulties may be unique to San Francisco, its physical design, its pattern of streets, lack of alleys, the zoning codes for off-street loading, and even the history of police priorities and political pressures. However, many are no doubt similar to problems and situations in other cities and our findings and recommendations may have application elsewhere. Several steps are underway to correct the problems in San Francisco and are listed below. More general recommendations for implementation of concurrent-flow transit lanes are included at the conclusion of this article.

The immediate tasks necessary in San Francisco to improve the effectiveness of the transit lanes and achieve this goal without heavy reliance on traditional police enforcement of moving violations include the following:

1. A thorough reevaluation of the allocation and placement of curb space to various needs, such as parking, loading, goods deliveries, and turning lanes;
2. Dramatically improved enforcement of the commercial loading zones and passenger loading zones;
3. Changes in the designs of all new buildings, including new hotels, to provide parking for service vehicles, deliveries, taxis, and tour buses on site or in a manner that will least impinge on the transit lane;
4. Adoption of special legislation to specifically prohibit double parking within a transit-only lane; and
5. Tightening of the regulation of day-time street construction along the critical transit streets, especially in areas of heavy midday congestion.

NONTRADITIONAL ENFORCEMENT TECHNIQUES

Where self-enforcement and design features of transit lanes are ineffective or insufficient in eliminating violations, other enforcement techniques must be pursued. The need for additional enforcement often arises when parking violations on an existing facility inhibit bus movement. Stricter enforcement practices may be required to reduce the conflict between goods movement and transit in the central areas of many major cities.

Traditionally, the need for stricter enforcement has been met by sworn police officers who issue citations to violating vehicles. However, many police departments question the economics of spending police officers' time on traffic details at the expense of other law enforcement duties. Public response to traffic officers has always been negative, which reinforces the view that other police activities are more important than traffic law enforcement. For these reasons, many police departments are turning to traffic enforcement procedures that do not require the specialized training, authority, and expense of a sworn officer. Although many such procedures have been widely accepted for a number of years in selected locations, they are given the generic label nontraditional enforcement techniques because they attempt to break from the traditional concept of enforcement in which a single uniformed police officer performs traffic enforcement activities randomly, along with the normal assortment of other police duties.

Table 1. Transit lane violation rate as percentage of all traffic on street.

Street	Time and Direction	Before (%)	After (%)
Mission	Morning inbound	16.5	19.6
	Evening inbound	25.2	23.4
	Morning outbound	20.2	19.6
	Evening outbound	23.0	23.6
Post	Morning inbound	4.7	2.5
Sutter	Evening outbound	5.7	4.5

Note: Data are preliminary.

Selective Versus Special Enforcement

Nontraditional enforcement techniques can be divided into two major classes--selective and special, depending on their frequency of application. Selective enforcement is generally a concentrated effort, applied periodically to areas where high violation rates have been reported. Because of the temporary nature of this strategy, no new personnel are normally required. Existing enforcement officers are temporarily reassigned until the program is concluded, usually for a period that ranges from a few days to two weeks (3).

Selective enforcement programs can be very well planned and executed at target areas on a scheduled basis, or they can be implemented based on the need for improved enforcement at specific locations. On the Interstate 35W bus bypass ramps in Minneapolis, selective enforcement campaigns are implemented by the police department when complaints are received from the public and from bus drivers. A selective enforcement program of the San Francisco-Oakland Bay Bridge toll plaza high-occupancy-vehicle (HOV) lanes is instituted following weeks when the violation rate exceeds 10 percent, as reported by toll takers and officers on patrol.

Special Enforcement

Special enforcement is characterized by (3) "continuing, systematic manpower allocations and enforcement tactics specifically dedicated to enforce HOV (or transit lane) violations." Special enforcement techniques are especially appropriate when routine enforcement measures cannot effectively address the special needs of the transit priority treatment without sacrificing performance of other duties given equal or higher priority by police management.

Special enforcement techniques vary greatly in their level of innovation, technology, use of police personnel, and cost. A special enforcement technique may be as simple as reallocation of existing staff to a transit priority enforcement batallion or as complex as use of photography and computers to issue citations. Although most special enforcement programs are relatively new and have not been thoroughly evaluated, they are generally regarded as successful from the standpoints of relieving the burden on sworn officers and improving the effectiveness of transit priority treatments.

Selective and special enforcement techniques can be combined in an integrated enforcement program. Use of each technique should be determined by the location of the facility, type and severity of

Table 2. Summary of field study findings.

Issue	Where Intended	Finding
Effect of buffer zone in arterial settings	San Francisco 24-h bus lane	No clear reduction in violations; no change in temporary special use lane intrusions
Effect of shoulder-mounted versus overhead signs	San Francisco	Violations reduced by 25-40 percent; drivers became more aware of special use lane
Effect of complete upgrading in information system	San Francisco arterial	Reductions in violations (25-40 percent) and temporary intrusions; effect lasted 30 days only on one of the two streets; increased driver awareness of special use lane

violations, and availability of enforcement personnel.

Enforcement Techniques

Many cities in the United States and elsewhere have used nontraditional enforcement techniques for all or part of their traffic enforcement program. The following techniques were examined as part of the transit preferential streets (TPS) demonstration project in San Francisco.

Raised and Differential Fines

The raising of fines for traffic violations is not in itself an innovative enforcement technique, but higher fines can induce self-enforcement when their rates are clearly advertised. Philadelphia recently raised fines for all traffic violations, and preliminary reports indicate both an increase in revenue and a decrease in the violation rate. City officials believe that the success of this program is due largely to the clear posting of the fines for violation of parking laws. Many motorists are willing to risk a citation for violating a parking restriction when the fine is equal to or slightly more expensive than the cost of parking in a downtown parking garage. However, fines that range from 5 to 10 times the cost of parking are a significant deterrent to violators.

Many cities have developed differential fines based on the severity of the violation problem in a given area. Chicago, for example, charges special fines for vehicles that violate parking restrictions on streets designated as snow routes. Parking violations in Chicago normally carry a fine of $20, but violators on cited snow routes when there is more than 1 in of snow are assessed a $100 fine. Repeat violations of the posted snow routes are assessed increasingly higher fines (e.g., $200 for second violation and $300 for third violation) and finally a license can be revoked.

Implementation of a raised or differential fine program is often politically difficult. However, raised fines tend to increase city revenues without additional public expense and without invoking an unpopular tax. Public acceptance of raised fines can be improved through media campaigns geared toward educating the public about the purpose and scope of the new fines. A selective enforcement campaign, where warning-only citations are written, staged shortly after the raised fines are enacted can attract media attention and effectively prepare the public for the new fines.

Civilian Officers

The use of civilians in jobs that are normally performed by sworn officers has increased greatly over the past two decades. A large number of police departments throughout the country, including Seattle and Fort Lauderdale, Florida, have used civilian personnel for all or part of their traffic enforcement program. The work performed by these civilians is usually of very high quality, largely because traffic enforcement is their primary responsibility. In Fort Lauderdale, where civilians write accident reports as well as enforce traffic laws, a study by the police department revealed that reports written by transit aides were of a higher quality than those written by sworn officers when evaluated on the basis of clarity, completeness, readability, explanation, and illustration.

Although San Francisco employed two types of civilian traffic aides prior to the TPS study, the study revealed many problems with their program. Traffic controllers were employed to direct traffic and issue citations for any traffic code violations they witnessed. However, the civilian aides generally did not have vehicles of their own and thus found it difficult to stop a motorist committing a moving violation. Parking controllers in San Francisco were mobile civilians who were empowered to issue parking citations only. Despite the mobility of the parking controller, problems developed with this program because of the physical danger to civilian aides who do not receive the respect accorded a uniformed police officer.

Despite the problems with civilian programs, they remain a primary resource for improving enforcement levels without employing sworn officers. Civilian officers generally return more revenue to the city treasury than they displace for salaries, training, and equipment. The effectiveness of a civilian program can be enhanced through capital investment in specially marked uniforms and patrol cars. These distinctions also help to give an aura of authority to civilian aides.

In Washington, D.C., a civilian force of 64 persons is responsible for more than half of all tickets written in that city. This program generated more than $6.5 million in revenue in 1977, and cost approximately $1 million. A cost-revenue breakdown for this program is shown in Table 3 (4, p. 7). Although the information in Table 3 is 3 years old, it can serve as an order-of-magnitude estimate for the potential application of this program to San Francisco. Additional savings can be realized when sworn officers are supplanted by civilians whose salaries and benefits are significantly lower than those of sworn officers.

Transit Employees as Enforcement Officers

Many transit agencies employ, or receive the services of, a transit police unit. In some cities this unit is a group of sworn officers who have full powers, including traffic control. More often, transit police are specially trained employees of the transit authority. In either case, their primary responsibility is crime prevention. The duties of the transit police could be expanded to include traffic control, especially during peak and daylight hours when the perceived danger in riding transit is low.

Other transit agency employees can also be used to assist in traffic law enforcement. In San Francisco, San Francisco Municipal Railway (MUNI) transit service inspectors have the authority to issue citations for both moving and parking violations in the transit lane. San Francisco is currently the only major city to employ such a program, which is seen as moderately successful by both MUNI and the police department. MUNI inspectors are primarily street supervisors and are limited because they operate on foot. Another limitation of this program is the time burden it places on the inspectors, who are fully occupied during peak periods. Their assistance can be most helpful in citing parking violations before and after the peak travel periods.

Public reaction to the use of transit personnel for traffic law enforcement has been generally unfavorable. The public views the role of transit police as strictly one of crime prevention and generally resists having their boundaries expanded. The use of other transit employees for traffic control is also viewed negatively because transit employees are not considered to have enough authority to enforce the law. However, proper public education could help this problem and give more flexibility in the selection of enforcement officials.

Table 3. Cost-revenue profile of civilian enforcement program, Washington, D.C.

