TRANSPORTATION RESEARCH

RECORD

No. 1404

Highway Operations, Capacity, and Traffic Control

Transportation System Management, Parking, and Travel Demand Management

A peer-reviewed publication of the Transportation Research Board

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY PRESS
WASHINGTON, D.C. 1993

Transportation Research Record 1404
ISSN 0361-1981
ISBN 0-309-05550-4
Price: $25.00

Subscriber Category
IVA highway operations, capacity, and traffic control

TRB Publications Staff
Director of Reports and Editorial Services: Nancy A. Ackerman
Associate Editor/Supervisor: Luanne Crayton
Associate Editors: Naomi Kassabian, Alison G. Tobias
Assistant Editors: Susan E. G. Brown, Norman Solomon
Production Coordinator: Sharada Gilkey
Graphics Coordinator: Terri Wayne
Office Manager: Phyllis D. Barber
Senior Production Assistant: Betty L. Hawkins

Printed in the United States of America

Transportation Research Record 1404

Contents

Foreword

The papers in this volume were presented at the 1993 Annual Meeting of the Transportation Research Board and are related by their focus on issues pertaining to the management of transportation systems.

Readers with a specific interest in the current state of the practice of transportation systems management will find papers on parking policy and market rates for parking, congestion-reducing measures and their effectiveness, use of forecasting models for predicting and mitigating the impacts of construction on traffic congestion and air quality, use of TRANSYT-7F model for transit operation, use of express lanes during major highway reconstruction, and modeling of queues to evaluate the delays to vehicular and vessel traffic caused by bridge openings.

Readers with a specific interest in parking and transportation demand management (TDM) analysis and practice will find papers on use of simulation modeling to determine locations for parking facilities, setting parking requirements for developments in the proximity of transit stations, evaluation of employer-sponsored trip-reduction programs, TDM and the urban university, gender differences in commuter travel and the implications for TDM programs, and the evaluation of travel reduction ordinances.

Publication of the papers in this volume was sponsored by the Committees on Transportation System Management, Methodology for Evaluating Highway Improvements, and Parking and Terminals, and by the Task Force on Transportation Demand Management.

Proposed Changes in Transportation and Parking Policies for Federal Employees

JESSIE STRAUSS

The purpose of this study is to provide background on the issues involved in transportation program policies, particularly parking policies, for federal employees, and to recommend a program that addresses problems in the current policy. Major problems caused by high vehicle use are congestion, air pollution, and petroleum fuel consumption. Several additional problems are inherent in the current transportation policy for federal agencies. Research has demonstrated that charging for parking is the most effective transportation demand management (TDM) strategy. The federal government, however, provides free parking for almost all of its employees. The author recommends a policy of charging market rates for parking and using the proceeds to support comprehensive TDM programs. Title 40 presently discourages agencies from charging for parking, and Title 5 prohibits using specific TDM strategies at federal agencies. Minor changes to these titles are needed to implement the recommended policy.

The purpose of this study is to provide background on the issues involved in transportation program policies, particularly parking policies, for federal employees, to recommend a program that addresses problems in the present policy, and to outline changes needed for implementation of the program.

This paper summarizes major problems caused by heavy vehicle use and recommends using transportation demand management (TDM) strategies to alleviate these problems. The paper demonstrates how Titles 40 and 5 of congressional law discourage and prevent federal agencies from implementing full TDM programs and lists some of the issues resulting from these limitations. A more effective parking or transportation program for federal employees is proposed, and required legal changes are detailed.

Use of the automobile has led to far-reaching transportation-related problems: traffic congestion is leading to gridlock during peak hours throughout the country; the automobile is the main cause of critical air pollution problems; even with more fuel-efficient engines, oil consumption for transportation continues to rise.

Building more roads is one solution to congestion, but this solution is extremely expensive and encourages more vehicle use, adding to air pollution and consumption of oil products.

TRANSPORTATION DEMAND MANAGEMENT

TDM is an approach that addresses all three problems. TDM attempts to maximize the movement of people, not vehicles, within the transportation system, thus avoiding more costly expansion of the system. TDM encompasses policies that promote shifts of peak period single-occupant vehicle (SOV) trips to other modes or times, or that promote reduction in peak period travel. Although TDM cannot be expected to solve all transportation-related problems, it has been shown to be effective as a partial solution.

Many different TDM strategies have been used. However, parking pricing is the TDM strategy that most affects employees' mode choice, a conclusion reached by many studies of TDM effectiveness (*1–4*). Willson and Shoup (*5*) found that ending employer-paid parking reduces solo driving by between 18 and 81 percent.

Another important aspect to operating an effective TDM program is offering a wide variety of strategies to meet the needs of a variety of commuters (*1,2,4*) (see also paper in this Record by Williams and Petrait).

Reducing the number of employees who drive to work is no longer simply an option for public and private employers. The Clean Air Act Amendments of 1990 (CAAA) place reliance on the adoption of transportation control measures (TCMs). Among the TCMs identified by law are employer-based transportation management plans, trip reduction ordinances, and programs to provide high-occupancy and shared-ride services (*6*).

Many locations, particularly in areas classified as ozone nonattainment areas, have requirements for decreasing vehicle use. For example, the California Clean Air Act requires areas that cannot achieve state air quality standards by 1997 to adopt TCMs to increase vehicle occupancy to 1.5 by 1999; the Washington State Commute Trip Reduction Law requires major employers to reduce employees' SOV commutes 35 percent between 1992 and 1999; and the Washington, D.C., area must develop a plan to reduce ozone-causing pollution (caused primarily by motor vehicles) by 24 percent by 1999.

Federal agencies are at a disadvantage in meeting trip reduction requirements because federal laws discourage federal agencies from charging for parking, the single most effective TDM strategy. In addition, federal agencies cannot offer a full range of complementary TDM incentives.

LEGAL OBSTACLES

Two congressional acts, Titles 40 and 5, have played a major role in discouraging or prohibiting federal agencies from maximizing the effectiveness of their transportation programs.

Title 40 discourages federal agencies from charging for parking by requiring that parking revenues in excess of actual operating and maintenance costs be returned to the U.S. Treasury as miscellaneous receipts. Although federal agencies

Metro, MS 128, 821 Second Avenue, Seattle, Wash. 98104.

have legal authority to charge for parking (established by President Carter and upheld by the United States Court of Appeals), the agencies have little incentive to institute charges because they cannot keep the funds that are collected. As a result, parking is free to almost all federal employees throughout the United States.

Title 5 prohibits federal employees from receiving supplemental income or benefits unless specifically authorized by law. One strategy prohibited by Title 5 is the Guaranteed Ride Home (GRH) program. GRH programs provide rides for employees in unanticipated situations. These programs eliminate one of the most frequently cited reasons for driving alone: the fear that employees will not have access to a vehicle if an emergency arises. Studies have indicated that employees who rideshare or take public transit, and who have a GRH program in place, believe that the program is an important factor in enabling them to continue using high-occupancy vehicle (HOV) modes. If federal agencies were able to offer this program, the cost would be minimal. Studies involving private companies in Denver, Colorado, and Bellevue, Washington, found the cost of GRH programs per employee per year was 10 and 8 cents, respectively.

Another benefit that Title 5 prohibited federal agencies from offering until recently was a transit subsidy. The passage of the Mikulski Amendment (Pub. L. 101-509, U.S.C. 629) in 1991 made it possible for nonmilitary federal agencies to offer transit subsidies. However, unless renewed, the legislation will expire in December 1993, and federal agencies will no longer be allowed to provide transit subsidies.

ISSUES ARISING FROM LEGALITIES

Several issues for federal agencies result from the legal restrictions mentioned. Federal agencies should be taking a leadership role in TDM, and particularly in parking pricing, the TDM strategy most likely to cause a reduction in SOVs. However, at present almost all federal employees who park at federal facilities park at minimal or no cost to themselves.

States, local governments, and private businesses, balking at the requirements of CAAA, are less likely to be cooperative when federal agencies themselves are not using some of the most effective TDM tools. However, as long as parking fees must be returned to the U.S. Treasury, federal agencies are not likely to charge employees for parking.

Another problem is that the cost of providing free parking to federal employees is astronomical, certainly somewhere in the billions of dollars annually. For the Washington, D.C., area alone, the cost is about $971,000 a day (*7*), or almost a quarter of a billion dollars a year. The ironic result of this federal expenditure is that it encourages a behavior that the federal government would like to discourage: driving a car to work alone.

Equity is also a problem. By providing free parking to employees, the federal government is providing substantial subsidies for employees who drive to work. For example, in the vicinity of the Nassif Building in Washington, D.C., where the U.S. Department of Transportation (DOT) headquarters is located, the average cost for parking at a private parking garage is $153 a month. However, DOT employees are charged between $10 and $21 a month. In essence, this is a subsidy of between $132 and $143 per month for people who drive to work. On the other hand, the benefit for employees who ride transit is $60 a month, and, unless the Mikulski Amendment is extended, this benefit will fall to $0 after 1993. Clearly, the free parking benefit to employees who drive is much greater than the transit benefit to those who use public transportation.

Yet another problem is recruitment and retention of federal employees, which is made more difficult by the inability of employees to reach work places quickly, economically, and comfortably. The worker who has to sit in long traffic delays is likely to have lower morale and less physical energy than one who arrives at work by transit, vanpool, or carpool. The expense to the employee in time and money will increase as congestion grows, an expense that potential employees will consider before accepting a position. When competing for quality employees, the federal government will need to ensure safe, efficient, and cost-effective access to government facilities.

PROPOSED FEDERAL TRANSPORTATION PROGRAM

A program is needed that will address the issues of federal leadership, parking expenses, inequity that favors drivers, and employee recruitment and retention, as well as congestion, pollution, and energy issues.

The proposed federal transportation program calls for federal agencies to begin to charge the full market rate for parking. The money collected at each agency site, beyond that needed to operate and maintain parking facilities, would go into a fund that would encourage alternative commute modes. These funds would be used to increase HOV incentives instead of to cover the expenses of TDM programs already offered. The goal of the proposed plan is to open commute options that will make employees' commute trips more convenient and less expensive.

Decisions about which incentives should be included in a transportation program should be determined by the conditions at each site. There is no one mix of strategies that may be prescribed for all federal agencies. Each site has a unique work environment and unique labor force characteristics, factors that should be taken into consideration in selecting appropriate incentives.

There are many advantages to the proposed program: administrative costs would be the only additional cost to federal agencies. The extra funds collected in parking fees would be used to finance new elements of the TDM program. The proposal enables federal agencies to serve as models to private industry and to local and state governments. The program punishes SOVs and rewards those who use alternative modes. Most important, the proposed program incorporates the single most effective TDM strategy: charging the market rate for parking. Private and public employers are hesitant to initiate parking charges, and having the federal government take a leadership role in this strategy is much needed.

It would appear that unions would favor the proposed program. The decline in benefits (loss of free parking) would be accompanied by many benefits to a large number of employees at lower grades. In general, the loss of free parking would not affect employees at lower grades. This is because, under Federal Property Management Regulations, at sites where parking is scarce (usually where parking has a market value), heads of agencies may park at government facilities, but other employees may park only if they rideshare.

Federal agencies, by making it easier and more economical for employees to get to work, would have less difficulty recruiting and retaining employees. In some cases, agencies might want to provide more TDM incentives than could be covered by parking fees, but the legal changes that will be suggested would enable the agencies to use the best TDM tools for their particular situations.

Studies indicate that the proposed program would decrease congestion. Shoup and Willson (*3*) studied five sites where employers who had been offering employees free parking began to charge for parking. These studies revealed an average difference of 19 automobiles per 100 employees before and after parking charged were implemented. A decrease in automobile use implies less air pollution and oil usage.

Some problems may also be anticipated with the proposed program. Whereas unions are likely to favor the changes, management probably would not; those most frequently receiving free parking privileges are executives. Another problem is that the program does not change anything in areas where there is no market value of parking.

A few legal changes need to be made in order to implement the proposed program. A change is urgently needed in Title 40, which requires that parking revenues in excess of actual operating costs be returned to the U.S. Treasury as miscellaneous receipts. Placing such revenues in a transportation fund at each federal site would provide agencies with motivation to charge the market rate for parking and would provide funds to counteract the cost of TDM strategies in the proposed transportation program.

The portions of Title 40 Section 490 that specifically apply read as follows:

> (j) . . . The Administrator is authorized and directed to charge anyone furnished . . . space . . . at rates to be determined by the Administrator. Such rates and charges shall approximate commercial charges for comparable space . . .
> (k) . . . Moneys derived by such executive agency from such fees shall be credited to the appropriation or fund initially charged for providing the service, except that amounts which are in excess of actual operating and maintenance costs of providing the service shall be credited to miscellaneous receipts unless otherwise authorized by law.

Although subsection (j) specifies that the rates for space (which includes parking) shall approximate commercial charges for comparable space, administrators have seldom set market rates for parking. Subsection (j) should be amended by a clause that directs the Administrator to set parking fees for SOVs at the full market value of the immediate surrounding area.

The clause "unless otherwise authorized by law" in Section (k) leaves open the opportunity to authorize that "the amounts in excess of actual operating and maintenance costs for parking shall go into a special transportation fund at each federal agency site. This transportation fund shall be used to support high occupancy vehicle use, walking, and biking."

A change is also needed in Title 5 Section 5536, which states, "An employee or a member of a uniformed service whose pay or allowance is fixed by statute or regulation may not receive additional pay or allowance for the disbursement of public money or for any other service or duty, unless specifically authorized by law and the appropriation therefor specifically states that it is for the additional pay or allowance." A change in Title 5 can make it possible for federal agencies to provide transportation subsidies and GRH programs.

The Mikulski Amendment enables federal agencies (excluding the military) to provide transit subsidies, a TDM strategy prohibited by Title 5. The Mikulski Amendment is limited to the use of public transportation, and therefore does not permit funds to be used for carpool riders or GRH programs. As noted previously, the provisions of this amendment will expire December 31, 1993.

Specific legislative authorization is needed to extend the Mikulski Amendment indefinitely, to extend its provisions to military personnel, and to permit employees to receive pay for agency-sponsored programs that encourage all alternative commute modes.

SUMMARY AND RECOMMENDATIONS FOR FURTHER STUDY

The current parking policy for federal agencies is restricted by provisions in Titles 5 and 40 of U.S. congressional acts. These restrictions are inequitable and are costly to federal agencies. They prevent federal agencies from taking a leadership role in addressing traffic congestion, air pollution, and excessive fuel consumption. The restrictions also make it difficult for federal agencies to recruit and retain employees.

Suggested changes in these titles would require federal agencies to charge the full market rate for parking and to offer TDM programs that encourage HOV use. Federal agencies could then serve as models in addressing the problems caused by high vehicle use.

More data are needed on parking policies, parking availability, and mode splits at federal agencies nationwide. No nationwide analysis has yet been done of the cost of providing federal employees with parking. A study should be conducted of the relationship of parking fees and mode choice for employees in upper income brackets, the employees who would be most affected by the changes in parking policy.

REFERENCES

1. COMSIS Corporation. *Evaluation of Travel Demand Management Measures to Relieve Congestion.* Report FHWA-SA-90-005, FHWA, U.S Department of Transportation, Feb. 1990.
2. E. Ferguson. Transportation Demand Management: Planning, Development, and Implementation. *APA Journal*, Vol. 442, Autumn 1990.
3. D. C. Shoup and R. W. Willson. Commuting, Congestion, and Pollution: The Employer-Paid Parking Connection. Paper prepared for Congestion Pricing Symposium, Arlington, Virginia, June 10–12, 1992.
4. K. Bhatt and T. Higgins. *An Assessment of Travel Demand Management Approaches at Suburban Activity Centers.* K.T. Analytics, Inc., NITS PB89-231856, DOT-T-92-06, July 1989.
5. R. W. Willson and D. Shoup. Parking Subsidies and Travel Choices: Assessing the Evidence. *Transportation* 17, 1990.
6. R. E. Huhnke. Paper presented at NAM-VECC 90 Motor Vehicle Emissions Control Conference, Dec. 1990.
7. *Commuter Parking Cost Study.* Metropolitan Washington Council of Governments and National Capital Region Transportation Planning Board, Washington, D.C., April 1991.