Item	Amount
Tickets	
Issued	975 000
Collected (%)	58
Avg collateral per ticket ($)	11.32
Gross revenue ($)	6 400 000
Cost ($)	
Salaries for 64 employees	766 000
Vehicles	97 000
Gasoline and maintenance	24 000
Equipment and supplies	124 000
Uniforms	19 000
Subtotal	1 030 000
Net revenue	5 370 000

Sleeping Police

The sleeping police technique has been successfully implemented by many cities and highway patrols, including that of Sacramento, California. This technique involves the stationing of an empty patrol car in a visible location in areas where a high violation rate has been experienced. Motorists who are aware of traffic laws generally exhibit a higher degree of compliance in the presence of a police vehicle. This technique is especially effective in reducing moving violations because it is difficult to determine whether a parked car is occupied from a moving automobile. The sleeping police technique can be combined with live foot or car patrols to increase the impact of the decoy. The sleeping police technique can be combined with any of the others to reduce the personnel costs of more-labor-intensive techniques.

Boot and Tow

A boot-and-tow program is the harshest of the innovative enforcement methods examined in this report. It is also the most successful at reducing violations. This program is actually a combination of two strong enforcement measures: a towing and impoundment and a booting operation. A program of this nature was instituted in Washington, D.C., in October 1978 in response to rampant parking violations in the central area.

Under the towing and impounding component, a unit of 33 civilian officers radio in the license plate number and location of the illegally parked vehicle to their supervisors, who phone or radio the dispatch office of a towing company under contract with the city. The civilian officer places a brightly colored orange citation under the windshield wiper of the violating automobile. The citation serves as a flag to the towing company and frees the enforcement officer from waiting for the tow truck to arrive. John M. Brophy, public parking administrator at the Police Department in Washington, D.C., says that the tow vehicles are radio dispatched within a given beat radius and response time to a supervisor's call generally varies from 15 min to 1 h. All towing operations connected with parking enforcement are provided by a private contractor, who is compensated with towing fees paid by violators. Dispatching and storage operations are controlled by the district.

All towed vehicles are automatically impounded. The registered owner of the vehicle must pay a $50 towing fine, $3/day storage charge, plus all fines for previous tickets that the driver may have accumulated. Ten dollars of the $50 towing penalty is returned to the towing company, leaving the remaining $40 for the city.

The booting component of the enforcement program in Washington, D.C., is designed to stop repeat-parking-law offenders and to decrease the number of parking citations that are not paid by violators.

Each day, a special group of traffic enforcement personnel is given a list and description of vehicles that have four or more delinquent tickets. Every time a traffic ticket of any kind is being issued, the enforcement officer checks the list to determine whether this vehicle has been a repeat delinquent offender. Sometimes an enforcement officer will find a booting candidate that may be parked legally. The vehicle will still be booted even if it is properly parked at that time, provided that it has four or more delinquent charges against it. If one of these cars is found, a boot is applied to the left-front wheel that prevents the vehicle from being moved. The boot will attach to vehicles both with and without a hubcap without harming the vehicle in any way. It can only be removed with a special key that is not reproducible. There has never been a recorded instance of a boot being removed by the violator.

To remove the vehicle, the owner must go to the Office of Traffic Adjudication, as instructed on the boot, and pay a fine of $25 plus all delinquent ticket charges. If a booted automobile is not claimed within 48 h, the car is impounded, and the towing-impounding fees are charged in place of the $25 boot charge. This year the department hopes that its staff of 28 full-time civilian field officers will boot 20 000 automobiles.

The boot-and-tow program has been considered successful, both by the police department and the transit authority. The primary positive impacts of the program have been the following:

1. Improved deterrence--The system discourages illegal parking because violators are aware of the high penalties of impoundment or booting.
2. Reduced operating costs--Contracting costs less than towing by the city; the district did not have to invest in a large equipment inventory or place an added burden on its vehicle maintenance operation; further, the civilian aides cost less than sworn police officers on a one-to-one comparison.
3. Increased towing activity--Increased towing activity, from 60 cars/day to 450 cars/day, improved clearance of critical automobile and bus lanes and reduced the number of hazardous and flagrant violations. From a January 1976 study of parking violations in the district, it was concluded that up to 40 000 cars daily commit a parking violation for which they could be towed.

A boot-and-tow program is relatively capital intensive. However, the experience of the District of Columbia indicates that the municipality can expect a net gain in revenues from this project, especially when fines for violations are increased for more serious or repeated violations. The boot-and-tow operation in Washington, D.C., cost approximately $2.8 million in 1977, including one-time start-up costs of approximately $600 000. The program currently has net receipts of more than $10 million, some of which is used to finance transit service.

Table 4 (5, p. 8) summarizes the costs and revenues derived from the program in Washington during the start-up year. One additional revenue source that is not cited in Table 4 is the expansion of parking meter revenues, which have risen by more than 35 percent since the boot-and-tow program was inaugurated. Much of this increase can be attributed to the self-enforcement aspect of assigning high penalties to parking violators.

Table 4. Cost-revenue profile of boot-and-tow operations.

Item	Tow ($)	Boot ($)	Total ($)
Revenue			
Tow revenue[a]	5 625 000		5 625 000
Boot revenue[b]		400 000	400 000
Delinquent fine revenue		3 734 000	3 734 000
Storage fee[c]	750 000		750 000
Gross revenue	6 375 000	4 134 000	10 509 000
Expenses			
Contract towing[d]	1 125 000		1 125 000
Salaries and supplies	624 000	457 000	1 081 000
Start-up costs	404 000	181 000	585 000
Total	2 153 000	638 000	2 791 000
Net revenue	4 222 000	3 496 000	7 718 000

[a] Tow revenue = 25 trucks x 12 h x 1.5 tows/h x 250 days x $50.
[b] Boot revenue = 10 crews x 8 boots x 250 days x 16 000 collections x $25.
[c] Storage fee = $3 x no. of tows.
[d] Contract towing = $10 x no. of tows.

Photography

Still photographs have been used as an aid to the traffic enforcement officer in experiments in England and New Zealand. Professional photographers are placed on the civilian police staffs and are used in accident investigation as well as in enforcing routine laws by photographing the license plate number of the car in a picture that clearly shows the infraction. A sworn officer or other civilian personnel issues a citation after the photographs are developed. The photograph is then considered admissible evidence in traffic court. Both the programs in England and New Zealand are still in the initial stages.

In this country researchers have been experimenting with the use of remote-controlled, time-lapse movie photography as a means of observing traffic flow. Three areas have been identified in which photography may be useful in enforcing traffic laws on transit priority streets. These are identifying violating vehicles, obtaining evidence of a violation, and studying violation patterns.

A number of problems are associated with the use of photography as an enforcement tool, except in cases where moving or still photographs are used to identify violation patterns rather than for identification of a particular violator. For the most part these problems need not preclude the use of photography as an enforcement tool but will limit the amount and usefulness of the data that may be obtained.

Camera Placement

To take a clear picture of a vehicle suitable for submission as evidence in traffic court, an average distance of 50 ft between the camera and the automobile should be maintained. This consideration poses a problem for facilities that do not have an adequate median or sidewalk area. Camera placement may also be affected by security considerations. Photographs used for observation purposes only should be taken by a well-hidden camera so as not to bias the sample. Cameras placed in the open may contribute to self-enforcement, but they are also susceptible to vandalism.

Weather and Lighting Conditions

Weather conditions are impossible to control and are thus, perhaps, the greatest single barrier to the use of this technique. Lighting variations, especially during the evening peak hours, can affect photograph quality. Other ambient conditions, such as thick fog or rain, can further impair photograph reliability.

Cost

The initial capital investment in camera equipment and the processing can be significant for this technique. These costs are particularly burdensome because the capital items may not replace any labor hours. Although a photographic detection system is highly mechanized, the analysis of data obtained from this technique is quite labor intensive.

Legality

Many municipal codes will not allow photographs as evidence in traffic court situations. In addition, there is a constitutional implication of invasion of privacy. Extensive research should be done on this aspect before an enforcement program is implemented.

Public Education Programs

Public awareness is a critical element in any enforcement program, particularly when the program includes innovative enforcement techniques. As the level of enforcement increases, so too should public awareness. However, public awareness is not a replacement for enforcement, it simply enhances a well-planned enforcement program. An extensive public education effort can reduce violations by giving active enforcement measures a self-enforcing characteristic. People who understand the need for improved enforcement generally have a more positive attitude toward the new enforcement program and the enforcement officers who carry it out.

In the planning phases of a project, informal and formal public meetings and hearings are an appropriate forum for discussion of the enforcement program and its content and consequences.

A small expense for pamphlets or news releases may generate far more coverage as the media gain knowledge of the new programs. Inexpensive techniques for public education include news releases and conferences, public service advertising, transit advertising space, speakers bureaus, and pamphlets or handouts. All public information should emphasize the positive aspects of a change in the enforcement program, such as improved transit trip times and generally improved traffic flow. Where possible, drivers should be made to feel that they have several avenues of recourse, which vary from the judicial process to riding transit.

In all cases, the primary message should be a simple statement of (a) what the law states and what is prohibited, (b) what will be done if a violation of that law occurs, and (c) what the consequences are if a violator is apprehended or cited. Other messages may be integrated, including the rationale for the law and appeals for mutual cooperation for the public good.

SUMMARY AND CONCLUSIONS

The San Francisco experience with a transit-first policy and transit lanes on city streets extends over 7 years. The program got off to a good start with a fair amount of interdepartmental cooperation, high expectations, and an extensive program of transit lanes and other transit preferential improvements. However, the program began to languish from a combination of inattention and less-than-hoped-for-impacts on transit operating performance. Resistance to expansion of the program to areas of greater need, hence greater potential impact on motorists and merchants, grew and political and staff support waned. One particular problem was the cost and difficulty of providing an active enforcement program with police personnel.

A 2-year UMTA grant has provided a full-time staff person to oversee the program and the means to fund and experiment with nontraditional enforcement techniques, including the design and evaluation of self-enforcing transit lanes. This focused attention has resulted in a new awareness of the potential and limitations of concurrent-flow transit lanes on city streets. An unanticipated byproduct of this study is a new emphasis on enforcement of parking regulations and a closer scrutiny of allocation of curbside parking and loading functions and their impacts on bus operating performance.