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

Evaluation of Congestion-Reducing Measures Used in Virginia

E. D. ARNOLD, JR.

Congestion on U.S. highways, especially in urban areas, is a serious problem that is growing steadily worse. In Virginia, approximately 28 percent of the daily vehicle miles of travel during peak hour traffic in 1989 was congested (volume/service flow ratio > 0.75). Further, the cost of urban area congestion in Virginia is expected to be more than $4 billion in the year 2000. Transportation professionals in Virginia need to implement congestion-reducing measures at every opportunity. Accordingly, this research was conducted to develop a list of congestion-reducing measures and to document the implementation of and experiences with these measures in Virginia. Documentation included a subjective evaluation of each measure's effectiveness, cost, and barriers to implementation. The scope of the research was limited to a literature review and a survey of transportation officials in Virginia.

During the past several years, congestion on U.S. highways, especially in urban areas, has attracted the attention of transportation engineers, planners, and researchers at all levels of government, and several national conferences on congestion have been held. Although Virginia is predominantly rural (78 percent of its road mileage), few Virginians have not experienced congestion. Eleven major urban areas are located entirely or partially in Virginia, as are 33 smaller urban areas. Roadways in these urban areas carry about 54 percent of the travel.

Statistical summaries from the Virginia Department of Transportation (VDOT) 1989 Highway Performance Monitoring System indicated that 28 percent of the daily vehicle miles of travel during peak hour traffic in Virginia was congested (volume/service flow ratio > 0.75).

Day-to-day (recurring) congestion cost Virginia's urban motorists an estimated $172 million in 1986. Adding the costs caused by incidents (nonrecurring congestion) brings the total cost to approximately $430 million. The cost of urban area congestion will amount to more than $4 billion in the year 2000 (*1*). Transportation professionals in Virginia need to implement congestion-reducing measures at every opportunity.

PURPOSE AND SCOPE

The research discussed here had two equally important purposes: (a) to develop a categorical listing of congestion-reducing measures to provide transportation professionals in Virginia with a readily available, comprehensive list of measures they might consider implementing in their area and (b) to document the implementation of and experiences with congestion-reducing measures in Virginia, including a subjective evaluation of each measure's effectiveness, cost, and barriers to implementation.

The research was limited to a synthesis of existing literature and a survey of transportation professionals in Virginia.

METHODS

A comprehensive literature review was conducted to develop a list of congestion-reducing measures currently in use. The primary source of literature was the DIALOG data base. Transportation professionals in the state were sent a questionnaire to determine which congestion-reducing measures had been implemented in recent years.

The questionnaire was mailed to officials in all 41 cities, 29 towns (population greater than 3,500), 13 urban counties, and 21 planning district commissions (PDCs) in Virginia. Metropolitan planning organizations (MPOs) are linked to the PDCs and thus had input to the survey. Within VDOT, the questionnaire was sent to the nine district traffic engineers, the Transportation Planning Division, the Rail and Public Transportation Division, and the planning section in the Northern Virginia District office. The questionnaire consisted of a categorical list of congestion-reducing measures from the literature. Respondents were asked to note whether each measure has been or is being used in their area and then to evaluate the effectiveness, cost, and implementation of the measure. Respondents were also encouraged to list additional measures and provide available supporting documentation. Measures were to be evaluated subjectively relative to congestion-reducing measures in general and according to the following rating scale:

- Effectiveness: 0 = measure has minimal effect on decreasing congestion; 1 = measure has average effect on decreasing congestion; 2 = measure has maximum effect on decreasing congestion.
- Cost: 0 = measure is inexpensive to implement or operate; 1 = measure has an average cost to implement or operate; 2 = measure is costly to implement or operate.
- Implementation: 0 = measure is easy to implement, with few or no physical, legal, or institutional barriers; 1 = measure can be implemented, with some physical, legal, or institutional barriers; and 2 = measure is difficult to implement, with significant physical, legal, or institutional barriers.

Virginia Transportation Research Council, Box 3817, University Station, Charlottesville, Va. 22903-0817.

RESULTS

Categorical List of Measures

A total of 53 measures used to reduce congestion was identified in the literature. The primary reference was the Institute of Transportation Engineer's *Toolbox for Alleviating Traffic Congestion* (2). The measures were categorized into supply side and demand side measures.

Supply side measures relate to the highway system or roadway itself and are often referred to in general as transportation system management (TSM) measures. Supply measures are further categorized into those that manage or more efficiently use the capacity of the existing system and those that increase or add to the capacity. The term TSM was first used in the transportation planning process to represent all actions that make better use of existing transportation facilities or services.

Demand side measures relate to the modification of travel behavior or travel demand and are often referred to in general as transportation demand management (TDM) measures. Demand measures are further categorized into those that manage or reduce existing demand and those that avoid or control demand growth.

Figure 1 shows the relationship between supply side and demand side measures, and Table 1 presents the 53 congestion-reducing measures in the four categories just defined. Many of these measures have appeared on lists of measures or strategies to be used for the Traffic Operations Program to Improve Capacity and Safety (TOPICS), to save energy, and most recently, to reduce air pollution (transportation control measures).

Experiences in Virginia

A total of 85 questionnaires was returned. Responses were received from transportation professionals in 23 cities, 8 counties, and 8 MPOs and PDCs located in urbanized areas (population of 50,000 or more) and 23 cities and 7 PDCs located in nonurbanized areas. Responses were also received from 9 transportation planning engineers, 6 district traffic engineers, and 1 public transportation engineer from VDOT.

A summary of the responses is presented in Table 1. The use of and the average rating for the effectiveness, cost, and implementation of the individual measures are included. Table 2 summarizes the same information by each of the four categories of congestion-reducing measures.

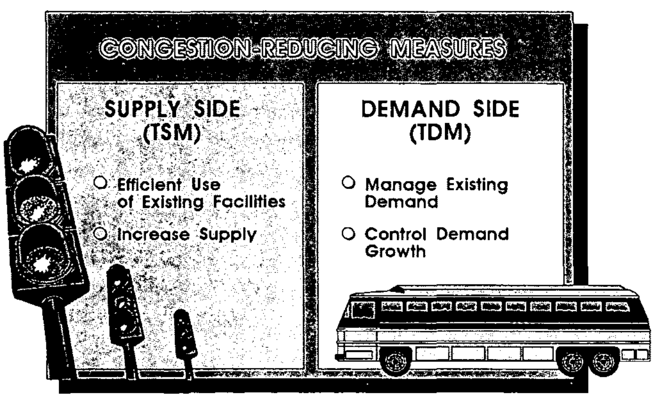


FIGURE 1 Categorization of congestion-reducing measures.

Evaluation of Individual Measures

From the information in Table 1, measures that are the most effective, least expensive, and easiest to implement may be determined. This is accomplished by arbitrarily choosing average ratings of 1.5 or greater, 0.5 or less, and 0.5 or less to represent the most effective, least expensive, and easiest to implement, respectively.

The only measure that was rated on average as being the most effective, least expensive, and easiest to implement was the prohibition of maintenance and repair work during peak traffic conditions.

The following TSM (supply side) measures were rated average or better:

- Incident detection and management systems,
- Motorist information systems,
- Traffic management teams,
- Provision of additional lanes without widening,
- Coordinated signal systems,
- Other signal improvements (e.g., retiming),
- Improvement of other traffic control devices,
- Intersection improvements,
- Turn prohibitions,
- One-way streets,
- Reversible traffic lanes on arterials,
- Prohibition or restriction of on-street parking,
- Traffic management during reconstruction, and
- Prohibition of repair work during peak traffic times.

The following TDM (demand side) measures were rated average or better:

- Flexible daily work hours,
- Commuter matching services (ridesharing),
- Carpool and vanpool preferential parking, and
- Park-and-ride lots.

Evaluation of Measures by Category

- Measures that reduce congestion by managing the existing supply are rated above average in effectiveness and below average in cost and ease of implementation.
- Measures that reduce congestion by adding to the supply are rated the most effective; however, they are also rated the most expensive to implement or operate and the most difficult to implement.
- Measures that reduce congestion by managing the existing demand are rated below average in cost and ease of implementation; however, they are rated below average in effectiveness.
- Measures that reduce congestion by controlling demand growth are rated above average in effectiveness and below average in cost; however, they are rated above average in ease of implementation.

TABLE 1 Congestion-Reducing Measures and Their Use in Virginia

Measure	Used Yes	Used No	Average Effectiveness	Average Cost	Average Implementation
Category I.A.: Managing Existing Supply/Using Existing Capacity More Efficiently					
Incident detection/management system/program	14	65	1.1	0.8	0.8
Traffic surveillance/control system	12	69	1.6	1.1	1.0
Motorist information system	7	74	1.1	0.9	0.6
Traffic management team	11	70	1.1	0.5	0.5
Integrated freeway and arterial surveillance/control system	3	76	1.4	1.4	1.1
Converting existing facilities to HOV facilities	8	75	1.3	1.0	1.5
Providing additional lanes w/o widening (shoulders, narrower lanes)	34	47	1.4	0.7	0.7
Coordinated signal systems (arterial, grid, closed loop)	66	15	1.6	0.8	0.5
Ramp metering	6	73	0.9	1.1	1.0
Other signal improvements, including hardware, upgrades, retiming, removal	71	16	1.3	0.8	0.3
Improving other traffic control devices	54	25	1.1	0.7	0.4
Intersection improvements, including channelization, turn lanes, signing, bus stop relocation	75	9	1.4	1.0	0.7
Turn prohibitions	59	22	1.0	0.1	0.5
One-way streets	52	32	1.2	0.5	0.9
Reversible traffic lanes on arterials	5	76	1.2	0.8	1.0
Reversible traffic lanes on arterials	5	76	1.2	0.8	1.0
Removing/restricting on-street parking	64	17	1.2	0.2	0.9
Arterial access management	19	61	1.1	0.4	1.1
Goods movement management	8	65	0.7	0.5	1.2
Traffic management during highway reconstruction or other major improvements	60	22	1.0	0.9	0.6
Prohibiting maintenance/repairs on major routes during peak traffic hours	52	28	1.7	0.5	0.4
Category I.B.: Increasing Supply/Adding Capacity					
Constructing new highways	56	26	1.7	1.9	1.4
Reconstructing highway with improved design	64	18	1.6	1.6	1.4
Widening by adding general purpose lanes	51	29	1.5	1.5	1.3
Constructing HOV lanes	9	74	1.7	1.5	1.7
Providing highway grade separations	27	55	1.8	1.9	1.5
Providing railroad grade separations	26	54	1.5	1.9	1.3
Choosing toll-based financing to expedite construction of new facilities	13	70	1.7	1.4	1.6
Category II.A.: Managing/Reducing Existing Demand					
Daily flexible work hours (staggered/flextime)	33	50	1.2	0.2	0.5
Alternative work hours (compressed work week)	23	58	0.9	0.1	0.5
Promoting nonvehicular alternatives to auto usage	26	56	0.7	0.8	0.8
Communication in lieu of travel (teleconferencing)	17	65	0.8	0.4	0.6
Communication in lieu of travel (telecommuting)	11	71	0.8	0.7	0.8
Implementing transportation management associations or organizations	19	63	0.8	0.7	0.7
Promoting/supporting ridesharing as an alternative to auto usage:					
Commuter-matching services	31	51	1.0	0.6	0.5
Reduced tolls	7	72	0.8	0.6	0.7
Providing public information on rideshare/transit	40	42	0.8	0.4	0.2
Guaranteed ride home program	11	72	0.3	0.3	0.3
Tax incentives for vanpools	12	69	0.8	0.7	0.8
Implementing/improving transit fixed-route services	34	49	0.8	1.0	0.6
Implementing express bus services	22	62	1.2	1.2	0.9
Implementing/improving rail transit or commuter rail services	10	74	1.3	1.5	1.3
Implementing/improving paratransit services	32	52	0.6	1.2	0.8
Reducing or not increasing transit fares	13	69	0.8	1.1	0.7
Subsidizing transit usage	28	55	0.9	1.2	0.6
Implementing parking strategies to encourage modal shift:					
Car/vanpool preferential parking	19	65	1.1	0.3	0.5
Park and ride lots	40	44	1.1	0.9	0.9
Differential parking rates	7	76	0.6	0.5	0.5
Governmental control of supply and location	11	70	0.6	0.7	0.8
Category II.B.: Avoiding/Controlling Demand Growth					
Growth management by public policy/ordinance/planning	41	35	1.1	0.7	1.4
Auto-restricted zones	25	52	1.3	1.0	1.3
Designing multiuse sites to minimize traffic (e.g., on-site services)	18	61	0.9	0.8	0.8
Road/congestion pricing (excluding traditional toll construction)	1	77	1.0	1.5	1.0
Requiring congestion-reduction strategies: reduced trip generation, transit for proposed development	11	67	1.2	0.6	1.4

TABLE 2 Evaluation of Congestion-Reducing Measures by Category

Category	Yes Responses		Average Effectiveness	Average Cost	Average Implementation
	Range	Average			
TSM					
Managing existing supply	3-75	34	1.2	0.7	0.8
Adding to supply	9-64	35	1.6	1.7	1.5
TDM					
Managing existing demand	7-40	21	0.9	0.7	0.7
Controlling demand growth	1-41	19	1.1	0.9	1.2

Evaluation of Measures by Use and Performance

- Use. Measures in the two TSM categories received a much higher number of positive responses than the measures in the two TDM categories, both with regard to the upper limits of the range and the average.
- Effectiveness. Measures in the two TSM categories were rated on average higher than the measures in the two TDM categories. Also, measures that add to the supply were rated on average considerably higher than measures in the other three categories.
- Cost. Measures that add to the supply were rated on average as by far the most expensive. Also, measures that address existing conditions, either through efficient use of the existing supply or management of the existing demand, were rated on average as the same—and the rating represents a cost of less than average.
- Implementation. Measures that address existing conditions, either through efficient use of the existing supply or management of the existing demand, were rated on average as about the same—and the rating represents a minimum of problems in implementation. Also, measures in these two categories were rated on average as easier to implement than measures that add to the supply or control the demand growth.

CONCLUSION

In general, measures dealing with supply have been used for years, whereas measures dealing with demand are relatively new. Accordingly, the supply measures are used much more than the demand measures and represent the traditional approaches to reducing congestion. More emphasis on the implementation of demand measures appears to offer potential for reducing congestion.

ACKNOWLEDGMENTS

The research reported here was financed through funds administered by FHWA. The opinions, findings, and conclusions are those of the author and not necessarily those of the sponsoring agencies.

REFERENCES

1. E. D. Arnold, Jr. *Congestion on Virginia's Urban Highways.* VTRC Report 88-R24. Virginia Transportation Research Council, Charlottesville, 1988.
2. Institute of Transportation Engineers. *A Toolbox for Alleviating Traffic Congestion.* ITE Publication IR-054A. Washington, D.C., 1989.