A number of lessons learned from this experience should be transferrable to other cities that have or may be planning concurrent-flow bus lanes. Several of these important lessons or recommendations are listed.

Self-Enforcement by Design

The chief conclusion of the San Francisco study was that properly designed streets and transit priority treatment would lead to lower violation rates. Attention should be given to proper width, lane markings, curb bulbing, and bus-stop design. Curb bulbing is the moving of the curb out the width of a parked car (6-7 ft) at a bus stop. This will prevent cars from parking in the bus stop. A poorly designed facility will continue to be an enforcement problem even with the most sophisticated and innovative enforcement techniques. Specifically, the following practice is recommended.

1. If at all possible, avoid lane designs that incorporate parking or turning movements within the lane by nontransit vehicles;
2. Design lanes that are highly visible, including a buffer strip between the lane and adjacent general travel lanes, large diamonds and the words "bus only" stenciled on the pavement, large roadside signs, diagonal markings or chevrons at the beginning of each block, and, if feasible, overhead signs that call further attention to the bus-only designation;
3. Design transit lanes of adequate width; if they are to include curb parking and loading, a minimum of 20 ft is recommended;
4. Develop the maximum publicity concerning the existence and purpose of the lanes and point out that enforcement by regular police personnel is an integral part of the program. If the fine for driving in the lane is written on the signs, this is an additional self-enforcing technique; and
5. Try to eliminate problems in the design stage by providing for the necessary loading, delivery, and service vehicle functions off-street, or at least away from the transit lane.

Public Information and Innovative Enforcement Techniques

Public information must be a part of both self- and active-enforcement programs. Public information is critical in both distributing factual information and gaining public acceptance for a new enforcement program.

The most effective of the innovative techniques are those that set strict penalties for violations, and thus encourage self-enforcement and reduce police labor hours in traffic enforcement. A properly administered boot-and-tow program, such as the one in Washington, D.C., is an excellent example of a good, strict enforcement plan.

Finally, in adopting a new enforcement plan, evaluate each element on the basis of cost, ease of implementation, public acceptance, and coordination with other elements of the enforcement plan. A fully integrated plan should incorporate both self- and active-enforcement techniques and should use both selective and special enforcement measures.

The Board of Supervisors in San Francisco has authorized a 10-month demonstration and evaluation of the first major new exclusive bus lane in several years. The lane was installed on Stockton Street through the heart of Chinatown and the Union Square retail area downtown early in 1981. Everything that has been learned in the last 2 years about the real and assumed causes of delay to transit influenced the design. The self-enforcing lane markings, lane signs, wider lanes, relocated midblock bus-curb bulbs, and a careful look at all adjacent land uses and the curbside access needs were incorporated in the Stockton Street lane. Enforcement, especially of the parking, loading, and double-parking regulations, is a key element of the 10-month program. This is the first time the city has authorized a transit-only lane in an area where it is vitally needed. Success will depend on the combination of many factors in the design and operation of the transit lane. However, in San Francisco, we are concerned that a large measure of the success or failure of the transit lane will depend on the enforcement and that enforcement begins in the courts.

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Enforcement as a Consideration in TSM Planning

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With the recent focus in transportation planning on obtaining more efficient use of the existing transportation system, many agencies unaccustomed to playing a major role in transportation planning and implementation are of critical importance in successful project development. This paper examines the role (and the obstacles of playing such a role) of enforcement agencies in the transportation system management planning process. Two transportation projects in Boston—a preferential lane on an expressway and a center city automobile-restricted zone—are described and used to illustrate the importance of enforcement in successful project implementation. The paper concludes that several institutional barriers hinder effective police participation in the project planning process. In general, police representation somewhere in the project development process was deemed necessary by police officials. In the case of Boston, the police agencies provided useful technical information to project planners. Strong enforcement should begin immediately at project initiation and then taper off to be reapplied when necessary. It is recommended that local transportation agencies provide opportunities for police participation in project planning, with the needed financial support if necessary. Also, the U.S. Department of Transportation should modify existing transportation programs (or seek the legislative changes needed to do so) so that enforcement activities can be funded. Technical information should be provided to both transportation planners and police officials on the role that enforcement has in transportation project development.

Urban transportation planning in the United States has changed tremendously during the past two decades. Most recently, transportation planning has experienced a pronounced shift toward planning that is service-oriented (rather than facility-oriented), that involves relatively inexpensive actions, and that seeks, through operational changes, the most efficient use of existing facilities (1). This shift in focus was first formally introduced into the transportation planning process by the joint transportation system management (TSM) planning regulations of the Urban Mass Transportation Administration (UMTA) and the Federal Highway Administration (FHWA) in September 1975 (2). One consequence of this type of planning is that it requires the participation of actors who never thought of themselves as being related to transportation planning because of the previous long-range focus and the general disregard for implementation concerns of such efforts. The purpose of this paper is to examine the role of one such group of actors--those agencies that are responsible for enforcing the TSM actions once they have been implemented.

TRANSPORTATION PLANNING AND ENFORCEMENT

Several examples in the transportation sector illustrate the enforcement component of TSM projects. In Miami, where minimal enforcement was provided for a preferential lane project on a major freeway in the region, the percentage of vehicles not in compliance with the mandated occupancy level reached 75 percent (3). Police enforcement of the Santa Monica diamond lane experiment kept the violation rate to only 10-20 percent (4). In Boston, a self-enforcing, voluntary diamond lane experienced a violation rate of greater than 80 percent (5). When police began ticketing violators through the mail, the violation rate fell to 35 percent (and the resulting congestion in the general use lanes became so unacceptable to expressway users that, through political pressure, the project was terminated). At a recent meeting of the regional TSM committee in Boston, a planner, in describing a recently implemented automobile-restricted zone (ARZ) stated that the enforcement campaign had been the biggest factor in the ARZ's success to date. In Washington, D.C., an innovative parking enforcement program has played a major role in controlling the illegal use of parking space and in maintaining traffic flow (6).

The literature in transportation planning seldom mentions the role of enforcement in project planning. In fact, a recent review of the literature, along with interviews of TSM planners in 18 U.S. cities, found the following (7):

1. Most police agencies consider traffic enforcement measures solely as a means to reduce accidents or improve the safety conditions of a specific facility. The use of enforcement to achieve other objectives (e.g., improve traffic flow or reduce parking availability) has not been found in the literature.
2. The transportation agency most often cited as having some interaction with the police department is the traffic engineering department. This interaction was necessary for accident prevention and other safety-related issues. Little evidence was found of cases where the police participated on an ongoing basis in a transportation planning process.
3. An effective enforcement program encompasses more than just the police agency; it also includes the courts, state licensing agencies, and transportation implementing agencies.
4. Administrative adjudication has been used in some cases to relieve the heavy load of traffic cases that the courts must hear. This has provided speedier, less-expensive disposition of traffic cases.
5. The important role of enforcement in parking management strategies has received the most attention in the transportation literature. Most authors, however, have simply commented on the necessity for enforcement and do not examine reasons why it might not occur.
6. Recent attention to the success and failure of high-occupancy vehicle (HOV) lanes has pinpointed enforcement as a critical factor in the operation of the facility. A concern over the safety of the police officer, a lack of resources to undertake such an effort, and the noninvolvement of the police agency in the project design phase have contributed to a hesitancy on the part of the police to enforce HOV lanes.
7. Those TSM plans that do mention enforcement include it as a component of specific projects. Few mention enforcement as a TSM strategy in its own right.
8. Few TSM planners consider enforcement during the planning process. Most planning for specific TSM projects assumes that the project will be enforced and that the specifics of the enforcement strategy will be worked out between the police agency and the implementing agency.

All of these examples underscore one important lesson--if we are truly serious about managing the existing transportation system, we cannot ignore enforcement as a strategy that has the highest potential payoff. And yet, few TSM planners consider problems of enforcement during the planning process. Further, representatives of enforcement agencies are not actively involved in the planning of such projects. These findings lead to some interesting research questions about what role enforcement agencies should have in the TSM planning process.

1. What are some of the institutional constraints that limit the participation of enforcement agencies in the transportation planning process?
2. How do police representatives view their involvement (or lack thereof) in the planning process?
3. What information or technical capabilities do enforcement agencies have that could complement existing planning approaches?
4. How can transportation agencies at all levels of government contribute to an increased role for the police? and
5. How do the characteristics of an enforcement strategy relate to project implementation?

To answer these questions, several case studies were conducted of TSM project planning in the Boston metropolitan area. Two projects--a preferential lane on a major expressway and an automobile-restricted zone in the center city--will be briefly discussed in this paper. A more detailed analysis of these and other projects and their relationship to enforcement concerns can be found elsewhere (8).

CASE STUDY A: THE SOUTHEAST EXPRESSWAY RESERVED LANE

The Southeast Expressway is the most heavily congested roadway in Massachusetts. This major highway serves the Boston metropolitan area. During the past 20 years, it has received increased attention from local transportation planners and engineers as to possible ways of decreasing the burden. The expressway has also become the focus of often heated public debate as the different attempts at solving the expressway problem have created negative impacts on several constituent groups. The Southeast Expressway reserved lane was the latest, and most controversial, effort to improve the performance of the expressway. The purpose of this case study is to examine the role of the enforcement agencies in the planning and implementation of the lane, with special attention given to the problems of such a scheme as perceived by those responsible for enforcement (9).

Enforcement Problem

The type and extent of enforcement for the Southeast Expressway reserved lane project were influenced by several factors. First, the reserved lane removed and existing lane from general use without providing for additional capacity, thus large numbers of drivers could be expected to attempt (and, in fact, did attempt) to circumvent the resulting congestion in the remaining general purpose lanes by using the reserved lane. The enforcement of the lane, therefore, given this large potential for violations, would have to be on an extensive scale. Second, the 8-mile reserved lane was to be separated from the general use lanes by 19-in plastic posts spaced 20 ft apart in heavily congested areas and 40 ft apart in the remaining areas. Given that there was no physical separation between the preferential and nonpreferential lanes, the safety risks of cars weaving in and out of the reserved lane were quite high. Third, there was no space along the length of the project where violators could be pulled over and ticketed. Enforcement control of the lane would thus have to occur at the beginning or end of the project. Finally, the project extended through two police agency jurisdictions, which required that some effort be made to coordinate the activities of both agencies.

The Planning Stages

The planning of the reserved lane began almost 2 years before it was actually implemented and involved most of the transportation agencies in the Boston region. The Massachusetts Department of Public Works (MDPW) was the key agency involved with the project in that it was responsible for the operation of the Southeast Expressway. Starting in November 1976, weekly meetings were held under its auspices with the other affected agencies to coordinate preparations for lane implementation. The other agencies included the Executive Office of Transportation and Construction (EOTC), which is the state department of transportation and whose officials were the major proponents of the lane; the Massachusetts Bay Transportation Authority (MBTA), which is responsible for operating public transportation in the Boston region; and the Metropolitan District Commission (MDC) and the state police, the agencies responsible for policing specific highways in the region.

The major proponents of the project viewed the lane as a very visible and effective means of showing the region's commitment to TSM and air quality and energy conservation objectives. Other transportation officials, however, were skeptical about the feasibility of the lane. The MDPW officials argued that the engineering considerations for implementing the project were formidable, and police officials stated that, given its design characteristics, the lane was unenforceable. Perhaps more importantly, the opportunity for cars to weave in and out of the lane created serious safety problems. It was decided early in the project planning process that driver compliance to the reserved lane would be on a voluntary basis because (10)

1. The voluntary approach simplified the legal requirements for implementation and enforcement of the express lane project.
2. Public acceptance of a voluntary lane would be greater and the concept could be proven without alienating those opposed to the project at the start. The responsibility for the success or failure of the project was, therefore, shifted to the general public (and each commuter then using the expressway) and away from a focus on the police's ability or right to enforce the three-occupant carpool requirement.

The role of the enforcement agencies was thus to be limited to assisting in accident situations and traffic control, which was the role both agencies were satisfied in playing.

Representatives from the MDC and state police agencies attended the weekly meetings at the MDPW and reported on their efforts to increase their capability to respond to any incidents on the expressway. Often at these meetings, however, police representatives expressed the concern that had worried them throughout the planning stage--the possibility of serious accidents caused by vehicles weaving in and out of the reserved lane. Police representatives repeatedly suggested that some procedure be adopted that would result in some respect for the cones. MDC representatives suggested that repeat violators be sent a letter to the effect that their action had been reported to the Registry of Motor Vehicles for disciplinary measures. They also requested that press releases about the reserved lane emphasize that, although compliance was voluntary, noncompliance was, in fact, a violation. Both of these suggestions were adopted.

In summary, both the MDC and state police agencies played an active role during the planning of the reserved lane. Both agencies, however, were of the opinion that (a) the lane was unenforceable and (b) serious safety problems were associated with the weaving of automobiles in and out of the lane. But, because the decision had been made to go ahead with the project, the agencies were very cooperative in designing a strategy for effective implementation.

Implementation

When finally implemented on May 4, 1977, the reserved lane extended along an 8-mile stretch of the Southeast Expressway and was reserved for buses and carpools of three or more occupants. During the early days of operation, the results were close to those expected. Travel times in the reserved lane decreased (between 20 and 40 percent), travel times in the regular lanes increased (by 40 percent), the number of carpools on the expressway increased (by about 33 percent), and the noncompliance rate was high (the percentage of legal users of the lane ranged between 22 and 41 percent). The high noncompliance rate was of serious concern to transportation officials because it not only negatively affected the ability of the lane to handle HOVs but also encouraged automobile drivers caught in the congested regular lanes to weave into the reserved lane. Indeed, the violation rate increased steadily until, by the end of May, it was decided that some enforcement effort had to be made.

Two major changes were made at the end of May that were designed to improve the compliance rate. First, the state began recording the license plate numbers of violators and sent them letters requesting that they comply. Second, additional plastic inserts were placed in those sections that experienced the highest rate of weaving movements. Signs were posted that noted the weaving restriction and the police began to enforce it. The enforcement and compliance observation was accomplished by having police cruisers travel in the lane nearest to the reserved lane, which provided the police officer with good opportunities to observe automobile behavior in the lane. The results of these enforcement efforts, however, were discouraging.

By early October, the reconstruction work on the expressway was completed. However, transportation officials had already decided to continue the lane past the reconstruction stage because they were convinced that the concept had been successful in increasing the productivity of the expressway and that it was now accepted by the commuters as a feasible use of road space. It was further decided that, if the lane were to have a major impact on travel in the corridor, it was essential that it be enforced and that fines be levied against those in violation.

The decision to enforce the lane created problems for the police agencies. The police agency representatives still maintained that the lane was unenforceable, except for sending citations through the mail, and they were uncertain as to the legality of this action. It was not until a local judge agreed that the mailing of citations was acceptable that the police agencies agreed to enforce the regulation. The regulation, similar to one already used by the Massachusetts Turnpike Authority in enforcing toll payment, stated that (11):

> ...Where a violation is observed by a police officer and the officer is unable to give the original of the citation to the violator at the time of such offense because the violator could not have been stopped or the failure is justified for some other reason...the citation shall be issued to the registered owner's last address as appearing in the records of the Registry of Motor Vehicles.

This regulation also provided for a maximum fine of $20 payable by the owner of the car in noncompliance.

This new phase in the lane operation began on October 17, 1977, and almost immediately there was a public outcry against the project. Several legislators introduced a bill that would have prohibited the MDPW from continuing the lane and another bill that would have decreased the occupancy requirement for the lane from three plus to two or more persons, an action that would have effectively killed the project. On November 2, 1977, the MDPW commissioner announced the immediate termination of the project. All citations that had been issued during the enforcement period were dismissed.

CASE STUDY B: THE DOWNTOWN CROSSING

The Boston downtown retail district has been the focus of many improvement programs during the past 15 years. Numerous new office buildings, the construction of a government center, and the recently completed and successful Faneuil Hall complex, all located in the downtown area, have made the Boston central business district (CBD) one of the most active and thriving in the United States. In an effort to encourage the continued physical and economic revitalization of downtown Boston, city officials proposed and implemented an ARZ centered on Washington Street, the center of the commercial district (12). The ARZ, called the Downtown Crossing, was designed to take advantage of the high level of mass transit access provided by four subway lines and several express and local bus routes and the pedestrian activity that occurs in the area. As has been stated by several Boston officials, however, the successful enforcement of restricted vehicle access and parking was the key factor in the initial acceptance and eventual success of the Downtown Crossing.

Enforcement Problem

The successful implementation of any innovative transportation project requires that the general public be informed of the new system or service and also that special efforts be made to ensure compliance with new rules or regulations, if such exist. One of the major components of plans for ARZs is a scheme for rerouting the traffic that originally traveled through the study area and a plan to direct those automobiles that were originally parked in the ARZ area to special parking locations at the periphery. The enforcement component of the strategy to implement an ARZ is thus to enforce all parking, traffic, and loading regulations in the study area and in the areas immediately adjacent to the ARZ. This enforcement is necessary not only to ensure the safety of the pedestrians who now use the street areas but also to maintain the flow of traffic that now bypasses the central area. The first objective (to ensure the safety of the pedestrian) is even more critical in those ARZ plans that do not begin with massive redesign of the street system so that it looks like a pedestrian zone but rather convert the existing street to pedestrian use as the first stage in an incremental implementation strategy.

The Downtown Crossing provided an especially difficult enforcement problem. Although the original traffic volumes on the streets that would constitute the ARZ were not large in comparison with those for other cities, the narrow streets and complex traffic circulation in the area produced high levels of congestion throughout the day. On Washington Street, for example, the evening peak-hour volume was close to 1000 vehicles, a traffic volume that would now have to find alternative routing (assuming that the Downtown Crossing would not significantly affect modal choice for the work trip). Another factor that exacerbated the congestion problem was the high level of illegal parking that occurred throughout the area. For example, a traffic study completed in 1976 indicated that traffic flow in downtown Boston could be increased by 35-40 percent if illegal parking were eliminated in the area (13). A previous study in 1972 found that 27 percent of all cars parked in downtown Boston on an average day were parked illegally (14). In specific regard to the Downtown Crossing, it was estimated that its implementation would eliminate approximately 600 on-street parking spaces, 240 legal and 360 illegal (15). Thus, the implementation of the Downtown Crossing would displace a large number of vehicles that would need alternative locations to park and presumably, if given the chance, would still be parked illegally in the Downtown Crossing area.

In addition to the large number of legally and illegally parked cars in the ARZ area, the downtown was the focal point for many deliveries of urban goods. On an average day, almost 3000 deliveries were made in the area that includes the Downtown Crossing and areas adjacent to it. Again, if the Downtown Crossing was to be a safe area for pedestrians, access to the area by delivery vehicles had to be strictly controlled and would require strong enforcement of loading and unloading restrictions.

In summary, the enforcement problems associated with the Downtown Crossing were formidable. The public had for many years considered illegal parking an acceptable risk to take because of the lack of follow-up to any tickets received. The crossing was also going to displace a relatively large number of parkers whose initial reaction would most likely be to park illegally in the ARZ area. Although the volume of traffic that now had to be rerouted was not large, the narrow streets would create high levels of congestion that, if augmented by delays caused by illegally parked cars, could become unbearable. Finally, the downtown area attracted almost 3000 delivery trips daily that would now have to be consolidated or the times of delivery changed so that the deliveries could be made during specified hours. Enforcement of these loading regulations would be critical to the success of the Downtown Crossing. All of these factors created the need for a well-conceived enforcement strategy and a potentially vital role for the police department in the project planning process.