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

Use of Traffic Forecasting Models in the Development of Traffic Management Plans for Construction of the Central Artery/Tunnel Project

MARC R. CUTLER

The Central Artery/Tunnel (CA/T) Project is a $6 billion federal highway project to be constructed in downtown Boston and adjacent areas. The major components are a Third Harbor Tunnel (I-90) linking downtown Boston and Logan Airport, and a new underground 8- to 10-lane Interstate highway (I-93) in downtown Boston to replace the existing 6-lane elevated highway. The construction will affect traffic operations in one of the densest urban environments in the United States. The purpose of this paper is to describe the transportation planning approach to manage traffic during this construction. The focus of this paper is on the extraordinary extent to which the CA/T project team is attempting to predict and mitigate the impacts of construction on traffic congestion and air quality. This effort has already resulted in major changes in construction staging and traffic management plans. The first section of the paper describes the CA/T Project and the accompanying traffic management issues that have been raised. The second section describes the process for developing traffic management plans, with particular attention on the interaction between traffic forecasting, traffic engineering, and the design of construction stages. The third section presents a case study of how the traffic forecasting process contributed to a change in the traffic management plan. The fourth section describes the application of traffic forecasting to air quality analysis, and the fifth section describes the approach to analyzing the role of public transportation as a traffic management mitigation measure.

The Central Artery/Tunnel (CA/T) Project is a $6 billion FHWA project to be constructed in downtown Boston and adjacent areas. Most of the project is eligible for federal Interstate funding. The project will be constructed entirely within the cities of Boston and Cambridge.

The project is under the direction of the Massachusetts Highway Department (MHD) with support from its management consultant, Bechtel/Parsons Brinckerhoff (B/PB). Traffic forecasts were developed by Cambridge Systematics, Inc., a subconsultant on the B/PB team. Regional input to the traffic forecasting process was provided by the Massachusetts Central Transportation Planning Staff (CTPS).

As shown in Figure 1, the project includes the following elements:

- An 8- to 10-lane underground highway (I-93) and 6-lane surface arterial to replace the existing Central Artery, a 6-lane elevated highway in downtown Boston;
- A four-lane Third Harbor Tunnel (I-90), doubling the cross-harbor capacity of the two existing harbor tunnels between downtown Boston and Logan International Airport;
- A four- to six-lane Seaport Access Highway (I-90) connecting the Third Harbor Tunnel to the regional highway system and to an interchange in the seaport and development area of South Boston;
- Three major new highway interchanges at the southwest, north, and east approaches to the city; and
- The South Boston Bypass Road, providing a truck route from the south to the South Boston seaport and industrial areas and to the Third Harbor Tunnel.

Construction is under way on the Third Harbor Tunnel and its approach roads, the first phase of the South Boston Bypass Road, and the early phases of downtown construction. An early opening of the Third Harbor Tunnel for commercial vehicles [trucks and high-occupancy vehicles (HOVs)] is scheduled for 1995. Full opening of the Third Harbor Tunnel is scheduled for 1998, and project completion is planned for 2001.

The Third Harbor Tunnel and related roadways are being constructed within Boston Harbor or on adjacent industrial land in South Boston and airport property in East Boston. Although major engineering, environmental, and planning issues are associated with this construction, it will result in little change in existing traffic operations. Construction of the Central Artery, however, must be undertaken in the heart of downtown Boston—one of the oldest and most densely developed urban areas in the United States. Although the existing elevated highway may be kept in operation, changes will be made in existing surface street operations and ramp connections to and from the highway.

The following are the four major phases of Central Artery construction:

- Relocation of utility lines in the path of the future tunnel boxes;
- Construction of slurry walls and installation of surface decking;
- Tunnel construction beneath decking; and
- Restoration of a permanent surface roadway system.

Planning and engineering are nearly complete for the first phase of this construction, with engineering approaching 100

Cambridge Systematics, Inc., Central Artery/Tunnel Project, 745 Atlantic Avenue, 2nd floor, Boston, Mass. 02210.

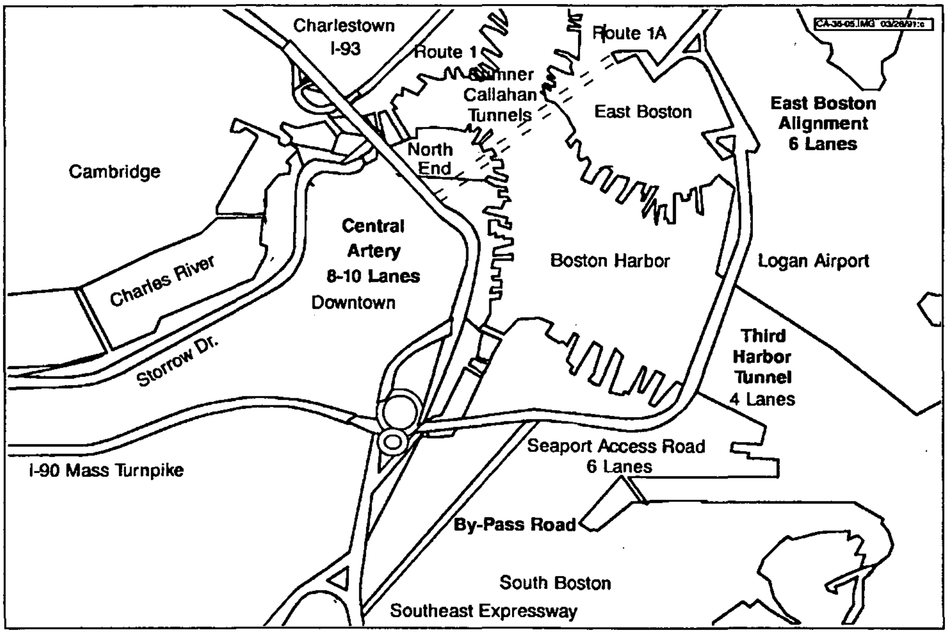


FIGURE 1 Proposed action for CA/T Project.

percent final design for parts of the remaining phases. This paper describes the steps being taken to manage traffic primarily during the first phase of downtown construction—utility relocation—although subsequent mainline tunnel construction is also discussed. Figure 2 shows some of the major impacts to existing traffic patterns that will result from the downtown utility relocation construction. These impacts are summarized as follows:

- Relocation of a major on-ramp to the Central Artery northbound (the Northern Avenue on-ramp). This ramp has a p.m. peak hour volume of 1,200 vehicles.

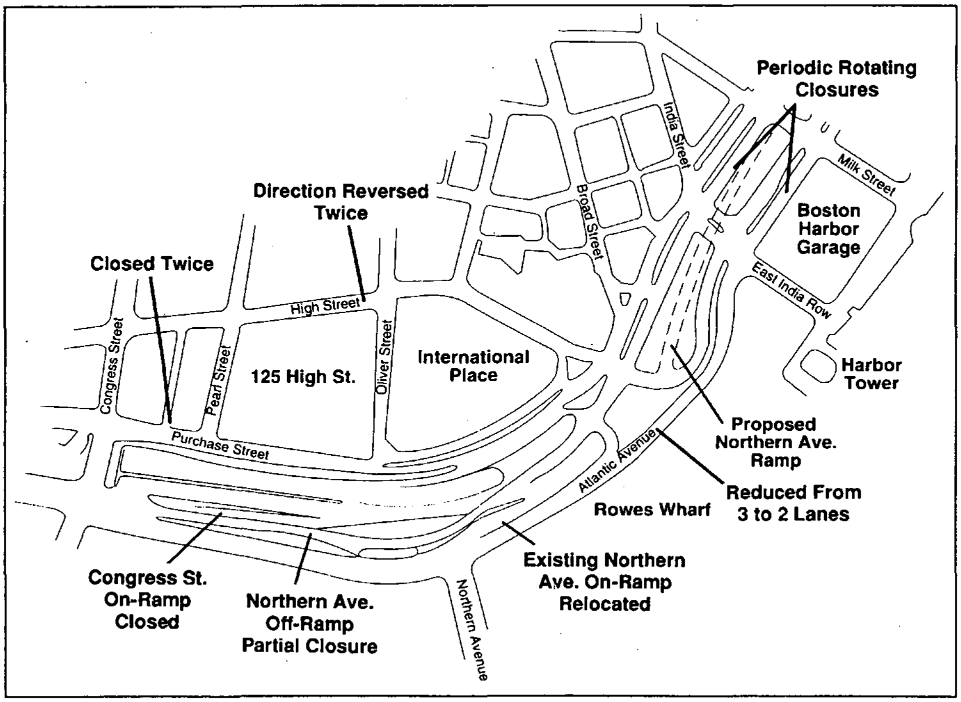


FIGURE 2 Selected major traffic impacts in the financial district.

• Elimination of a major branch of a northbound off-ramp (the Northern Avenue off-ramp). This ramp has a total p.m. peak hour volume of 2,000 vehicles, with 1,500 using the eliminated branch.

• Reconfiguration of the surface street pattern along the downtown waterfront. Today, there are two parallel two-way roadways (Atlantic Avenue and the Surface Artery) with a combined capacity of 10 lanes on average plus parking lanes. The revised condition will create a single one-way pair with a combined capacity of six to eight lanes and no parking.

• Relocations and capacity reductions on several major arterial routes carrying regional traffic flows into the city from the north and south.

• Closure of a major southbound surface arterial in the financial district with traffic diverted to an underused parallel roadway in combination with peak period parking restrictions.

DEVELOPMENT OF TRAFFIC MANAGEMENT PLANS

It is likely that no highway project in the United States has been subjected to as extensive an analysis of traffic operations during construction as has the CA/T Project. This process began during the preparation of the Supplemental Final Environmental Impact Statement (SFEIS), which received federal approval in 1991. The SFEIS described a proposed construction sequence based on 25 percent preliminary design plans. All traffic detours required to implement this construction sequence were described in detail and subjected to manual traffic reassignments using existing volumes.

In addition, the environmental reviewing agencies [U.S. Environmental Protection Agency (EPA) and Massachusetts Department of Environmental Protection (DEP)] also required that a sample quantitative analysis of traffic operations during a construction "snapshot" be incorporated in the final document. The primary motivation for this requirement was concern about the potential air quality impacts of extensive construction-related traffic detours in the downtown area. Boston has for many years been in nonattainment status with federal Ambient Air Quality Standards (AAQS) for carbon monoxide (CO).

An analysis was completed for a period designated as "1994," during which time the mainline Central Artery tunnels would be under construction downtown before the planned early opening of the Third Harbor Tunnel. This scenario is believed to represent one of the likely worst cases for traffic management. Results of this analysis indicated that there would be major volume increases at three intersections as a result of the proposed closure of the Northern Avenue off-ramp from I-93 northbound and its replacement with a ramp several blocks to the south that is currently closed. The ramp to be closed carries a volume of 2,000 vehicles in both the a.m. and p.m. peak hours. The surface intersections near the reopened ramp could not handle the increased volume. As a result, these intersections would exceed the 8-hr concentration for CO.

Although project managers stressed that this was a preliminary finding based on 25 percent design, it served to heighten the concern of the oversight agencies that the project could not be constructed without significantly worsening traffic congestion, resulting in air quality degradation. In order to alleviate these concerns, MHD and FHWA entered into a Memorandum of Understanding (MOU) with the oversight agencies. This MOU provided for an ongoing analysis of the traffic and air quality implications of the construction staging plans. The agreement is administered by the interagency Construction Air Quality (CAQ) Committee, which meets quarterly.

In order to implement the MOU, the traffic forecasting capability of the project had to be expanded. In support of the SFEIS, forecasting models had been developed for the project's base year (1987), opening year (1998), and design year (2010). The construction year forecast for 1994 included in the SFEIS had been developed by simply assuming that traffic volumes would fall roughly halfway between those of the base year and opening year. Project design year traffic forecasts were based on parcel-by-parcel assumptions about growth in land use within the study area. The study area included all of Boston east of Massachusetts Avenue and small portions of several adjoining municipalities. Trip assignments were made to a detailed roadway network developed specifically for the project study area. A personal computer-based Tranplan network was used. Input from the larger regional network was provided to the project by CTPS.

The process used to develop the opening and design year forecasts for the SFEIS was replicated for the construction period. Three models were developed:

• 1992—Early utility relocation downtown,
• 1994—Mainline tunnel construction downtown before the Phase I opening of the Third Harbor Tunnel, and
• 1996—Mainline tunnel construction downtown after the Phase I opening of the Third Harbor Tunnel.

These models were initially based on the preliminary design plans for construction staging and traffic detours as presented in the SFEIS, with the intention of updating them as final design plans became available. An extensive data base management system, as shown in the sample in Figure 3, is used to administer the large number of link changes required for each model scenario.

Given the scale of the CA/T Project, final design is being awarded to more than 22 individual section design contractors (SDCs). Each SDC is responsible for the development and analysis of construction staging and traffic detour plans within

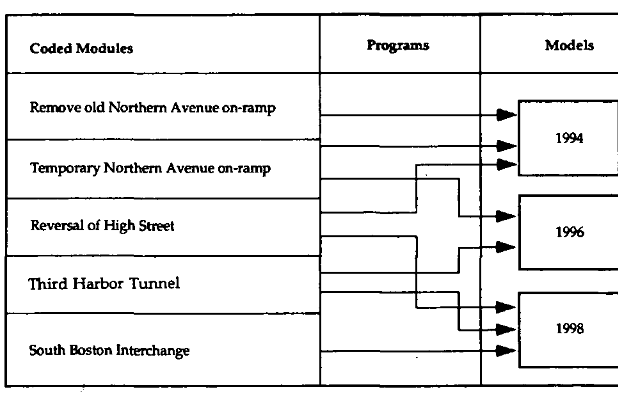


FIGURE 3 Data base management of construction scenarios.

its design area. The management consultant retained responsibility for ensuring consistency and continuity across section boundary lines. On the traffic side, this was accomplished through the use of the construction phase traffic forecasting models.

The process works as shown in Figure 4. When an SDC begins work, the management consultant provides it with the traffic forecasts for each construction scenario based on the preliminary design plans. As the SDC proceeds toward 75 percent final design, a series of working sessions are held with a management consultant team consisting of design engineers, construction planners, traffic engineers and planners, community liaisons, and environmental permitters. Major traffic staging concepts that differ from the preliminary design plans are tested via the forecasting models; the resulting volume estimates are used by the SDC's traffic engineers to analyze operating conditions. The traffic management plans for specific sections may be analyzed in the context of other construction activity performed simultaneously. At 75 percent design, the SDC's plans are submitted to MHD and the Boston Transportation Department (BTD) for review. After resolution of comments the plans are reviewed by community groups, major abutters, and other public agencies. Changes are then incorporated into the 100 percent design plans, which serve as the basis for the plans, specifications, and estimates (PS&E) that define the bid package for the construction contractors.

At the 75 percent design stage, the management consultant revises the traffic forecasting model to reflect the changes from preliminary design recommended by the SDCs. The downtown area was divided into three separate utility design contracts. Each SDC was responsible for analyzing traffic impacts within its design area. By creating a forecasting model based on the three SDC design plans, the management consultant was able to comprehensively examine traffic operations throughout downtown, assuming that all of the utility relocation work occurred simultaneously (a worst case assumption). The resulting traffic forecasts then served as the basis for an analysis of CO concentrations as per the air quality MOU. A similar process is now under way for the analysis of mainline construction. The intersections analyzed as part of this process and the three utility contracts are shown in Figure 5. Only the intersection at State Street and Atlantic Avenue (#6) showed a significant degradation in level of service (LOS)—from C to E. This is a major intersection that regulates the movement of surface traffic. The degradation was caused by the reduction in lane capacity on the surface arterial system and the proposed elimination of the Northern Avenue on-ramp to the Central Artery northbound (see Figure 2). The issues raised by the proposed elimination of this ramp are used as a case study of how the traffic forecasting process resulted in the modification of the proposed traffic management plan.

CASE STUDY: NORTHERN AVENUE ON-RAMP

The elimination of the Northern Avenue on-ramp was a controversial element in the traffic management plan for downtown utility relocation, although it had been included in the preliminary design plan as presented in the SFEIS. The ramp is in the path of the new utility corridor and future slurry wall of the tunnel box. In addition, it juts out into the adjacent surface street (Atlantic Avenue), making it impossible to maintain sufficient surface capacity while performing the required construction.

Opposition to the ramp removal was expressed by BTD, interests along adjacent surface streets in the downtown area, and trucking interests associated with the seafood industry in nearby South Boston. Because this part of the utility relocation work was located within the boundary of the former tidelands of the Commonwealth of Massachusetts, a waterways license was required under Chapter 91 of the Massachusetts General Laws. Chapter 91 imposes stringent public-purpose requirements on nonwater-dependent activities on the former tidelands and gives special standing to such water-dependent users as seafood wholesalers.

The SDC traffic management plan provided for three alternate routes to replace the ramp. Traffic could detour back to an on-ramp one block to the south at Congress Street via two routes. The combined volume of the two existing on-ramps at Northern Avenue and Congress Street is approximately 2,000 vehicles in the p.m. peak hour. By making minor improvements to the Congress Street ramp so that it would have increased storage capacity, it could theoretically accommodate this volume. In addition, the SDC assumed that some

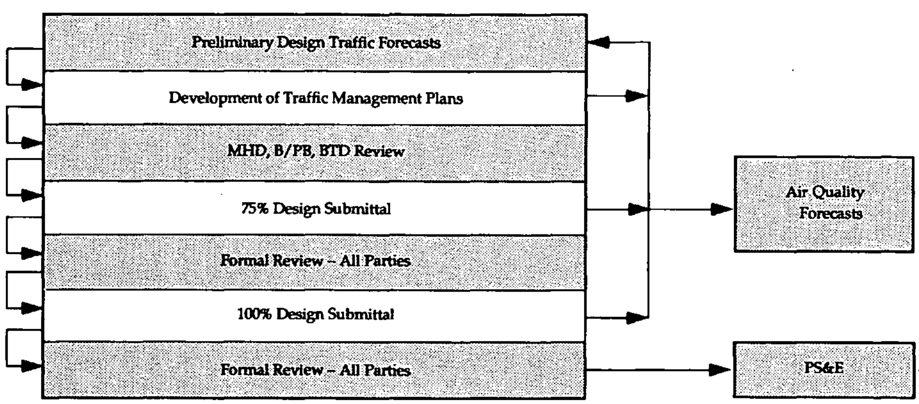


FIGURE 4 Development of traffic management plans.

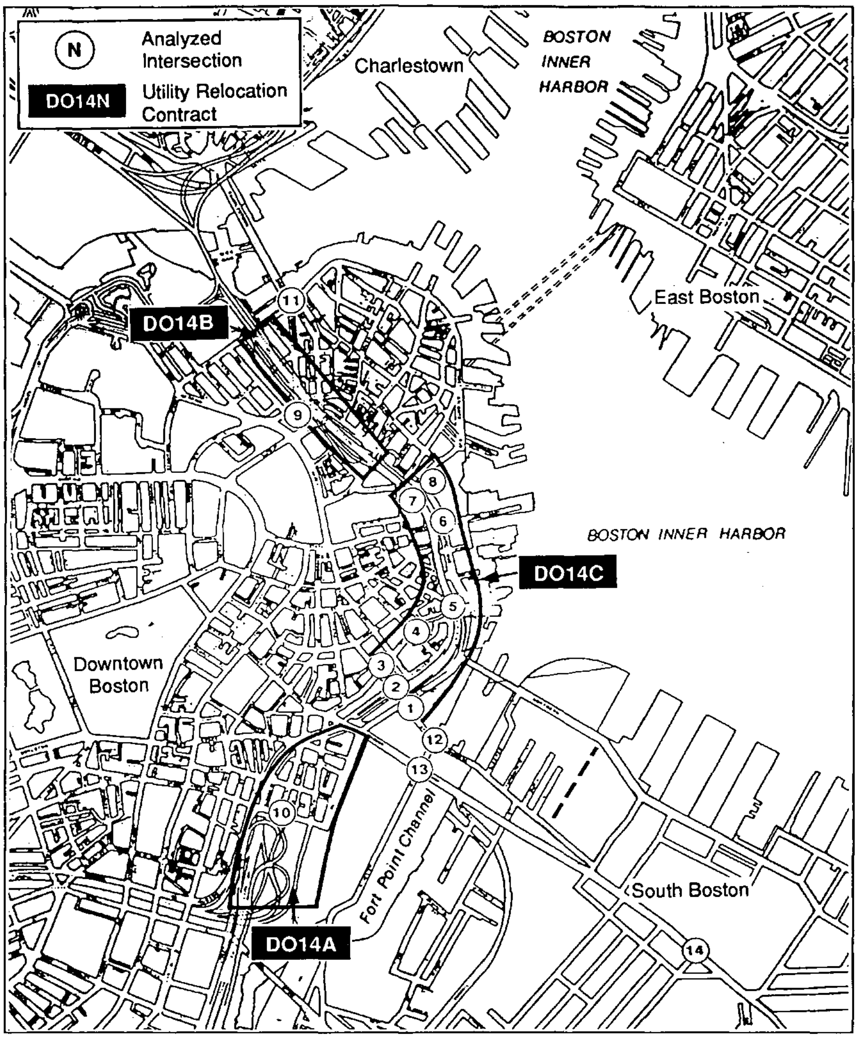


FIGURE 5 Downtown utility relocation contracts and analyzed intersections.

trips would proceed north on surface streets instead of accessing the Central Artery in this area.

In developing this plan, the SDC manually assigned approximately 140 peak hour trips to one of the detour routes. This assumption was not tested in the traffic forecasting model. When the model was later updated on the basis of the 75 percent design plans, it assigned no trips to this route. This was intuitively correct because it is unlikely that Boston drivers would travel south within the downtown area to access the congested northbound Central Artery instead of seeking alternate surface routes to the north. As a result of this experience, the process of model testing SDC assumptions before 75 percent design was initiated.

BTD proposed that the ramp be replaced approximately one block to the north, as shown in Figure 2. The new ramp could be constructed off-road in a median area and was out of the way of the planned utility relocations. At the same time, the SDC designing the mainline tunnel section in this area rejected the preliminary design plan calling for the elimination of the Northern Avenue off-ramp. This was the element that had been tested during the SFEIS and was found to cause traffic and air quality problems. Instead, the SDC proposed that the off-ramp be reconstructed in the space occupied by the Congress Street on-ramp and that the on-ramp be eliminated. The location of the future slurry wall precluded maintaining both ramps. Eliminating the Congress Street on-ramp required, however, that a Northern Avenue on-ramp move be maintained.

As a result of the convergence of these two events—opposition to the removal of the Northern Avenue on-ramp and the desire to retain the Northern Avenue off-ramp—MHD agreed to pursue the replacement on-ramp. As with most policy choices on the project, this decision produced its own negative reactions. It was opposed by residents of Harbor Towers, an upscale, 2,000-resident condominium complex partially fronting on the proposed new ramp. Also, the final designer objected to the design of the ramp because its interface with the Central Artery could not be made to conform to AASHTO standards. Because the Central Artery predates AASHTO standards, no ramp on the road conforms to them. FHWA was willing to grant a design waiver as a temporary construction measure. Although many temporary ramps will be constructed as part of the CA/T project, this is the only case in which a new mainline interface was required because the location of the ramp was changed.

The traffic forecasting model was modified to test the results of adding the replacement ramp. The project team developed the capability to use the geographic information system software ArcInfo in conjunction with Tranplan to more graphically display the results of a particular assignment. This was a useful tool in both evaluating the intuitive correctness of an assignment and displaying the results in a manner that the public could understand.

Inclusion of a replacement on-ramp caused volume along Atlantic Avenue to decrease by around 200 vehicles in the p.m. peak hour because drivers chose to access the Central Artery via the relocated ramp. This would result in an improvement in traffic operations to LOS D at the critical intersection #6 (State Street and Atlantic Avenue). Although this still represents a degradation from the existing LOS C due to reduction in arterial capacity, it is significantly better than the previously forecast LOS E.

AIR QUALITY ANALYSIS

In addition to traffic operations, CO concentrations were also forecast throughout the downtown construction area for the traffic management plans with and without the replacement on-ramp. ArcInfo was also used to display these findings. Under both the build and no-build conditions, four intersections were predicted to exceed the AAQS for CO of 9 ppm for 8 hr. However, due to changes in traffic flow, the location of several of the intersections in exceedance was predicted to change.

Two intersections affected negatively were State and Atlantic (#6) and Congress and Atlantic (#1). Both were affected by the removal of the Northern Avenue on-ramp—State and Atlantic by the increase in northbound volume on Atlantic Avenue, and Congress and Atlantic by the diversion of trips to the Congress Street on-ramp. The addition of the replacement on-ramp would slightly reduce ambient CO levels at both intersections in comparison to the build scenario without the on-ramp, although they would remain above 9 ppm.

Actual CO concentrations were monitored at the State and Atlantic intersection (and one other) before the start of construction to establish baseline conditions. This was a joint program implemented by the project team and EPA and DEP. Monitored concentrations were less than half the level of that predicted by the no-build models, with values in the range of 4 to 5 ppm instead of more than 9 ppm. This tended to confirm that the modeling process (on both the traffic and air quality sides) indeed simulated worst case scenarios.

Although the modeling process provided a certain amount of comfort to the process participants that real conditions were apt to be better than forecast conditions, there was also some concern about the apparent inaccuracy of the process. The primary factors causing this disparity were the regional recessionary conditions that had depressed projected increases in traffic volume and the requirement to base CO forecasts on worst case meteorological conditions. In particular, the use of cold and calm winter days to forecast CO concentrations in Boston is somewhat unrealistic because of the rarity of sustained calm wind conditions, particularly in cold weather.

However, these findings were generally acceptable to the CAQ Committee, which agreed that the project should proceed with the proposed traffic management plan.

ANALYSIS OF TRANSIT MITIGATION PROGRAMS

A major theme throughout the planning effort for the CA/T Project was that public transportation should continue to play a major role in regional transportation. This applied to the project construction period, when public transit would be expected to attract additional riders from the highway system, and after completion of the project to prevent the new highway system from being overwhelmed by new trip attractions.

The Massachusetts Bay Transportation Authority (MBTA) operates or contracts for the operation of bus, rail, and water transportation services in Boston and surrounding communities. MBTA has aggressively upgraded and expanded services during the past 2 decades and continues to do so. These projects have been justified on their own merits but have also been cited in the planning documents of the CA/T Project for their potential benefits in reducing highway tripmaking during and after CA/T construction.

MHD officials wanted to more directly demonstrate a link between transit projects and the mitigation of potential traffic congestion caused by CA/T construction. It contracted with MBTA to conduct this analysis with technical direction provided by the CA/T project. This study is being conducted by the firms of Vanasse Hangen Brustlin and Multisystems, with support from CTPS.

In Phase I of the study, a list of some 60 possible transit mitigation measures was developed. These measures were qualitatively evaluated on the basis of six criteria; about 20 measures were eliminated through an interagency review process. The remaining measures were then packaged into six alternative concepts. The evaluation criteria were as follows:

- Compatibility with existing and planned services,
- Environmental impact,
- Feasibility of implementation in the short term,
- Subsidy required,
- Impact on traffic operations, and
- Cost-effectiveness (subsidy versus impact).

The evaluation packages are as follows:

- Demand management with limited service expansion,
- Improved express bus service (with and without HOV facilities),
- Improved downtown bus operations,
- Fringe park-and-ride facilities,
- Rail and water transportation improvements, and
- Hybrid—the best elements from each category.

These measures are primarily short-term operational actions that MBTA did not plan to implement on its own within the time frame necessary to mitigate CA/T construction impacts. Because the traffic analysis for the 1992–1993 utility relocation work did not demonstrate a need for major transit mitigation actions, the focus of the study was on the early stages of mainline tunnel construction in the downtown area, scheduled for 1994.

Using the 1994 preliminary design traffic forecasts, the consultants identified potential traffic problem areas and mitigation actions that could divert automobile trips to transit. A process was established to quantitatively analyze the most promising measures. CTPS, using its regional modeling capability, is analyzing the potential ridership attractiveness of each package of transit alternatives. The results of this analysis will be used by the CA/T traffic forecasting group to reduce the number of automobile trips in the CA/T study area consistent with the ridership forecast for each set of alternatives. Traffic operations at key intersections will then be compared; the standard construction scenario with no transit mitigation will be compared with construction with each of the possible transit mitigation scenarios.

The objective of this analysis is to quantitatively determine the most effective transit mitigation strategies and the extent to which these strategies will be useful in reducing traffic congestion.

CONCLUSION

The CA/T Project has extensively applied traffic forecasting capability to the development of traffic management plans for project construction. The level of analysis undertaken for the construction period is probably unprecedented in projects of this type and is more typical of the level of analysis applied to final build conditions in most projects. This iterative process of design and traffic analysis has led to a number of significant changes in construction staging and traffic management strategies. The final test of the effectiveness of this approach will become apparent during the coming decade of CA/T construction.

ACKNOWLEDGMENTS

The author would like to thank Peter Shields and Glen Berkowitz of MHD for their leadership in the development of mitigation strategies for the construction of the CA/T Project and Tom Rossi, Elizabeth Harper and the entire Cambridge Systematics CA/T staff for the technical expertise and dedication they have brought to the development of the project's traffic forecasting capability.

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

Demonstration of the Characteristics of the TRANSYT-7F Model as Modified To Represent Near-Side Transit Stops

MARIA ALICE PRUDENCIO JACQUES AND SAM YAGAR

The TRANSYT-7F model has been altered to represent the common case of near-side transit stops in shared lanes. This paper demonstrates the operation and principal characteristics of the new simulation model by describing its application to a sample network. It is seen that delays and stops can be reduced considerably when signal timings reflect the transit loading operation appropriately. Some rules of thumb for timing of traffic signals in response to the arrival of transit vehicles are developed through the new model and discussed in the paper. It is seen that some accepted intuitive responses to transit arrivals are wrong.

The intrinsic characteristics of the TRANSYT model (*1*) and the TRANSYT/5 extension, commonly known as BUS-TRANSYT (*2,3*), do not represent the situation in which the transit vehicle holds up other traffic during its passenger loading or unloading operations, referred herein as loading. Therefore, the on-line near-side transit stop, which is common at signalized intersections in North America, cannot be represented properly.

TRANSIT-RELATED ENHANCEMENTS

To remedy this situation, a simulation supplement, compatible with fixed-time control models such as TRANSYT-7F, was developed to capture the real-time effect of the near-side transit stops on the other traffic (Jacques and Yagar, unpublished data).

This supplement was incorporated into TRANSYT-7F to produce a deterministic simulation model that simulates the traffic at each time increment (step) until the whole simulation period (usually two cycles) is covered. The supplement makes the following changes or approximations, none of which should seriously compromise its realism and some of which improve its representation:

- Instead of relying on a single signal cycle for all cycles, with or without transit, as previous versions of TRANSYT did, this supplemented model considers an appropriate mix and sequence of nontransit cycles (NTCs) and transit cycles (TCs).
- The number of TCs and NTCs is assumed constant for the considered time period.
- Any sequence of (TC) and (NTC) can be approximated in terms of the following three sets of two-cycle sequences: (TC-NTC), (TC-TC), and (NTC-NTC), which do not spill over to one another.
- The different two-cycle sequences are modeled by means of independent parallel network structures.
- The hourly traffic volumes are allocated among the links of the parallel network structures on the basis of the percentage of the total cycles they represent, with appropriate saturation flow rates.
- The transit vehicles arrive at external links once per TC and at the same point in time in each TC.
- The transit vehicles are not dispersed (as per platoon dispersion).
- The transit link, and the links sharing the lane with it, move only in protected phases; there is no gap seeking.
- The transit vehicle may start loading during either the green or red phase if it reaches the designated stop location (green phase) or a position sufficiently close to the stop location while in queue (red phase).
- The approach saturation flow can be set to zero (for the case of total blockage of the approach) or to any other appropriate value during the load and unload operation.