Round 1: The Early Stages

Transportation problems in Boston have, for a long time, received a great deal of attention from city officials and professional planners. The governor's decision in the early 1970s to halt plans for major highway construction in the city created a cadre of transportation professionals concerned with many of the then nontraditional approaches to TSM. Thus, during the past decade we have seen in Boston efforts to increase parking restrictions, the imposition of a freeze on the provision of new commercial parking spaces, consideration given to discouraging commuter traffic through neighborhood areas, and greater emphasis on the important role that transportation investment can have on encouraging development in the downtown area. With this as a background, it is not surprising that serious efforts would be made to implement an ARZ in downtown Boston.

The Downtown Crossing was not the first time that an automobile restriction had been tried in Boston. In the 1950s, Winter Street had been closed on an experimental basis several times. In 1971, Washington Street was closed on Saturdays to allow car-free shopping. However, the Downtown Crossing was the first attempt to create an ARZ on a permanent basis. The idea for the crossing came from officials in the mayor's office who thought that the crossing made sense not only from a transportation planning point of view but also as an illustration of the mayor's concern and interest in maintaining the Boston downtown area as the focal point of regional economic activity. In these early stages, three agencies were involved in the project development process--the Boston Redevelopment Authority (BRA), the Boston Traffic and Parking Commission, and the mayor's office. However, only after the major proponents of the crossing left the mayor's office and became key officials in the Traffic and Parking Commission did the Downtown Crossing become a priority item on the transportation agenda for the city.

The perspective on the enforcement component of the Downtown Crossing plan differed significantly between the staffs of the different agencies involved. Staff members of the BRA thought that the project had to be designed for self-enforcement (i.e., the project should incorporate as many features as possible that make the Downtown Crossing look like an area where cars should not be). Suggestions for these features included mountable curbs, brick paving, and special lighting. Staff members of the traffic and parking commission thought that, given the public attitude toward enforcement, any effort to enforce the regulations in the crossing area would be ineffective and that the best strategy would be to sign and signalize the area so as to discourage drivers from entering. The officials in the mayor's office, however, felt very strongly that, unless a major effort were made to actively enforce the crossing, it would be a failure. Their desire for an active enforcement program grew over time, especially when representatives of the downtown merchants stated that their support for the project was contingent on the provision of police enforcement.

Thus, when planning for the Downtown Crossing became a priority activity, the question of what level of enforcement would be appropriate and feasible for the project became very important. The role of the police department up to this time had been minimal. With enforcement now an issue, the police department had to be involved in the project planning process and, at the request of the traffic and parking commissioner, a representative of the police department participated in formulating the enforcement component of the project proposal. His major role, however, was to review the proposed enforcement strategies and to identify barriers to their successful implementation.

The proposal to UMTA to request federal money to support the Downtown Crossing included a request of $134 400 in Section 6 of the Urban Mass Transportation Act of 1964, as amended, demonstration grant funds for the provision of enforcement. This figure included funds for four police officers (two from 8:00 a.m. to 4:00 p.m. and two from 4:00 to 10:00 p.m.) and two additional tow-truck operators, both groups for a period of 52 weeks. The enforcement costs were to cover (16) "immediate police towing of illegally parked cars and the assignment of officers at the two major entry points into the TTIP [Downtown Crossing] area and at the intersections which require traffic officers."

Up to the submission of this grant application, the police department had not been actively involved in the project planning process. However, enforcement was now clearly identified as a major factor in the likely success of the Downtown Crossing. Police officials were to play a critical role in the successful implementation of the Downtown Crossing, although this role was not so much a result of police department policy as it was of personal commitment to the project.

Round 2: Implementation

With approval of the UMTA demonstration grant, more detailed plans could be made on the specific implementation steps needed to complete the project successfully. An enforcement plan, so detailed as to discuss the exact position of police officers on the streets, was developed by a planner in the traffic and parking commission and an official in the mayor's office who was familiar with the then existing towing program. The police department representative reviewed this plan and identified the problems that would be faced in its implementation (such as the personnel assignments being incompatible with the existing structure of work shifts). As before, the role of the police department throughout this stage of the project was one of reviewing the plans made by others rather than developing a plan of its own. However, individual police officers were soon beginning to influence the evolution of the plan as they became actively involved with specific components of the plan.

One of the most useful inputs from the police department came from a group of lieutenants being trained in the Boston Police Academy. They were asked as an exercise in one of their classes to examine the enforcement plan of the Downtown Crossing and to recommend changes that would make the plan more effective. The enforcement resources in the original proposal were considered by this group to be too small by half. The lieutenants recommended a three-phase program. The intensive phase 1 included five entry control officers, three of whom patrolled successive blocks of Washington Street that led to the restricted area. These officers were to siphon off traffic before it could cause a disruption at the entry point. Additional resources allocated in phase 1 included five tow trucks and four meter maids. Phase 2 was to be a program to maintain continuous enforcement surveillance in the area, and phase 3 would be an intensive program done randomly to freeze positive enforcement attitudes (17).

The plan was thus to provide heavy enforcement during the first month, remove the pressure for two weeks, and then reapply it for two more weeks. The reasoning for this strategy was that the public had to be convinced early in the project operation that city officials were serious about enforcing the restrictions. Enforcement could then be allowed to taper off but reapplied at periodic intervals or when circumstances dictated. Another element of the plan included a concentration of enforcement efforts on the main street and allowances given to illegal parking on side streets. The lieutenants thought that this differentiation between important areas and less-important areas helped create an image of enforcement in the crossing area while not tying up traffic on peripheral steets with massive towing of vehicles. The maintenance of the traffic pattern was considered by the lieutenants a crucial objective of the enforcement plan.

Another key police actor in the development of the enforcement plan was the lieutenant in charge of the police towing enforcement unit. The lieutenant and an official in the mayor's office worked closely in devising a towing program for the Downtown Crossing that made available towing capability by switching the duties of existing tow operators from general scofflaw apprehension (tow and hold) to a concentrated effort on the Downtown Crossing. No additional towing resources were thus necessary, and there was also no added pressure placed on the adjudication process, which was already reaching capacity.

The initial towing program consisted of motorcycle officers, meter maids, and police tow trucks supplemented by private-contractor tow trucks. As it turned out, the meter maids did not participate in the enforcement program because union rules required that they be consulted in any decisions to reallocate their services. This had been overlooked by the enforcement planners, and accordingly the meter maids refused to participate. Although drivers of the buses that use the Downtown Crossing were requested to call the dispatcher to report any illegally parked cars, there are few examples of any bus driver doing so. The major reason for this seems to be that many of the bus drivers were unaware of their having such a capability.

Three days before the Downtown Crossing was implemented, leaflets that informed drivers of what was about to happen were placed on the windshields of all automobiles in the study area. In anticipation of having to tow a much larger number of vehicles than under normal circumstances, the police towing unit focused on three major streets prior to the initiation of the crossing and raised its towing rate to 60 tows/day.

The Downtown Crossing opened on the Tuesday after Labor Day, and the strict enforcement started that Thursday. The police lieutenant and the transportation official from the mayor's office supervised the towing program directly by riding around the study area and giving instructions and calling in tow trucks. Both felt that consistency was the most important attribute of the towing program during the initial phase of the operation. Initially, 50-75 cars/day were towed. The reaction time of the police tow trucks was very small--as soon as a car parked in a tow area, a truck was called and the car removed. Close to 600 cars were towed in the first week and 400 in the second week.

One of the major problems with the towing program was associated with the private contractor. The initial contract stipulated that the contractor would receive payment on a per tow basis, which encouraged the truck drivers to quickly dispense of the cars they were handling and return to the streets to get more. Several cars were damaged in these high-speed runs to the impoundment lot, which resulted in claims against the city. In response, police officers in the Downtown Crossing called their own tow vehicles when the need arose. As a result of these problems, and also given an increased public understanding and acceptance of the crossing, the tow rate decreased to about 10 tows/day when the contract expired in June 1979. Currently, there is no special attention given to towing in the crossing area. The problem of illegal parking is minimal because the crossing has now been redesigned with the pedestrian totally in mind (i.e., it is obvious to the automobile driver that he or she should not be in the area).

CASE SUMMARIES AND INTERPRETATION

The reserved lane on the Southeast Expressway is perhaps the best example of the role of enforcement agencies in the planning of innovative projects. The two police agencies involved (the MDC and the state police) cooperated in the project planning process, although they often expressed severe reservations about the project. Specifically, they argued that the project was unenforceable and that the possibility for high levels of weaving between the general purpose and reserved lanes created unacceptable safety hazards. It was not until the decision had been made by high-level officials in the MDPW and the EOTC that there would be a project that the police agencies turned to developing a strategy for enforcing the project. This response reflects the general behavior of the police agencies throughout the project planning process--decisions made by higher authorities will be implemented.

Because of the difficulties with geometric design, the lane operated on a voluntary basis during the reconstruction of the expressway. As was expected, the violation rates were quite high and, although notifications of violation were sent through the mail, the noncompliance rate remained high throughout the summer. Safety issues once again were the dominant concern of the police agencies and they played an important role in identifying weaving sections that were particularly dangerous and that were to be the focus of increased enforcement efforts.

When transportation officials decided to continue the project beyond the end of the reconstruction period and also decided that the only way to make the lane successful was to enforce it, police officials once again voiced concerns about the enforceability of the lane. They were particularly worried about the legality of sending citations through the mail and were not about to participate actively in the enforcement program until they had assurances that the courts would permit such a scheme. This attitude illustrates a key characteristic of police behavior in traffic enforcement--the legality of the action and the capability and willingness of the courts to follow through on citations were important points to establish before the police agencies participated willingly in the program.

The enhanced enforcement strategy of the reserved lane was indeed successful in that the violation rate decreased significantly. In one location, the violation rate was almost halved--from 74 percent to 35 percent of the vehicles in the lane in noncompliance. However, the negative impact on the general use lanes was so dramatic and significant that the resulting controversy resulted in the termination of the project. For example, the average travel time on the expressway (11.4-mile segment) in the general use lanes jumped from 24 min during the construction phase to 40 min during the enforcement phase, an increase of 67 percent (this figure is for a time period that starts at 7:30 a.m.). One could conclude, therefore, that the enforcement strategy was indeed successful in making the lane operate more effectively by discouraging violators from using the lane. One of the ironic results of this case, however, is that the success of the enforcement strategy could have been a major cause for the controversy that surrounded the project and its eventual termination.

The results of this case suggest two courses of action that could have been taken by transportation officials that might have changed the outcome of the project. First, the enhanced enforcement program (i.e., sending citations through the mail) could have begun at the beginning of the project, when the lane was more closely associated with the reconstruction. To begin enforcement after 5 months of operation, when drivers are now accustomed to the delays and congestion, and also taking away the original rationale for the project had a high potential of raising the anger and frustration of the expressway users. The second option for the authorities was to continue lane operation as it had occurred during the reconstruction (i.e., low levels of enforcement and accept the high level of violations). This option was not acceptable to the transportation officials, who argued that the project would, to all intents and purposes, be worthless.

This case illustrates what seems to be the most-effective enforcement strategy for innovative TSM projects--enforce the project from the beginning of operation. This means that a great deal of effort must be made to ensure the willing cooperation of the enforcement agencies and to alleviate their concerns about public safety, legality, and judicial follow-through.

Although city officials had considered the enforcement component of the Downtown Crossing for some time, the final traffic enforcement strategy was defined by the requirements of the plan submitted by the police lieutenants. Swift, sure, and firm enforcement had to be provided in order to change the habits of Boston motorists. Instant towing and plenty of traffic direction were the cornerstones of the learning process for the Boston driver. The initial intense effort was to taper off to a lower level after the new patterns had become established. Periodic crackdowns would occur whenever violations became a problem in order to freeze positive enforcement attitudes.

Another more-passive enforcement strategy was to make the restricted area as self-enforcing as possible. This approach, led by BRA, involved designing the restricted areas to look as though automobiles did not belong there so that police needs would be kept to a minimum. Although not available in the beginning, capital improvements such as bricking, lighting, and amenities were made during 1978 and 1979. They define the regulated areas well and keep present-day entry enforcement requirements to a minimum. Long-term ability for self-enforcement is a worthwhile goal and, combined with vigorous enforcement, makes an effective campaign for the establishment of new driver behavior patterns.

Announcements about the crossing and the changes to be made were distributed through the media. Radio stations were helpful in referring to the changes positively and not as potential disasters precipitated by downtown congestion. The support of the public and motorists was deemed crucial to the success of the plan, where success was defined as improvement of the downtown environment for shoppers and businesses. The public had to know what changes were being made and how they could cope with them.

In general, the large level of effort expended in considering all facets of the implementation process was rewarded by the success the crossing now experiences. Even in this case, where police officers played an important role in the implementation of the project, some problems can still be identified. Even though the police department had some input in the planning through the lieutenants' critique of the plan, it was generally left out of the planning process itself. Some police officers felt as though the plan was handed to them as a fait accompli and were resentful of being excluded from the planning. They felt that, in projects that involved police participation, a police representative should attend meetings regularly so that at least one officer becomes familiar with the project. The meter maids' reaction is illustrative of what happens when key actors are not involved.

Other agencies, in turn, are reluctant to include police officers in project planning for fear of police intransigence. This attitude between transportation planners and police officials is long standing and well known in the limited literature of traffic enforcement planning. This attitude, combined with an admitted lack of resources (and perhaps interest) in traffic enforcement on the part of the department, creates a complex and frustrating set of relationships between the images of various city agencies. In the case of the Downtown Crossing, where ties of cooperation and friendship existed, planning was well done and actions well executed. Where contacts were not so strong (meter maids, MBTA drivers), few successes were seen.

The conclusions that can be drawn from the Downtown Crossing project are straightforward and recognized by most of the actors involved. In light of previous experimental failures as a result of ineffective enforcement and management, enforcement for the crossing was judged critical. Merchants insisted on it and the new traffic pattern would demand it, at least initially. The use of federal funding to support enforcement was essential. Even though the enforcement effort was considered at least as important as any other feature of the plan, it comprised only 4 percent of the total expense of the project.

The coordination of planning and enforcement agencies was very important. Coordinated actions worked effectively, but those without coordination were not successful. This coordination could be facilitated if some formal relationship were established to overcome the lack of regular established relations between agencies. Planning groups should seek out contacts in areas in which they have little or no expertise if they want to develop effective plans. The early involvement in the process of agencies critical for successful implementation is essential.

All persons questioned considered the Downtown Crossing successful and thought that it has improved downtown Boston. Enforcement and coordination were named as key issues. Although generalization from the Boston experience might be dangerous, the favorable results in Boston help support a stated need for police agency involvement in the planning process of innovative TSM actions.

CONCLUSIONS

This paper began by listing several research questions on what role enforcement agencies should have in the TSM planning process. The case studies described in this paper have provided some insights on the answers to these questions.

1. What are some of the institutional constraints that limit the participation of enforcement agencies in the transportation planning process?

Enforcement agencies tend to be isolated from the other agencies in a metropolitan area involved with transportation efforts. They have not traditionally held close liaison with planning and implementing agencies, and, indeed, have often focused resources on other issues perceived more important than traffic law enforcement (e.g., serious crime apprehension and prevention). Further, enforcement agencies tend to be closely tied with the judicial system and do not undertake actions that will not be supported by the courts. Finally, the lack of financing of police participation in transportation planning and project implementation creates serious obstacles to effective implementation.

On the other side, transportation planners often ignore the potentially critical role that police officers have in the design of TSM projects. Police representatives are often incorporated into the project planning process, but usually late in the process and without full recognition of the contribution that such representatives could make.

2. How do police representatives view their involvement (or lack thereof) in the planning process?

The Boston case studies represent a very small sample on which general conclusions can be made. Indeed, in these cases, police officers expressed two viewpoints on this particular issue. One group suggested that the current situation of law involvement was most appropriate given the other more important demands on the police force. However, another group, represented by those most actively involved in the Boston projects, felt that a more active involvement was necessary. This group could not understand why the police department was added to the planning process as a minor actor when police participation during project implementation was absolutely critical to project success. In general, most police officers felt that a strong police representation somewhere in the project development process was necessary.

3. What information or technical capabilities do enforcement agencies have that could complement existing planning approaches?

Police officers are probably the most qualified individuals to comment on driver response to changing circumstances. They work on a day-to-day basis with this type of behavior. Thus, police representatives would be able to provide insightful comments on the feasibility of project concept and design and also establish the basic characteristics of an enforcement strategy that would effectively reinforce desired project results.

These conclusions were borne out most visibly in the Downtown Crossing project where police representatives changed the enforcement plan prepared by transportation planners and devoted a lot of resources during the initial stages of project implementation. Without this input, the project might not have been quite so successful.

4. How can transportation agencies at all levels of government contribute to an increased role for the police?

Government agencies should adopt three major actions to accomplish this increased role. At the local level, transportation agencies should recognize the importance of police participation in project and plan development and provide formal opportunities for their participation. These opportunities should be supplemented with financial support where necessary to allow such participation.

At the federal level, the U.S. Department of Transportation should (a) provide for the funding of enforcement activities in the existing funding programs (and strive for legislative changes where necessary) and (b) disseminate information to transportation planners and police officers as to the important role of enforcement in project implementation. Often both groups do not understand the processes, procedures, and motivation of the other.

5. How do the characteristics of an enforcement strategy relate to project implementation?

In both Boston project cases (and in others examined in this research project), the implementation of the project depended heavily on enforcement. The lessons from these projects indicate that heavy enforcement of the project should be provided in the initial stages of implementation with a gradual tapering off, if necessary. And, as illustrated by the reserved lane, enforcement should be provided at the beginning of the project so that desired travel behavior is encouraged from the beginning. The project implementation process is as critical (if not more so) in the design of a project as the planning process, thus great care should be made in providing for early and effective police involvement.

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New Jersey Turnpike Automatic Traffic Surveillance and Control System Performance Observation

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The New Jersey Turnpike Authority's Automatic Traffic Surveillance and Control system became fully operational in January 1976. The system has proven to be an effective tool for managing traffic flow on the New Jersey Turnpike's most heavily traveled section. Motorists are provided with a diversion capability to the least-congested roadway by means of changeable message signs. The paper describes the unique roadway configuration covered by the system as well as the traffic parameters that dictate sign changes. Traffic flow affected by the system during the afternoon and evening peak hours of two high-volume traffic days was evaluated. Automatic sign changes, the magnitude of traffic parameters that caused the sign changes, and the number of vehicles diverted during these two days are described in this paper.

The New Jersey Turnpike Authority's Automatic Traffic Surveillance and Control (ATSC) system was installed and made operational in January 1976. This system was originally conceived and developed prior to and during the widening of the northern 36 miles of the New Jersey Turnpike in the latter part of the 1960s. Its purpose is to completely automate traffic control on the 12-lane section of the New Jersey Turnpike that extends 36 miles from central New Jersey to the George Washington Bridge approaches. The ATSC system provides traffic surveillance and control based on traffic data received from the field. The traffic parameters obtained from the computer are occupancy, average running speed, volume, unused capacity, and vehicle classification. These parameters are collected by means of 850 loop detectors imbedded in the pavement of all roadway components of the 36-mile network.

The traffic data collected are transmitted via buried cable to two front-end processors that process and compress the raw data and, in turn, transmit the refined data to a main computer for further analysis and action, if necessary. This main operating computer is a Digital Equipment

Corporation PDP 11-40. The traffic control is implemented by this main computer through use of traffic control strategies and accompanying algorithms programmed therein that react to the data collected and, by remote control, operate various changeable message directional signs, variable message speed limit signs, and hazard warning signs installed at key locations throughout the 36-mile section.

The purpose of this paper is to examine the performance of the ATSC system during peak-period travel times. A comprehensive description of the system can be found elsewhere (1). The ATSC system has saved motorists from delays by means of diversion. The diversion capability is due to the unique design of the roadway in the most northerly 36 miles.