The model's assumptions and characteristics, as well its implementation into the TRANSYT-7F program, are described elsewhere (Jacques and Yagar, unpublished data).

CHARACTERISTICS OF THE ENHANCED TRANSYT MODEL

Although transit operations do not allow for an equilibrium cycle operation as is assumed by the TRANSYT model, it is feasible to reasonably represent the operation by an equivalent mixture of equilibrium two-cycle "supercycles," of the type shown in Figure 1.

Figure 1 shows the TRANSYT flow profiles leaving an intersection for a two-cycle sequence, represented by 120 TRANSYT steps (e.g., of 1-sec duration) during which a transit vehicle arrives during the first red phase and loads during most of the next green phase. Although the new model may allow a queued transit vehicle to start loading at any specified position that is sufficiently close to the designated loading position, in this case it is assumed that it may load only after it has reached the front of the queue. In the upper diagram of Figure 1(*a*), there are only small slivers of time

Department of Civil Engineering, University of Waterloo, 200 University Avenue West, Waterloo, Ontario, Canada N2L 3G1.

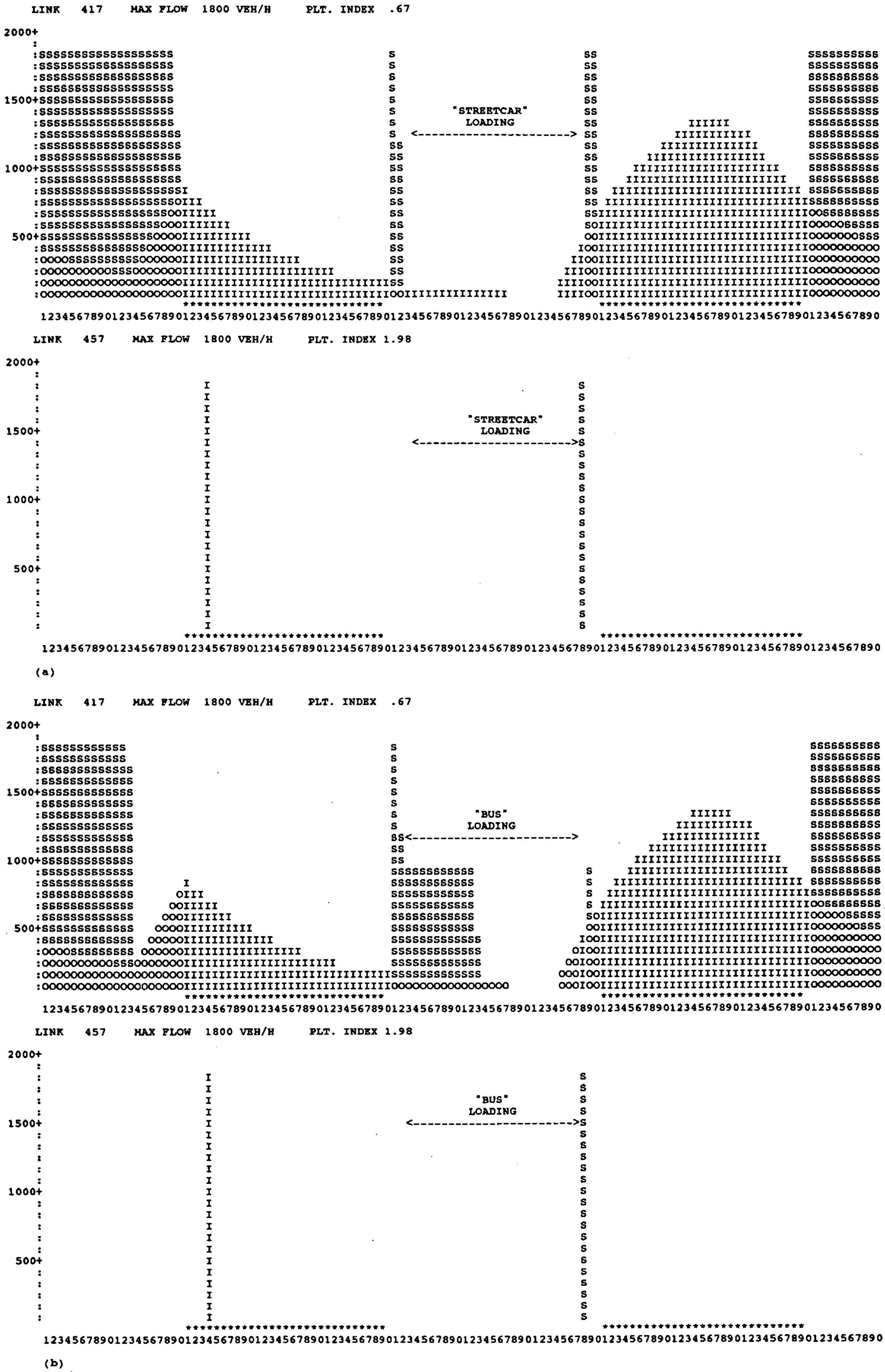


FIGURE 1 Adjustment of service capacities for (*a*) full or (*b*) partial blockage caused by transit loading.

at the beginning and end of this first green phase that can serve vehicles. Otherwise the saturation flow is zero in the 26-step period denoted as "streetcar loading," during which the transit vehicle effectively blocks the whole approach, as would be the case with a streetcar loading in the median lane from the sidewalk. In Figure 1(*b*) the saturation flow is merely reduced during the loading time because the transit loading operation blocks only part of the approach (such as a bus loading in one lane while traffic passes in other lanes).

The symbols used in Figure 1 and other figures in this paper have the following standard TRANSYT meaning (*4*):

- For the flow profile, I = arrivals that queue; S = departures from queue, either at the saturation flow rate or maximum flow rate; and O = arrivals and departures during green phase; when below S's or I's, these arrivals join the back of the queue.
- For the horizontal axis, (blank) = protected green intervals; * = red intervals; and (numbers) = the time scale in units of steps.

In Figure 1 (and Figures 4–9, which appear later in the paper), the actual loading times for the transit vehicles are specified to orient the reader.

The lower portion of Figure 1(*a*) represents a streetcar (denoted by the spike of I's) (a) arriving early in the red phase; (b) reaching the front of the queue and starting to load early in the green phase; and (c) finishing the passenger loading late in that green phase and departing (spike of S's).

There is no streetcar arrival during the second phase, which wraps around to the left side of the diagram in TRANSYT's representation.

The upper portion of Figure 1(*a*) (starting at the left side) shows the following:

- A queue being served at the saturation flow of about 1,800 vph of green (S's and O's) for virtually the whole green phase,
- Arrivals queuing during the red phase (I's),
- A short period of queue service at saturation flow (S's) until the streetcar reaches the loading spot and halts the flow of traffic for a period of time ("streetcar loading") equal to the loading time,
- Another short period of queue service before the signal turns red,
- A red phase (I's),
- A green phase serving at saturation flow (S's) and wrapping back around to the left side.

This example shows a case in which the green phase with the streetcar is mostly wasted because of the streetcar loading, causing the green without the streetcar to be virtually fully saturated. The only difference between the bus example in Figure 1(*b*) and the previous streetcar example is the saturation flow during the loading time. In the bus case a saturation flow of 900 vph of green can be maintained during the loading procedure (to represent blockage of only one of two traveled lanes, for example). Because this is enough capacity to serve the queue, there is no leftover queue at the end of that green phase. Therefore, the next green phase (which wraps around to the left side) is far less saturated and can finish serving its queue with about one-fourth of the green time left.

Figure 1 shows that the transit-enhanced version of TRANSYT-7F can reasonably represent the noncyclical transit effects in terms of cyclical multicycle "supercycles" and shows this in terms of typical streetcar–no streetcar and bus–no bus sequences. This was done to orient the reader to the new form of transit-enhanced flow profiles that can be produced by the TRANSYT model.

A corridor operation will be modeled in the next section to demonstrate (a) TRANSYT's flow profiles in a network context, (b) the characteristics of transit-responsive signal timings, and (c) benefits in terms of performance index that might be achieved with the use of an appropriate transit modeling procedure within TRANSYT.

EXAMPLE APPLICATION OF THE NEW TRANSYT MODEL

The operation of the new model is illustrated using the four-signal one-way arterial shown in Figure 2. This sample arterial has been given the following characteristics for the following reasons:

- Only one-way traffic was used to allow the optimization to easily achieve the characteristics that a TRANSYT solution would tend toward in cases in which it can account for the interference of transit loading with flow. Although two-way flow could have been simulated and optimized by the model, it would have needlessly complicated the demonstration objectives of this paper.
- Low transit speeds (20 km/hr) and no platoon dispersion were used for the transit vehicles, in contrast to higher travel speeds (40 km/hr) and platoon dispersion for private vehicles. This was combined with large intersection spacings to simulate breaking of the platoons behind transit vehicles and observe TRANSYT's reactions in terms of signal timings.

Data

- Streetcar volume = 45 vph,
- Car volume = 1,000 vph,

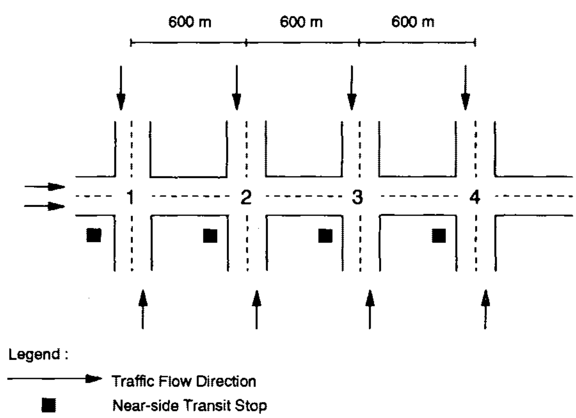


FIGURE 2 One-way street with near-side streetcar stops and no refuge island for passengers.

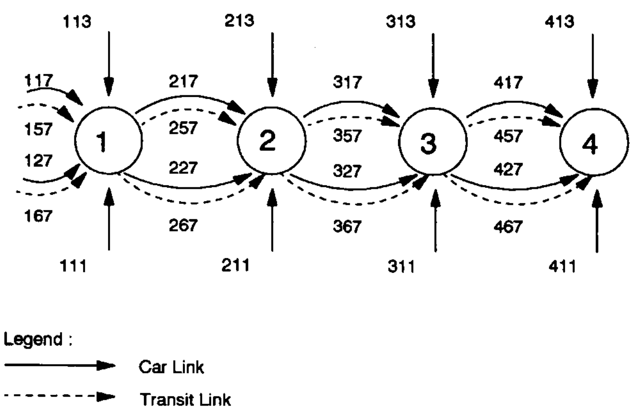
- Saturation flow (two lanes) = 3,600 vphg,
- Cycle length = 60 sec,
- Average car speed = 40 km/hr (25 mph),
- Average streetcar speed = 20 km/hr (12.5 mph), and
- Average dwell time for all stops = 25 sec.

Consistent with the procedure of the new transit-enhanced model described elsewhere (*4*) and the data just presented, the standard 1-hr TRANSYT study period is considered to consist of 45 TCs and 15 NTCs. The type of cycle occurring with the smaller frequency (15 NTCs in this case) is combined with an equal number, 15, of TCs to form 15 double cycles of the (TC-NTC) type. This leaves 15 (TC-TC) cycles in the parallel network. An example of a (TC-NTC) type double-cycle has already been shown by the case shown in Figure 1.

The link-node representation for the parallel networks required to simulate the above (TC-NTC) and (TC-TC) cycles using the modified TRANSYT model is shown in Figure 3. The input data for the modified TRANSYT-7F simulation run are presented in Table 1.

These data are similar to those required by the conventional TRANSYT-7F (*4*), except for the inclusion of some "optional" cards (Card Type 3, Card Type 30, and Card Type 32), which indicate that the new simulation model is being selected, and provide the parameters for the use of this new model. Details on the new model input data cards are provided elsewhere (Jacques and Yagar, unpublished data).

In Table 1, the first column of data indicates the card number. Card Type 30 shows the identifying numbers for the links that form the parallel network structure. Consider, for example, the first Type 30 card. According to this card, the links 117, 127, 157, and 167 form a parallel network structure. Links 117 and 157 operate in the sequence (TC-NTC), whereas links 127 and 167 operate in the sequence (TC-TC). This is specified by Card Type 32, where the second field indicates how the transit links have to be simulated: a 3 means that the transit link is to be simulated in the sequence (TC-NTC), and a 4 means that transit link is to be simulated according to the sequence (TC-TC). Because each type of sequence represents exactly half of the 1-hr study period (15 of 30 double cycles), the total nontransit flow in the approach (1,000 vph) is split equally between links 117 and 127; the total saturation flow is split in the same way, as can be observed from the two first Type 28 cards used for Node 1. Because links 117 and 157, and 127 and 167 are, respectively, shared stopline links (see Card Type 7), no saturation flow rate is specified for transit links 157 and 167.



Shared Stopline Links		Sequence Type
117	157	[TC-NTC]
127	167	[TC-TC]
217	257	[TC-NTC]
227	267	[TC-TC]
317	357	[TC-NTC]
327	367	[TC-TC]
417	457	[TC-NTC]
427	467	[TC-TC]

FIGURE 3 Node-link representation.

Results of Simulation and Optimization Runs

The total system results for both simulation and optimization runs are presented in Table 2, which indicates a significant improvement in performance index for both transit and cars when the transit-enhanced TRANSYT optimizes the signal timings (splits and offsets). Although this is encouraging, it might be expected, especially for a one-way street.

The results are examined next by intersection and discussed in detail for Intersection 2.

Intersection 1

Intersection 1 may be considered an upstream dummy intersection used for the input of flows at a fixed rate, as specified by TRANSYT. In contrast, transit vehicles are represented as discrete vehicles in the transit-enhanced TRANSYT, and are inserted onto the transit line at consistent times in TRANSYT cycles. Although it will be seen that transit vehicles will quickly tend to converge to a pattern of fixed arrival times at downstream signals, it is nevertheless best to insert them into the network at optimal times and not risk messing up one or more intersections on the network boundary.

Operating agencies may select the times within the signal cycle at which to release streetcars at the beginning of the line. This may be simulated using a dummy intersection. Various transit entry times may be tried within the cycle and TRANSYT run for each to determine the best insertion times for the particular network and transit line. In this case the streetcars are released from Intersection 1 at the beginning of the green phase, causing them to arrive at Intersection 2 (on links 257 and 267) 16 sec before the end of the green phase.

Intersection 2

Figures 4(*a*) and 5(*a*) show how the streetcars hold up the traffic while loading and then leave precisely at the beginning of the next green phase. In optimizing, TRANSYT shifted the phases by 10 sec, as shown in Figures 4(*b*) and 5(*b*), so that the lost green time due to loading was reduced to 6 sec. The authors note the following, however:

- The streetcar still leaves the intersection at precisely the beginning of the next green phase; and

TABLE 1 Input Data for TRANSYT-7F

```
     1    60    60           1     1     0     0     1    10     0    60     0     0     1
     3     2                      25
     7   117   157
     7   127   167
     7   217   257
     7   227   267
     7   317   357
     7   327   367
     7   417   457
     7   427   467
    10     1
*
*  NODE  1
*
    12     1     0     1    30     0     1    28     0     1
    21     1     1     1     2     3    31   117   157   127   167
    22     1     4     4     5     6    29   111   113
    28   117     0  1800   500
    28   127     0  1800   500
    28   157     0          15                    2025
    28   167     0          30                    2025
    28   111     0  1800   200
    28   113     0  1800   200
*
*  NODE  2
*
    12     2    40     1    30     0     1    28     0     1
    21     2     1     1     2     3    31   217   227   257   267
    22     2     4     4     5     6    29   211   213
    28   217   600  1800   500         117   500    40
    28   227   600  1800   500         127   500    40
    28   257   600          15         157    15  2025
    28   267   600          30         167    30  2025
    28   211     0  1800   200
    28   213     0  1800   200
*
*  NODE 3
*
    12     3    30     1    30     0     1    28     0     1
    21     3     1     1     2     3    31   317   327   357   367
    22     3     4     4     5     6    29   311   313
    28   317   600  1800   500         217   500    40
    28   327   600  1800   500         227   500    40
    28   357   600          15         257    15  2025
    28   367   600          30         267    30  2025
    28   311     0  1800   200
    28   313     0  1800   200

*  NODE 4
*
    12     4    50     1    30     0     1    28     0     1
    21     4     1     1     2     3    31   417   427   457   467
    22     4     4     4     5     6    29   411   413
    28   417   600  1800   500         317   500    40
    28   427   600  1800   500         327   500    40
    28   457   600          15         357    15  2025
    28   467   600          30         367    30  2025
    28   411     0  1800   200
    28   413     0  1800   200
*
    30   117   127   157   167
    30   217   227   257   267
    30   317   327   357   367
    30   417   427   457   467
*
    32     3   157   257   357   457
    32     4   167   267   367   467
*
    40   117   157   127   167
    40   217   257   227   267
    40   317   357   327   367
    40   417   457   427   467
*
    50
    90
```

TABLE 2 Global Results of the Simulation and Optimization Runs

SIMULATION RUN

<SYSTEM WIDE TOTALS INCLUDING ALL LINKS>

TOTAL DISTANCE TRAVELED (VEH-KM/H)	TOTAL TRAVEL TIME (VEH-H/H)	TOTAL UNIFORM DELAY (VEH-H/H)	TOTAL RANDOM DELAY (VEH-H/H)	TOTAL DELAY (VEH-H/H)	AVERAGE DELAY (SEC/VEH)	TOTAL UNIFORM STOPS (VEH/H-%)	TOTAL FUEL CONSUM (LI/H)	OPERATING COST	PERFORMANCE INDEX	SPEED (KM/H)	
1881.00	114.66	40.38	25.04	65.42	40.74	4404.8(76%)	494.65	357.87	66.64	17.81	<TOTALS>
81.00	8.02	2.70	1.07	3.77	75.44	180.0(100%)	62.06	28.84	3.82	10.72	<BUSES>
1800.00	106.64	37.68	23.97	61.64	39.63	4224.8(75%)	432.59	329.03	62.82	18.35	<OTHER>

OPTIMIZATION RUN

<SYSTEM WIDE TOTALS INCLUDING ALL LINKS>

TOTAL DISTANCE TRAVELED (VEH-KM/H)	TOTAL TRAVEL TIME (VEH-H/H)	TOTAL UNIFORM DELAY (VEH-H/H)	TOTAL RANDOM DELAY (VEH-H/H)	TOTAL DELAY (VEH-H/H)	AVERAGE DELAY (SEC/VEH)	TOTAL UNIFORM STOPS (VEH/H-%)	TOTAL FUEL CONSUM (LI/H)	OPERATING COST	PERFORMANCE INDEX	SPEED (KM/H)	
1881.00	75.59	25.05	1.29	26.34	16.41	4034.8(70%)	371.54	289.61	27.47	28.26	<TOTALS>
81.00	6.01	1.71	.05	1.76	35.24	180.0(100%)	47.01	22.67	1.81	14.61	<BUSES>
1800.00	69.58	23.34	1.24	24.58	15.80	3854.8(69%)	324.53	266.95	25.65	29.50	<OTHER>

NOTE: PERFORMANCE INDEX IS DEFINED AS:

PI = DELAY + STOPS

- The lost time is reduced by 10 sec, effectively increasing the approach capacity and reducing delays to the streetcars.

It has been shown that TRANSYT tends to have the streetcars leave the intersection at the beginning of the green phase, thereby reducing delays and increasing capacities. This solution will tend to maximize capacity and is quite robust to variations in loading time.

Figures 6 and 7 show the flows into and out of Intersection 3, and Figures 8 and 9 show the flows into and out of Intersection 4.

The (*a*) parts of Figures 4 through 9 are those created from the input data of Table 1 (simulation run), whereas the (*b*) parts show the flow profiles corresponding to signal timings for the optimization run.

The optimization run alters the offsets in such a way that they tend to cause the transit load and unload operations to occur mainly during the red signal indication, resulting in savings in capacity. The amount of improvement varies from link to link. Figure 4(*a*) indicates that existing settings cause a loss of 16 sec of green, respectively, whereas the optimal settings reduce this loss to 6 sec, as shown in Figure 4(*b*) for the (TC-NTC) sequence at Intersection 2. For the (TC-TC) sequence, the lost green time for the existing timings [Figure 5(*a*)] is only 12 sec because the streetcar arrives to find a residual queue caused by a streetcar in the other half of the double cycle and must wait 4 sec to preempt that approach's capacity. It still has plenty of time to load before the next green phase and therefore leaves at the beginning of that next green phase.

Intersections 3 and 4

The optimization procedure produces even greater reductions in loss of green time at Intersection 3 (Figures 6 and 7) and Intersection 4 (Figures 8 and 9).

The following features of the new transit simulation model are observed from these figures. First, the transit vehicle arriving during the green starts its load and unload operations only when it reaches the stopline, after all vehicles queued ahead it have been dispatched [see the simulation runs of Figures 5(*a*), 6(*a*), and 7(*a*)]. Second, when the transit vehicle arrives during the red, if the number of cars queued ahead it is greater than the upper limit on the number which will still allow it to start its loading time (zero in this case), it cannot begin the load and unload operations until after the cars queued ahead of it have been dispatched during the next green [see Figures 8(*a*) and 9(*a*), simulation run]. This is the worst case because the transit vehicle is delayed at the intersection by both the red signal indication and the loading time. Figures 8(*b*) and 9(*b*) show how a proper coordination can eliminate this undesirable situation.

It also can be verified that when the network operates under the optimal signal settings, the combined effect of the red signal and loading time ensures that the results of the simu-

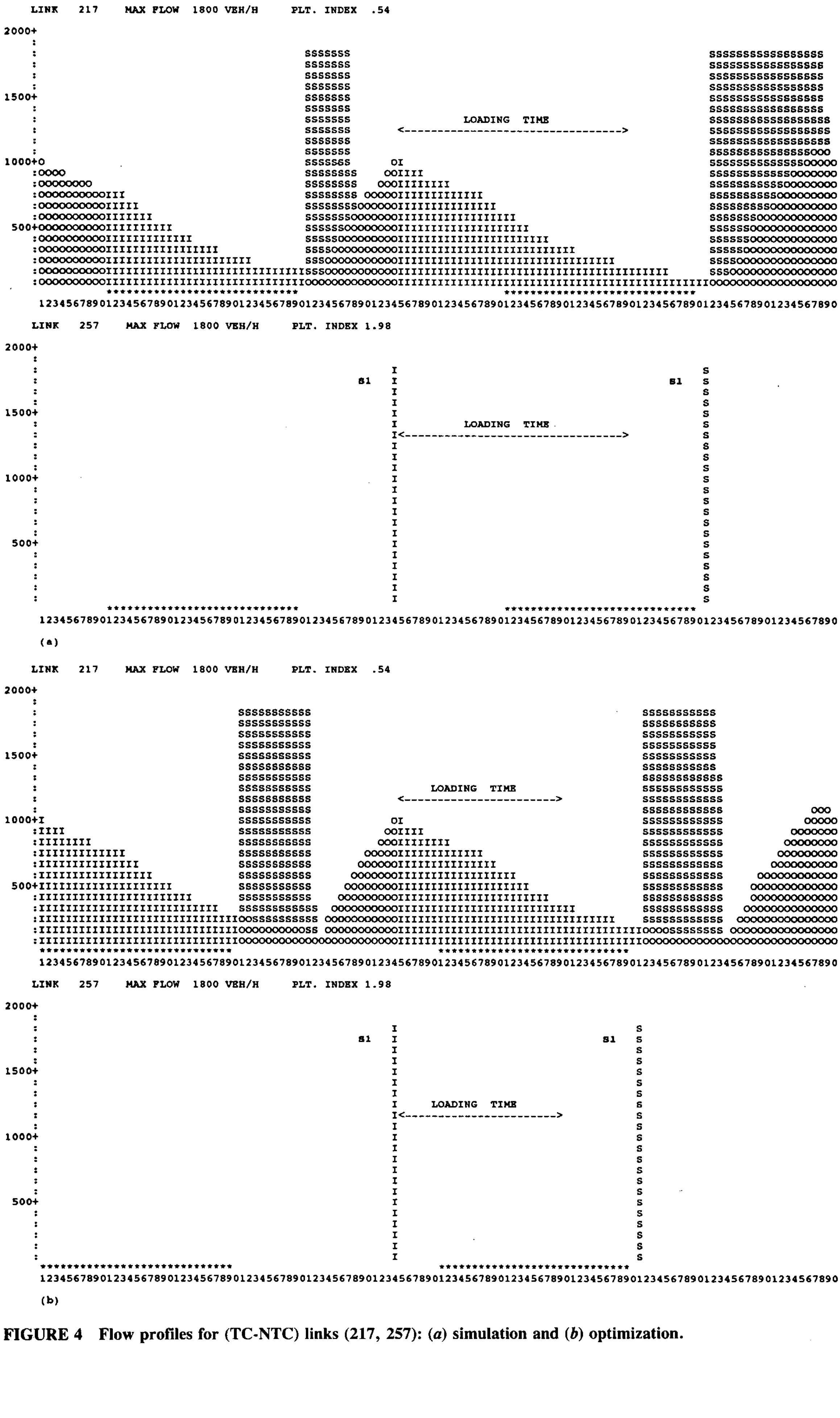


FIGURE 4 Flow profiles for (TC-NTC) links (217, 257): (*a*) simulation and (*b*) optimization.

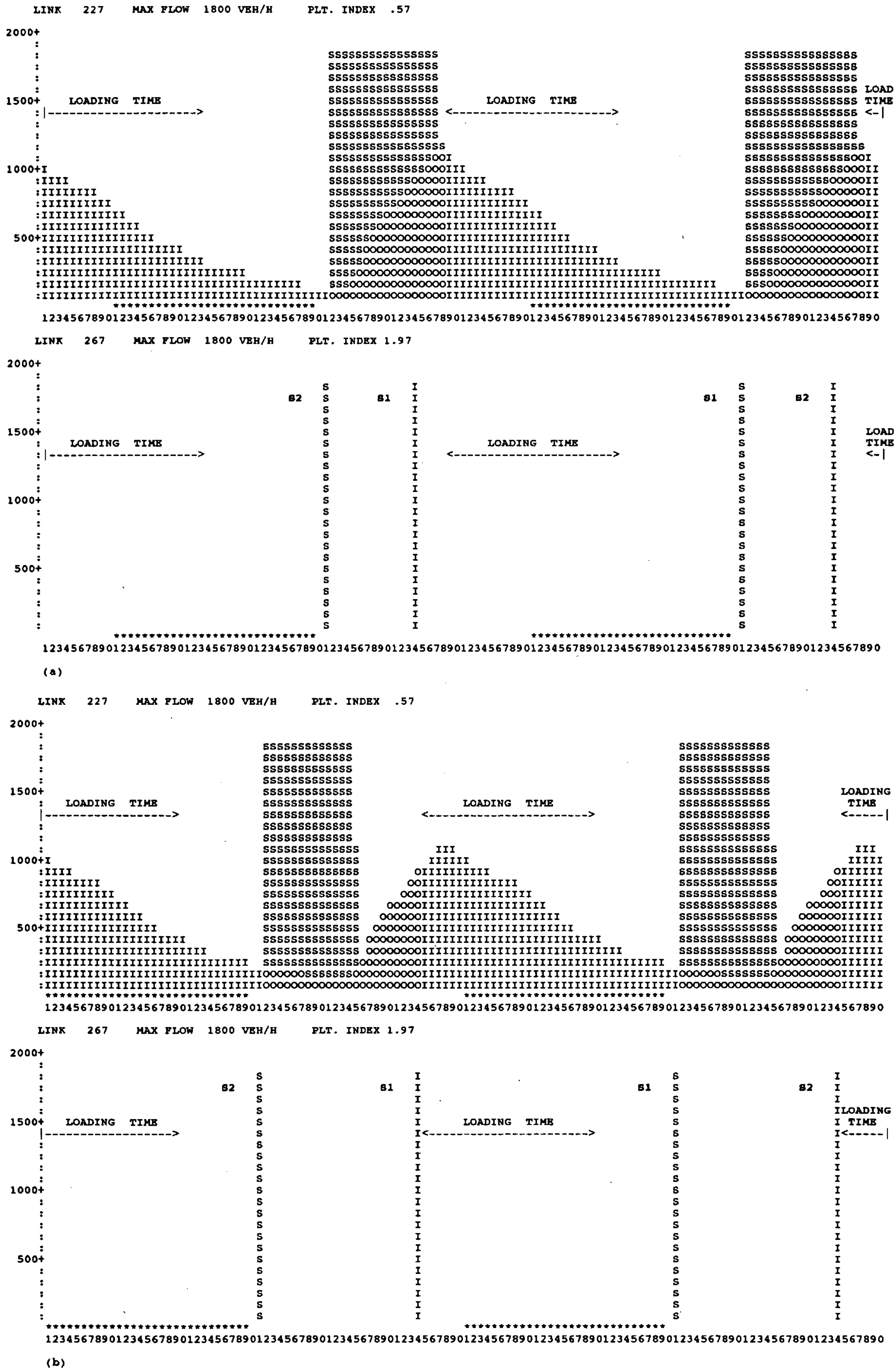


FIGURE 5 Flow profiles for (TC-TC) links (227, 267): (*a*) simulation and (*b*) optimization.