The two parameters obtained directly from the field that dictate sign changes are occupancy, used for the purpose of incident detection, and unused capacity, used for balancing traffic on two parallel roadways. The occupancy parameter is defined as that portion of time, in percent, that vehicles occupy a loop detector during 1 min. For example, if vehicles occupy the loop detector for 6 s during a 1-min interval, the occupancy is 10 percent. The unused capacity parameter is a measurement that takes into consideration existing hourly equivalent volume based on 1-min measurements and the capacity of the roadway. Unused capacity is defined as the capacity of the roadway minus the hourly equivalent volume. Normally the capacity of the roadway is set at 1800 equivalent vehicles/h per lane. However, in some locations a roadway-capacity adjustment is made to achieve proper sign changes. For example, in the area near interchange 14, where considerable merging and diverging maneuvers take place, the capacity of the roadway is set at 1500 vehicles/h per lane. The hourly equivalent volume is the volume per minute multiplied by 60. Vehicle classifications are done by means of the measurement of vehicles over a loop trap configuration. A vehicle length threshold of 23 ft was found to give excellent results. Passenger car equivalency of 2.5 for each commercial vehicle was found to be most effective, based on observations of sign changes triggered after using passenger car equivalency between 1.8 and 2.8

The advantage of using the occupancy parameter for monitoring quality of flow is that this parameter can be measured directly in the field, by using pulse lengths transmitted directly from the detectors. The percentage of occupancy, based on 1-min measurement, is equal to

$$Q = 100[(T_1 + \dots T_n)/60] \quad (1)$$

where

Q = percentage occupancy during a specific minute,

T_1 = first pulse length(s) during the specific minute, and

T_n = last pulse length(s) during the specific minute.

The ATSC system also provides average running speed per minute at each loop detector site. The average running speed is used only for monitoring the motorist's compliance in certain sections where the speed limit is reduced. Figure 1 indicates the relationship between percentage occupancy and average running speed. This information was obtained from various ATSC system computer printouts that showed percentage occupancy and average running speed for the same period. Figure 1 also contains level-of-service indicators. Table 1 shows level-of-service A-F as it related to occupancy and average running speed. The relation between the average running speed and the level of service was taken from a Transportation Research Board circular (2, Table 2.1, p. 168).

The congestion-producing incident is detected by means of a mathematical formula that takes into consideration the percentage occupancy at an upstream and downstream loop detector. This mathematical formula is composed of the following:

$$\text{Occupancy upstream} - \text{occupancy downstream} > 10 \text{ percent} \quad (2a)$$

$$100 \text{ percent}[(\text{occupancy upstream} - \text{occupancy downstream}) \div \text{occupancy upstream}] > 50 \text{ percent} \quad (2b)$$

Equation 2b ensures that the ATSC system would not consider an incident when the roadway is heavily congested. For example, if the upstream detector indicates an occupancy of 53 percent and the downstream detector indicates an occupancy of 30 percent, Equation 2b is not satisfied. However, when the two conditions are satisfied, an incident alarm will sound off. Then, the computer will make appropriate sign changes that result in the diversion of traffic from the incident area. Traffic diversion will also occur when the unused capacity on the three-lane roadway section is less than 500 equivalent vehicles, provided that the parallel roadway is capable of accommodating the diverted traffic. The computer can determine the effect of the diverted traffic prior to the actual sign change. The projection is done by using historical traffic data that are stored in the computer. An example of actual sign changes triggered as a result of occupancy and unused capacity is described in the last part of this paper.

ROADWAY SECTION

For the purpose of explaining the action taken by the ATSC system, a brief explanation of the area is given. As previously indicated, the ATSC system covers 36 miles between the area near interchange 9 (milepost 82) and its northern terminus at US-46 (milepost 118). The area between mileposts 82 and 106 is known as the dual-dual roadway. This section is composed of two separate three-lane parallel roadways that are separated by a median barrier. Under normal conditions, all trucks and buses that enter the dual-dual roadway must use the outer roadway. Passenger cars, on the other hand, can use either the outer or the inner roadways. The area between mileposts 106 and 118 is composed of two separate roadways, which are known as the easterly and westerly roadways. All vehicles are allowed to use either roadway. The easterly roadway primarily services traffic to and from the Lincoln Tunnel (interchanges 16E and 17) and the westerly roadway primarily services through traffic on Interstate 95 to and from the George Washington Bridge (interchange 18W). Figure 2 shows the area of the New Jersey Turnpike covered by the ATSC system. Tables 2 and 3 show the 28 locations where the changeable message signs are located at points where traffic can be diverted to a desired roadway on both the northbound and the southbound directions, respectively.

EXAMPLES OF TRAFFIC DIVERSION

The following section describes an actual traffic diversion executed during two peak travel days. A search of the records indicates that the effectiveness of the ATSC system's performance can best be described by examining the following two days: Wednesday, November 23, 1977, the Wednesday preceding

Figure 1. Average running speed versus percentage occupancy by level of service.

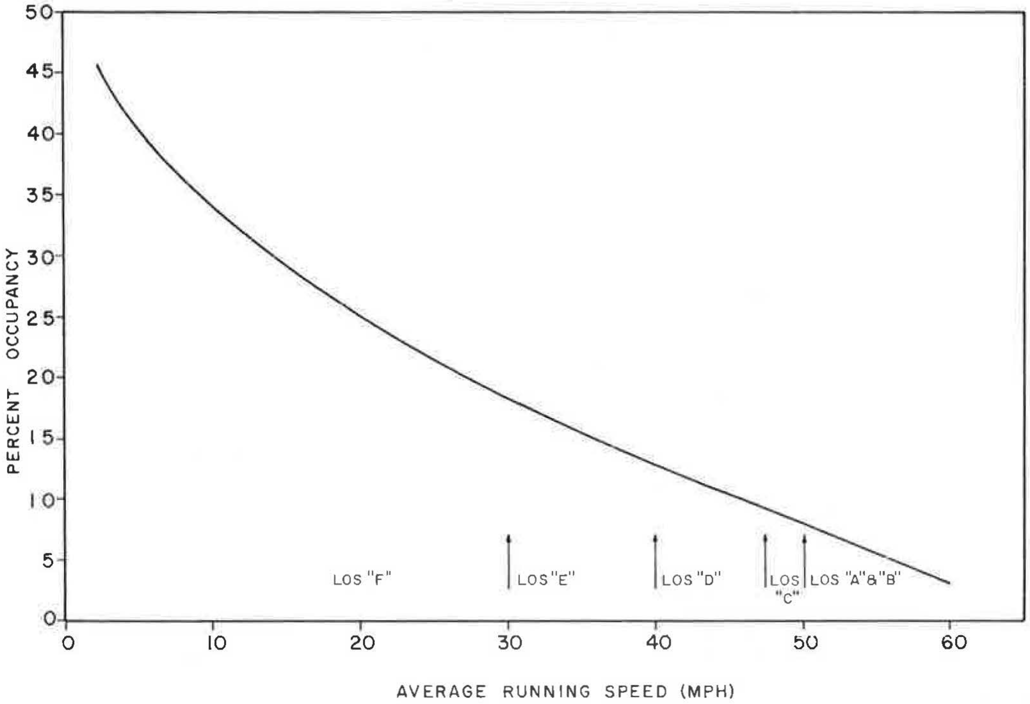

Table 1. Level of service descriptions.

Level of Service	Traffic Flow Description	Average Running Speed (mph)	Occupancy (%)
A	Free flow	>50	0-12
B	Free flow	>50	0-12
C	Stable flow	48-50	12-14
D	Approaching unstable flow	40-48	14-16
E[a]	Unstable flow, capacity	30-40	16-20
F	Forced flow	<30	≥20

[a] Capacity occurs when average running speed is equal to 30 mph and percentage occupancy is equal to 20 percent.

the Thanksgiving holiday, and Friday, June 23, 1978. These two days were selected because they represent days on which sign changes took place to a large extent due to heavy traffic flow. On Wednesday, November 23, 1977, most of the traffic consisted of long-distance holiday travelers. Traffic on the second day consisted primarily of travelers to summer resorts located in New Jersey. On both days commuter traffic was also a significant factor. The total traffic on the New Jersey Turnpike during November 23, 1977, was 438 485 and on June 23, 1978, it was 450 623. This traffic volume can be compared with the 1977 average annual daily traffic (AADT) of 311 408 vehicles and the 1978 AADT of 330 473 vehicles. On November 23, 1977, sign changes were due to congestion that resulted from accidents and heavy traffic flow. On the other hand, on June 23, 1978, sign changes were due to congestion that resulted from heavy traffic flow only. For the purpose of simplifying the description of the ATSC system's performance, the following roadway designations are used:

SNO--outer roadway, northbound;
NSO--outer roadway, southbound;
SNI--inner roadway, northbound;
NSI--inner roadway, southbound;
SNE--easterly roadway, northbound;
NSE--easterly roadway, southbound;
SNW--westerly roadway, northbound; and
NSW--westerly roadway, southbound.

The first letter of the designation signifies the direction from which traffic is coming; the second letter signifies the direction of traffic flow, and the third letter describes the roadway. These roadway designations are also used by operating personnel, which includes State Police, emergency vehicle operators, and the New Jersey Turnpike Authority Operations Center's dispatchers.

November 23, 1977

The following is a description of sign changes and traffic characteristics for vehicular flow on the New Jersey Turnpike that took place on November 23, 1977, between 3:25 and 6:00 p.m., the time when all signs returned to normal.

At 3:25 p.m., an accident occurred at milepost 110 SNW. This location is about 1 mile north of interchange 15W. The accident resulted in blockage of the left and center lanes. An occupancy reading of 24 percent was detected at a loop detector located just south of the accident. On the other hand, the downstream detector north of the accident indicated a reading of 5 percent. Since the congestion criteria for an incident detection was met, an alarm was sounded to indicate to the operator that an incident had just occurred.