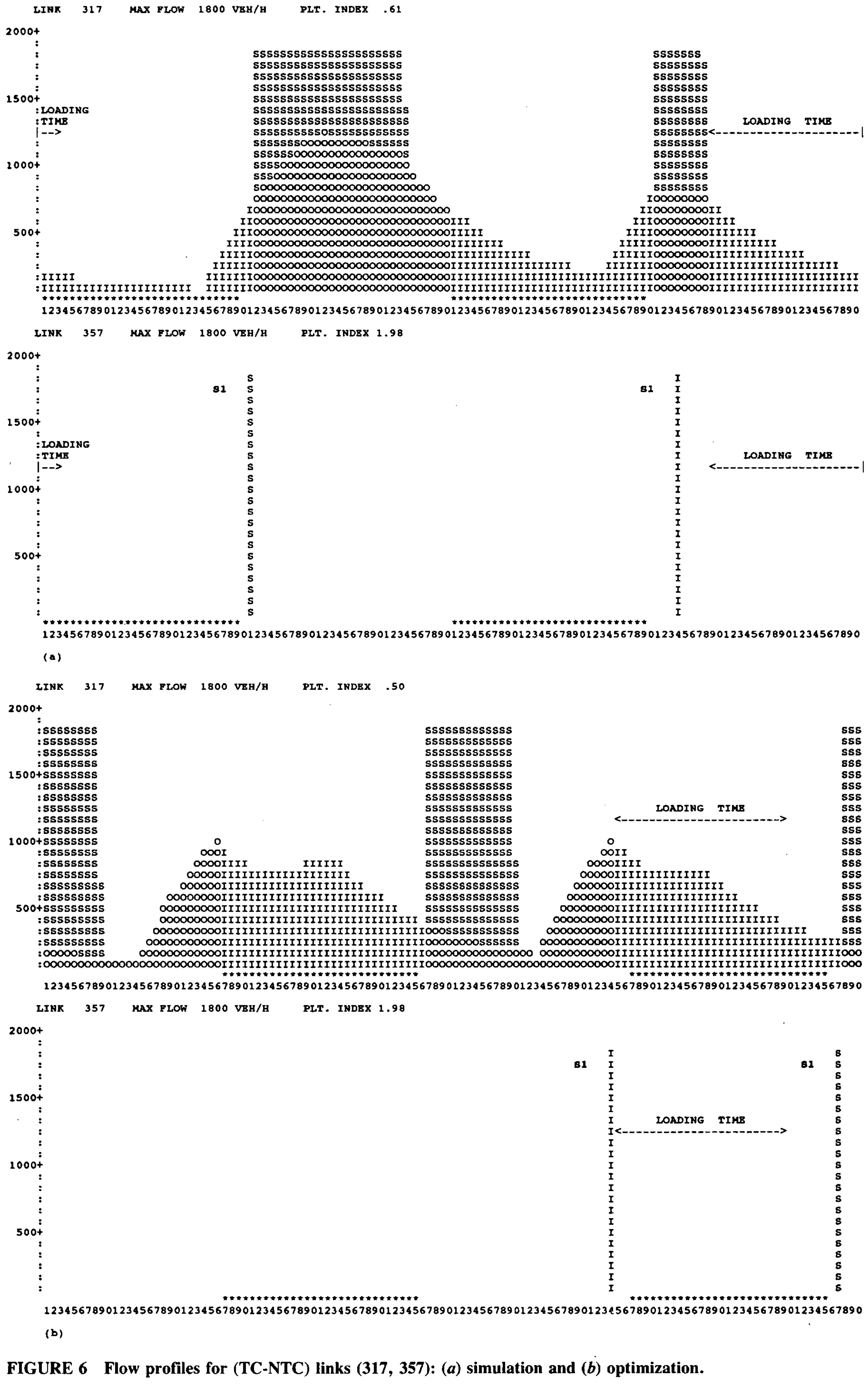


FIGURE 6 Flow profiles for (TC-NTC) links (317, 357): (*a*) simulation and (*b*) optimization.

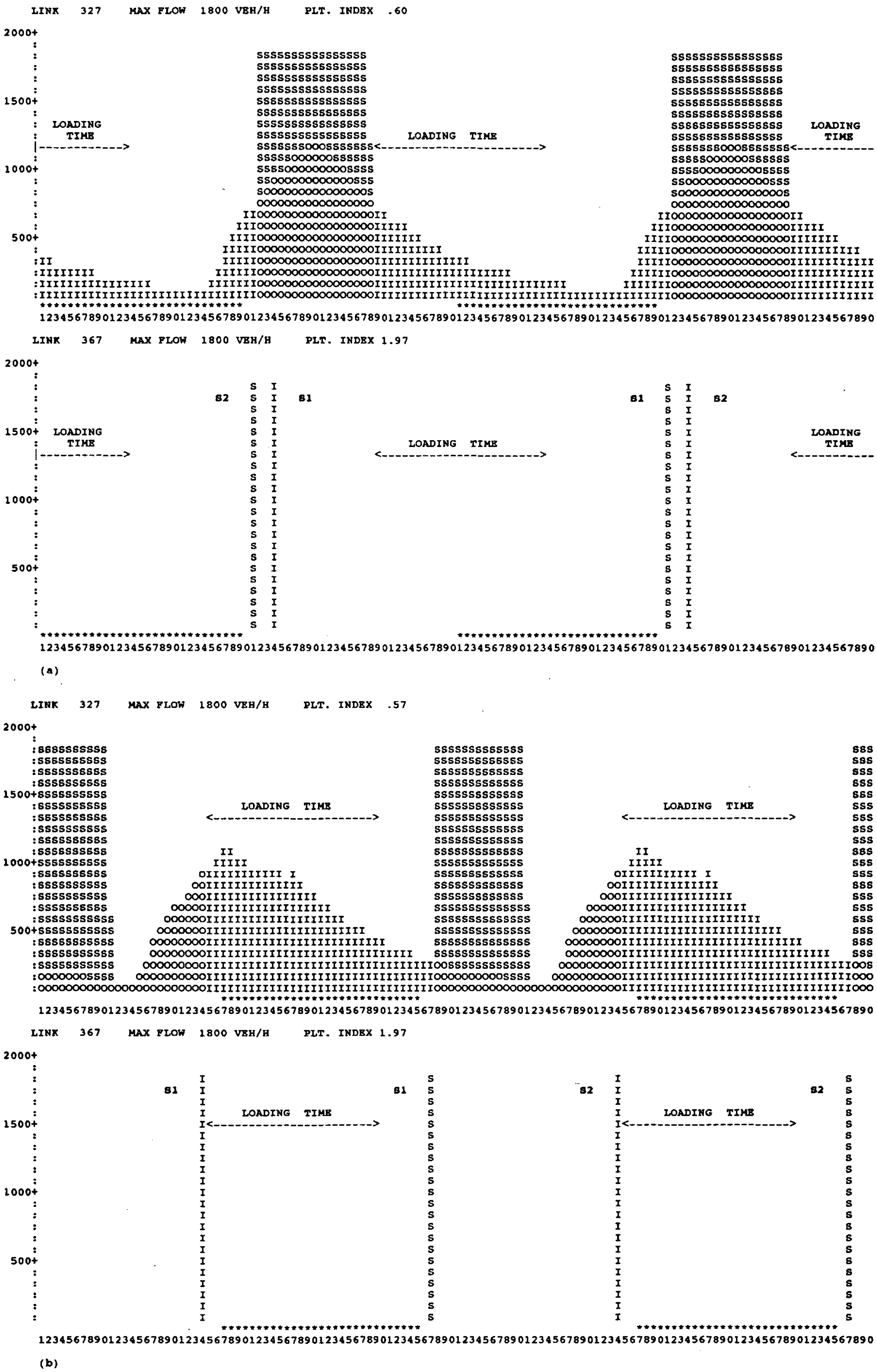


FIGURE 7 Flow profiles for (TC-TC) links (327, 367): (*a*) simulation and (*b*) optimization.

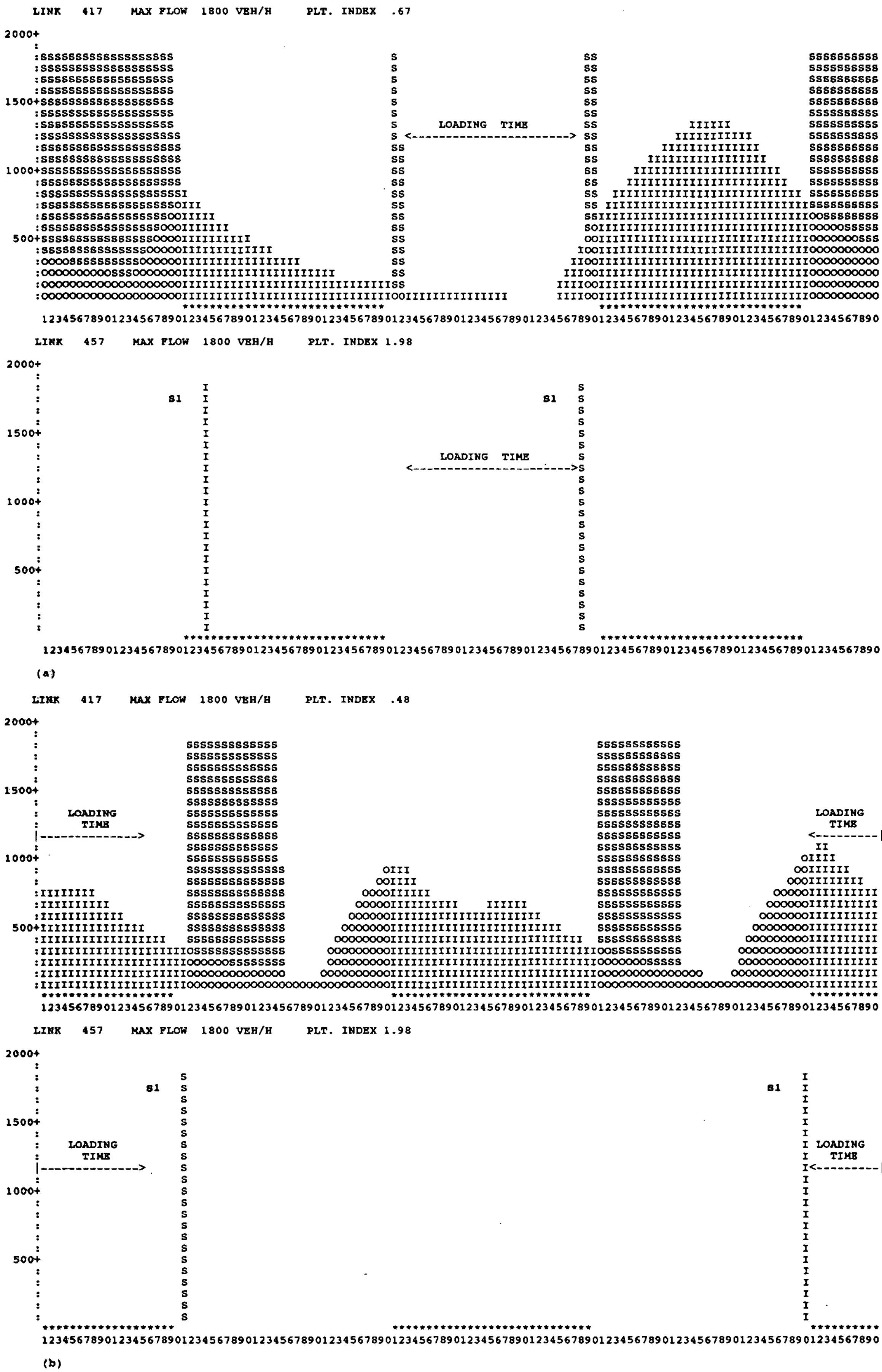


FIGURE 8 Flow profiles for (TC-NTC) links (417, 457): (*a*) simulation and (*b*) optimization.

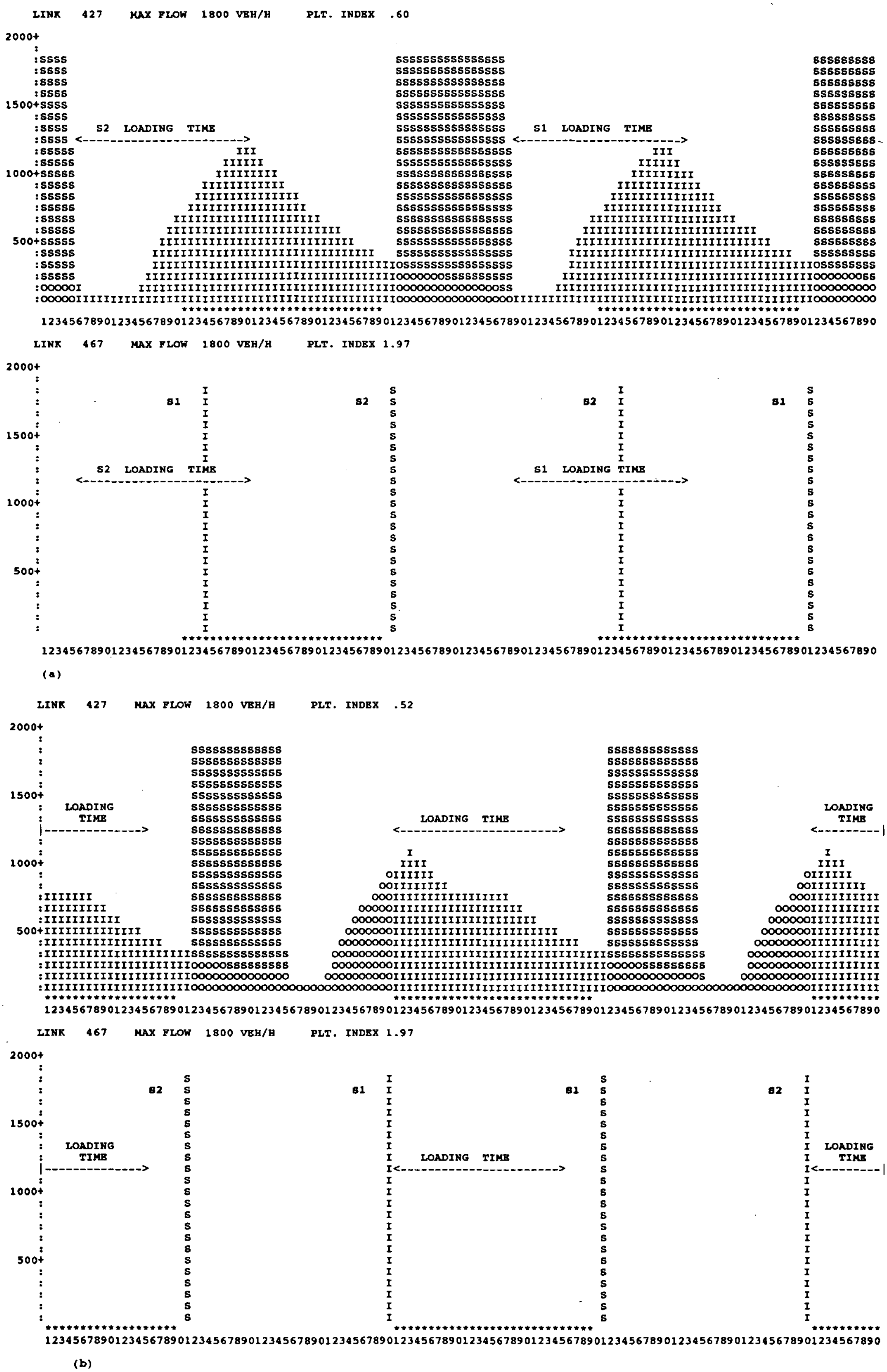


FIGURE 9 Flow profiles for (TC-TC) links (427, 467): (*a*) simulation and (*b*) optimization.

lation will be valid even for some random variations in the loading time because the transit vehicle will leave at precisely the beginning of the green phase if it finishes loading at any time during the red phase.

On the other hand, when the network operation is simulated using the original signal settings, the results provided by the model are not as robust to variation in loading times and may not hold for certain large variations in the loading time. For example, in Figure 6, the simulation results will hold for loading times varying from 22 to 51 sec, all of which correspond to finishing the loading during the red phase and then merely waiting for the next green phase. However, if the actual loading time is less than 22 sec, the results of the simulation under the original settings are no longer valid because the streetcar would really leave at some time during the same green phase in which it arrived, resulting in flow profiles different from those shown in Figure 6(*a*).

Similarly, the results of the simulation with optimal settings will be valid for any loading time from 3 to 32 sec, which is a more realistic interval for an average loading time of 25 sec.

As an extreme case, the simulation results with the original signal settings in Figure 8(*a*) are only valid for loading times exactly equal to the mean value, whereas with the optimal settings of Figure 8(*b*) the model's results are valid for loading times from 0 to 29 sec.

DISCUSSION OF RESULTS

When used for optimization purposes, the transit-enhanced TRANSYT model tends to coordinate the intersections such that the transit load and unload operations occur mainly during the red phase. In fact, the optimal settings tend to cause the transit vehicle to dwell for an entire red phase (while loading or waiting for a green signal). This can be seen as a disadvantage for the transit vehicle if its loading time is usually less than the length of the red signal. That is, allowing the transit vehicle to load and unload during the green might have given it the opportunity of being delayed only by the amount of time corresponding to its loading time.