At this point, the changeable message signs located at the SNO and SNI roadways about 1 mile north of interchange 14 displayed the message ALL TRAFFIC to direct traffic to the SNE roadway. The message to the SNW roadway from the SNO and SNI roadways displayed the message EXIT 15W ONLY. These message displays were mandatory rather than advisory. In addition, the computer displayed a 35 mph speed limit message at milepost 109 SNW and 45 mph at milepost 107 SNW. The computer also activated the speed warning signs at these locations to read REDUCE SPEED AHEAD--CONGESTION. On the verification

Figure 2. Area on New Jersey Turnpike covered by ATSC system, mileposts 82-118.

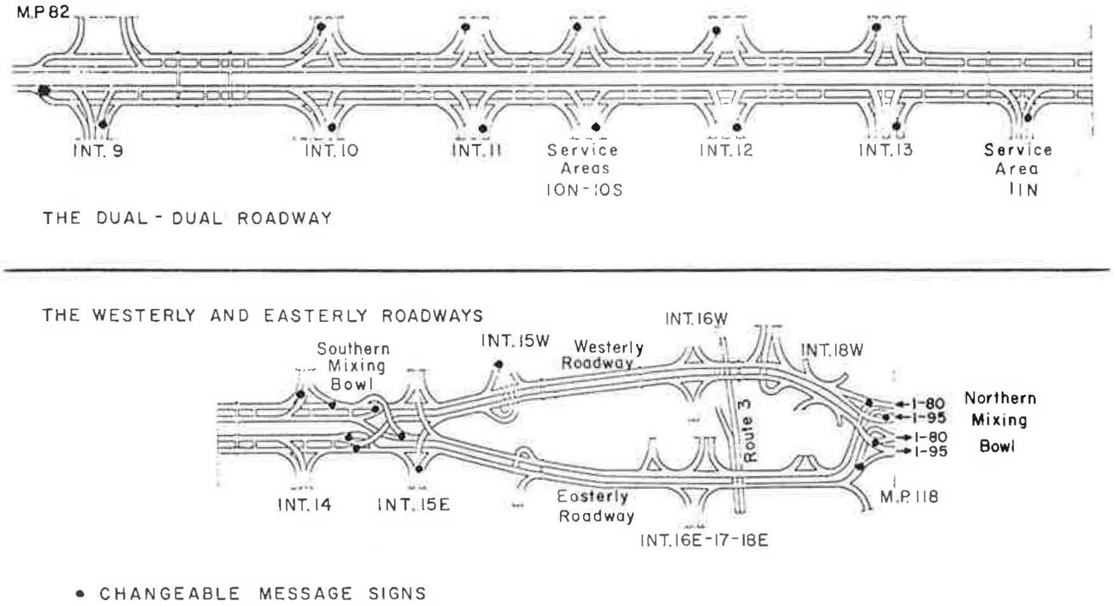

Table 2. Location of entry points where northbound traffic can be diverted.

Location of Entry	Milepost	Diversion Capability
Dual-Dual Roadway		
Mainline split	82	Outer or inner roadway
Interchange 9	83	Outer or inner roadway
Interchange 10	88	Outer or inner roadway
Interchange 11	91	Outer or inner roadway
Service area 10N	93	Outer or inner roadway
Interchange 12	96	Outer or inner roadway
Interchange 13	100	Outer or inner roadway
Service area 11N	102	Outer or inner roadway
Interchange 14	105	All traffic to outer roadway, no diversion capability
Easterly and Westerly Roadway		
Main line, southern mixing bowl	106	Easterly or westerly roadway
Interchange 15E[a]	107	Easterly or westerly roadway
Interchange 15W[b]	109	Westerly or easterly roadway
Interchange 16W[b]	112	Westerly roadway (normal message) or easterly road via NJ-3 eastbound to interchange 17
Interchange 17[a]	112	Easterly roadway (normal message) or westerly roadway via NJ-3 westbound to interchange 16W
Main line, northern mixing bowl	117	I-80 westbound or US-46 westbound, I-95 eastbound or US-46 eastbound

[a] Located on easterly roadway. [b] Located on westerly roadway.

Table 3. Location of entry points where southbound traffic can be diverted.

Location of Entry	Milepost	Diversion Capability
Easterly and Westerly Roadway		
Mainline from I-80 and U-46, northern mixing bowl	117	Easterly or westerly roadway
Mainline from I-95, northern mixing bowl bowl	117	Easterly or westerly roadway
Service area 13	116	Easterly or westerly roadway
Interchange 16W[a]	112	Westerly roadway (normal message) or easterly roadway via NJ-3 eastbound to Interchange 16E
Dual-Dual Roadway		
Mainline, southern mixing bowl	106	Outer or inner roadway from easterly roadway
Mainline, southern mixing bowl	106	Outer or inner roadway from westerly roadway
Interchange 14	105	Outer or inner roadway
Interchange 13	100	Outer or inner roadway
Interchange 12	96	Outer or inner roadway
Service area 10S	93	Outer or inner roadway
Interchange 11	91	Outer or inner roadway
Interchange 10	88	Outer or inner roadway
Interchange 16E[b]	112	Easterly roadway (normal message) or westerly roadway via NJ-3 westbound interchange 16W

[a] Located on westerly roadway. [b] Located on easterly roadway.

of an accident, the word ACCIDENT was added to the speed warning sign.

During the period between 3:25 and 3:50 p.m., 1450 vehicles that normally would have used the westerly roadway were diverted to the easterly roadway, away from the accident area. Although traffic on the easterly roadway became quite heavy due to the additional traffic, it was easier to remove the vehicles that were involved in the accident more expeditiously. At 3:50 p.m. the computer changed the signs on the SNO and SNI roadways, and displayed a normal message. Note that all three lanes on the SNW roadway at the accident location were available at 3:48 p.m. At 3:50 p.m., the speed limit sign located at milepost 107 SNE displayed 45 mph and the speed limit sign at milepost 109 SNE displayed 30 mph. The location of milepost 109 SNE is about 3 miles south of interchange 16E.

At 4:00 p.m., the computer displayed a message to divert all northbound traffic at interchange 15E to the westerly roadway. During the 15-min display of this message, about 250 vehicles were diverted from interchange 15E to the westerly roadway, thus the load on the easterly roadway was eased. At 4:30 p.m., the occupancy on the SNW roadway was 24 percent, and on the SNE roadway the occupancy was 16 percent. During the period between 4:30 and 5:35 p.m. several sign changes took place, which lasted no more than 10 min at a time. These sign changes resulted in a diversion of 1300 vehicles. At 4:30

p.m., the speed limit on the SNE roadway was back to 55 mph; at 5:05 p.m., the speed limit at milepost 107 SNW was returned to 55 mph; and at 6:00 p.m. the speed limit sign at milepost 109 SNW was back to 55 mph. In addition, all changeable message signs were back to normal at 6:00 p.m.

During the period between 3:25 and 6:00 p.m., all speed limit adjustments, as well as diversionary sign displays, were done automatically by the computer. However, these sign changes were carefully monitored by traffic engineers and Operations Center personnel. An examination of the ATSC computer printout information indicated that the level of service attained on both the SNW and SNE roadways at 6:30 p.m. could not have been attained prior to 8:00 p.m. without the availability of the ATSC system.

June 23, 1978

Another example of traffic diversion occurred on Friday, June 23, 1978. The diversion on this date occurred primarily on the southbound roadways. Traffic from the NSW and NSE roadways traveled through the southern mixing bowl to the NSO and NSI roadways. The normal signing directs all buses and trucks and all vehicles destined to interchange 14 from the NSW and NSE roadways to use the NSO roadway. On the other hand, passenger cars from the NSW and NSE roadways can use either the NSI or NSO roadways.

On Friday, June 23, 1978, due to traffic volume, sign changes were made to direct the southbound traffic from the NSW and NSE roadways and from interchange 14 southbound. At 3:30 p.m. all NSE roadway traffic was diverted to the NSI roadway. The reason for this change was based on unused capacity figures. The unused capacity on the NSO roadway was 0. The NSI roadway had an unused capacity of 2260 equivalent vehicles. During this period the occupancy in the area between the southern mixing bowl southbound and interchange 13 on the NSI roadway was 9 percent. The occupancy at the same location on the NSO roadway was 12 percent.

At 5:00 p.m. the changeable message signs from the NSE roadway were back to normal. All NSW traffic was directed to the NSI roadway. During this period the unused capacity on the NSO roadway was 0 and the unused capacity on the NSI roadway was 1580 vehicles. The occupancy during this period was 10 percent on the NSI roadway between the southern mixing bowl and interchange 13 and 12 percent in the same location on the NSO roadway. At 5:10 p.m. all traffic from the NSE roadway was directed to the NSI roadway. Between 5:20 and 5:30 p.m. all traffic from the NSE roadway was directed to the NSO roadway. From 5:30 to 5:40 p.m. all traffic from the NSE roadway was diverted again to the NSI roadway and traffic from interchange 14 was diverted to the NSO roadway. At 5:30 p.m. the unused capacity in the area between the southern mixing bowl and interchange 13 was 900 on the NSI roadway and 1400 at the same location on the NSO roadway. At 5:40 p.m. all changeable message signs and all speed limit signs were returned to normal. An examination of the ATSC system computer printouts indicated that about 50 min of delay time were saved by motorists who were traveling southbound from the easterly and westerly roadways.

CONCLUSIONS

The New Jersey Turnpike Authority's ATSC system has proved to be an effective tool for traffic management. Comparison of operational experience before and after the installation of the ATSC system indicates an improvement in traffic flow on the New Jersey Turnpike, especially during times of peak travel demand. Without the system, proper accommodation would have been difficult for the 15 percent growth in traffic on the northern 36 miles of the New Jersey Turnpike that occurred between 1976 and 1979. The system has provided motorists with an effectively used roadway network and authority personnel with a valuable tool for providing optimum service to the traveling motorist in terms of rapid incident detection, rapid response time, and alleviation of congestion.

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