However, a more careful analysis could conclude that on the basis of overall network performance it is usually better to have the transit vehicle load during the red phase, even if it could otherwise have left during the same green phase in which it arrived. The adverse effect of the lost capacity caused by loading during the green phase is probably worse than the added delay for the transit vehicle caused by waiting for the next green, except for the case of short loading times. Also, allowing the transit vehicle to load and unload during the green phase may lead to excessive delay when it cannot complete the process during that green phase.

It was found that for our transit-enhanced networks a different list of step sizes for the optimization hill-climbing process gave better results than the default TRANSYT-7F sequence. Although the reason for this is not clear, it indicates that some research in this area might be productive.

CONCLUSIONS

The principal advantages of applying the transit-enhanced TRANSYT model to find optimal signal settings are as follows:

- More regularity and predictability in transit operations,
- Substantial reduction of the cases in which the transit vehicle is delayed by both loading time and red signal indication,
- Reduction of the adverse effect of near-side transit stops on the other traffic, and
- Maximization of the approach capacity.

REFERENCES

1. R. A. Vincent, A. I. Mitchel, and D. I. Robertson. *User Guide to TRANSYT Version 8*. Report LR888. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1980.
2. D. I. Robertson and R. A. Vincent. *Bus Priority in a Network of Fixed-Time Signals*. Report LR666. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1975.
3. J. R. Pierce and K. Wood. *BUS TRANSYT—A User's Guide*. Report SR266. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1977.
4. C. E. Wallace et al. *TRANSYT-7F User's Manual*. Transportation Research Center, University of Florida, Gainesville, 1988.

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

Operation Big Switch: Successful Implementation of an Express Lane Concept To Manage Freeway Traffic During a Major Construction Phase

DARRELL W. BORCHARDT AND STEVEN Z. LEVINE

As work progressed on the $200 million reconstruction and expansion effort on the U.S. 59 Southwest Freeway in Houston, it was recognized that it was possible for each contractor to concurrently complete Phase 2 and for the traffic shift from this phase to Phase 3 to occur simultaneously. A traffic control plan was adopted to close all entrance and exit ramps, close the outside main lane (dedicating it as a work zone), and maintain express traffic on the remaining two main lanes. The public information and traffic management measures that were implemented during this project are discussed. Results of the strategy are discussed, and conclusions are presented.

The U.S. 59 Southwest Freeway reconstruction project consists of five separate but adjacent contracts along a 13.6 mi section of urban freeway. This represented approximately $200 million in contract work. Work on these projects was performed by four different contractors (Figure 1). The contracts were let in successive months in accordance with the policy of the Texas Department of Transportation (TxDOT). Although each project had an individual traffic control plan, the plans were part of a coordinated traffic control strategy that helped ensure a smoother transition for motorists from segment to segment.

The construction on each project was divided into three phases. Phase 1 consisted of construction of the permanent frontage roads. Phase 2 consisted of construction of the outside freeway lanes and shoulders and permanent exit and entrance ramps. Phase 3 consisted of construction of inside freeway lanes, shoulders, and the high-occupancy vehicle (HOV) lane. Higher-than-normal liquidated damages were specified to ensure that contractors completed each phase. However, each contractor could not be expected to reach the end of each phase at the same time. Therefore, a specific traffic control plan to manage traffic during the traffic shift from one phase to the next was developed. This shift consisted of relocation of concrete median barriers and temporary pavement transitions.

As work progressed on the project, project personnel recognized that it was possible for each contractor to concurrently complete Phase 2 and for the traffic shift from this phase to Phase 3 to occur simultaneously. The principal advantage to implementing a concurrent traffic shift for all four projects was in reducing the response of the workers and public to at least four traffic shifts that would have to take place at night. Weekend nighttime hours were the only allowable times for the freeway main lanes and ramps to be closed to accommodate the shift.

Consequently, the possibility of implementing a concurrent traffic shift was investigated. It was then determined that the following sequence would provide enough time for the relocation of concrete median barriers and the construction of highway and ramp transitions:

1. Closure of the outside freeway lane in three lane sections, the outside two lanes in four lane sections, and all entrance and exit ramps from 8:00 p.m. Friday to 10:00 a.m. Saturday.
2. Continuation of the above, with the exception that the highest volume entrance ramp located approximately one-third of the way in the closure limits on Saturday from 10:00 a.m. to 10:00 p.m.
3. Closure of all freeway main lanes and ramps from 10:00 p.m. Saturday to 5:00 p.m. Sunday.

The effect of this sequence on motorist delays was conducted. It was determined that a diversion of 50 percent of the total traffic using the Southwest Freeway during this time period would be needed.

A meeting among all four contractors, TxDOT project personnel, district traffic engineering and construction personnel, and the City of Houston Traffic and Transportation Department was held to initially discuss this option. On the basis of past experience, all parties agreed that this level of diversion could be attained with the implementation of an effective public information campaign and associated traffic management measures. The public information and traffic management measures that were implemented are discussed in this paper. In addition, the results of the strategy and conclusions are presented.

DESCRIPTION OF CORRIDOR

U.S. 59 Southwest Freeway is one of the most congested freeways serving the Houston area, with excessive delays to

D. W. Borchardt, Texas Transportation Institute, 701 North Post Oak, Suite 430, Houston, Tex. 77024-3818. S. Z. Levine, Texas Department of Transportation, P.O. Box 1386, Houston, Tex. 77251-1386.

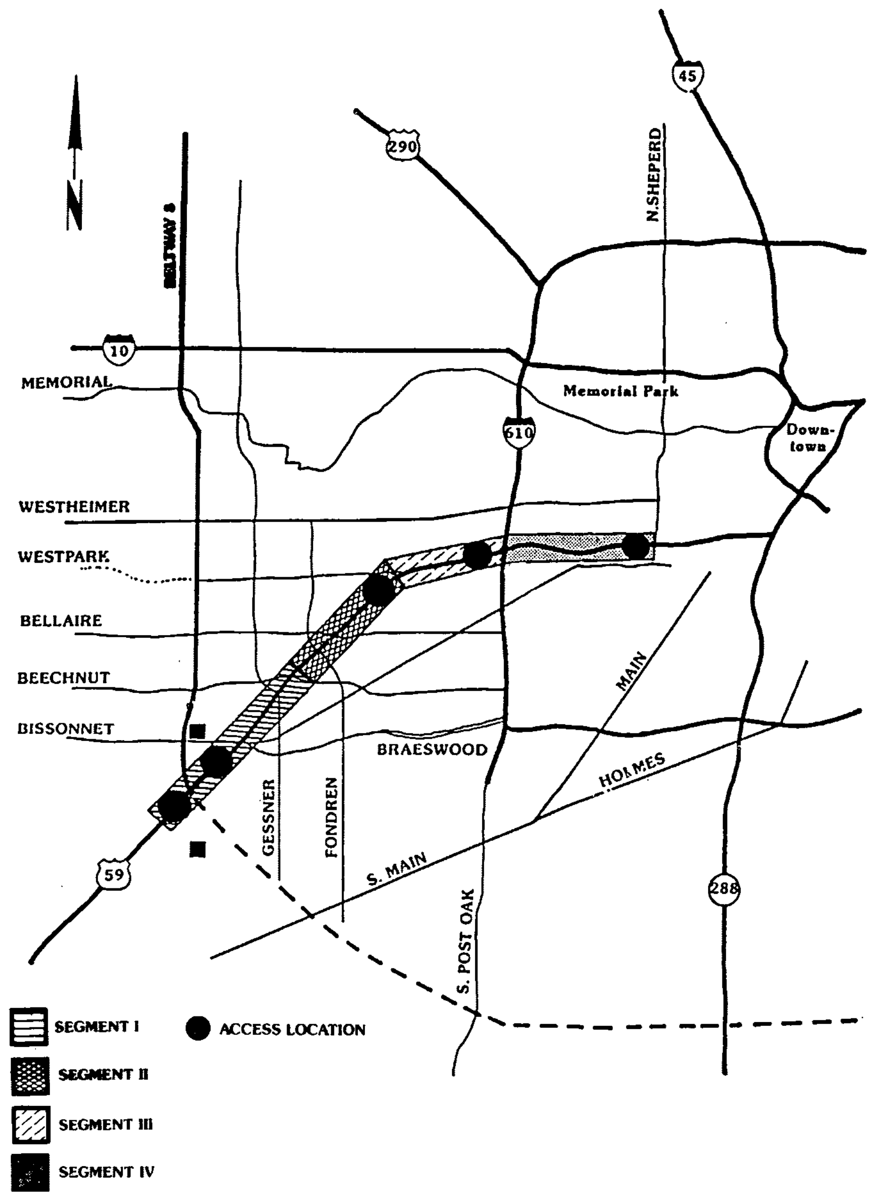


FIGURE 1 U.S. 59 construction segments.

motorists during periods of high traffic demands. To alleviate this congestion, TxDOT and the Metropolitan Transit Authority of Harris County (METRO) are working together to improve the operation of the freeway and frontage road system. At the conclusion of the approximate 3-year construction effort, users will benefit from increased freeway and roadway capacity, an additional freeway interchange, selected ramp reversals, frontage road intersection improvements, extension of the frontage road system, and pavement rehabilitation. In addition, a barrier-separated HOV lane with elevated interchanges at selected locations will be constructed in the freeway median to serve the HOV demand. Figure 1 presents the limits of the construction project. Construction in Segments 1, 2, and 3 simultaneously began in mid-1989; that for Segment 4 began approximately 6 months later.

Vehicle classification studies in a six-lane section of freeway south of Westpark in June 1991 indicated that average daily traffic for a typical weekday was approximately 124,000 vehicles per day. Heavy trucks accounted for 5.2 percent of the total vehicle demand. Because of the congested conditions, peak hour volumes of only 4,734 vehicles per hour (northbound) and 5,266 vehicles per hour (southbound) were observed during the study. Similar studies east of the construction in a 10-lane section measured approximately 201,000 vehicles per day; the truck percentage was observed at 3.1 percent. Previous studies completed on weekends indicated minimal differences for Saturday traffic demands for the entire 24-hr period. However, peaking was not evident; the traffic was somewhat evenly distributed during daylight hours. Sunday traffic demands were about 80 percent of the weekday totals.

The geometrics of the surface street system throughout the corridor varies. However, most of the roadways studied are four- or six-lane divided arterials. There were no computer controlled signal systems operating in the corridor during Operation Big Switch; the timing of traffic signals was not adjusted during the freeway closure.

ADVANCED PLANNING

The first major task in this study was the development of a traffic control plan such that all four contractors could complete their work as soon as possible. Meetings with all those involved began in July, approximately 2 months before the planned traffic switch. This meeting and several others that followed were attended by representatives of the contractors, TxDOT, METRO, the Texas Transportation Institute (TTI), and the City of Houston. Items discussed in detail are summarized in the following list:

- Traffic control plan: Maintain two express lanes for through traffic as long as possible, and provide exits for emergency vehicles near hospitals within corridor;
- Public information: Begin as soon as possible to encourage the public to avoid the freeway;
- Signing: Use temporary static, electronic changeable message signs;
- Diversion: Approximately 50 percent of the total existing traffic must be diverted for the operation to be successful;
- Weather (a major concern): Barrier relocation may proceed in the rain, but dry pavement is necessary for pavement marking;
- Contractors' progress: Concern about whether all four contractors would be ready to make the traffic switch by the planned weekend was expressed;
- Other events: Schedule closure to avoid major events within the corridor.

TRAFFIC CONTROL PLAN

The basis for the traffic control plan was prepared by a consultant for METRO. All involved agreed that this would be the preferred method to complete the traffic switch. A summary of the traffic control plan and its development is presented next.

When TxDOT and METRO first established the traffic control philosophy for the Southwest Freeway Project, traffic was to be shifted on all three segments at one time. After months of review and schedule slippages, this was deemed to be too idealistic. As a result, new milestones were established for the contracts. To further complicate the shift, a fourth segment was introduced in April 1990. The current arrangement requires traffic to be placed on temporary transitions at each end of each segment. These transitions involve main lane traffic weaving movements of 36 to 44 ft. Again, this independent arrangement was not the preferred method of traffic handling envisioned during early stages of plan preparation. A staggered traffic shift would mean transitions at each end as well as between each project segment. A concurrent traffic shift would require transitions at each end only, some 12 mi apart. It now appears possible that all four segments can make a Phase 2 (main lane) inbound traffic shift on the same date with little coordination. This shift was targeted for September 7, 1991. The contractor's schedules were reviewed and supported an inbound traffic shift on September 7, 1991. Everyone would benefit (the traveling public, METRO, TxDOT, and the contractors) by accomplishing this major shift simultaneously. Some of the apparent benefits were cost savings to METRO and TxDOT for not performing the transitions, minimization of the out-of-service time for the Chimney Rock exit ramp, elimination of main lane traffic weaves throughout the project, and savings to the contractors by not performing traffic control associated with the transitions.

Several options were considered to achieve the main lane inbound traffic shift within the project's limit. Serious consideration was given to maintaining the current three lanes on the freeway during the preparatory work for the lane shift. If three lanes are maintained, the traffic in the right lane will be close to the concrete median barrier moving and resetting activities and expose a high vertical edge of embankment, pavement, or both to the traffic in the outside lane. An attempt to maintain full capacity would place the traveling public, as well as workers, at risk, which far outweighed the potential benefits. The unanimously agreed upon General Philosophy for the Phase 2 inbound shift was to close all exit and entrance ramps, close the outside main lane (dedicating it as a work zone), and maintain express traffic on the remaining two main lanes. This would only remain in effect for the weekend shift. Main lane traffic would flow and should have adequate capacity. The only ramps to remain open were those at IH-610. The exit ramp at Fondren could also be maintained for emergency vehicles. The inbound shift was planned to be implemented during one weekend in September 1991. All traffic was planned to be on the new inbound Phase 2 pavement by the following Monday. Freeway main lane through traffic and local exit service road traffic was split before the beginning of Segment 1 to prepare for the main lane shift. The point of separation was not addressed in any of the project's traffic control plans. This point must be carefully chosen to best serve the safety of the workers, the safety and convenience of the traveling public, including that on the Sam Houston Tollway and city streets, and the least possible disruption to the merchants along these travelways. The following two scenarios describe in detail the approach end transitions. The departure end of Segment 4 does not present any unusual problems and is straightforward in its implementation.

RESULTS OF TRAFFIC STUDIES

Traffic studies were completed by TTI at 56 count sites from September 3 through 16, 1991. Table 1 presents a listing of the completed counts; Figure 2 provides approximate locations for each count. The count sites were selected to provide answers to two questions that arose during the extensive planning process undertaken before the operation was implemented. The first addressed documentation on the diversion of motorists avoiding the construction area. A second concern was major impacts on traffic patterns near retail centers within the corridor. Most count sites were studied at regular 6-month intervals once construction began.

Addressing the second question is important when considering the public image of TxDOT and METRO. The two major locations of concern were the traffic patterns near the Sharpstown and Westwood malls. The traffic patterns on streets

TABLE 1 Traffic Count Locations, U.S. 59 Southwest Freeway Corridor

Traffic Count Locations	Map Code
Beechnut EB -- East of US 59	14-A
Beechnut EB -- West of US 59	13-A
Beechnut WB -- East of US 59	14-B
Beechnut WB -- West of US 59	13-B
Bellaire EB -- East of Fondren	18-A
Bellaire EB -- East of US 59	23-A
Bellaire EB -- West of Fondren	17-A
Bellaire EB -- West of US 59	22-A
Bellaire WB -- East of Fondren	18-B
Bellaire WB -- East of US 59	23-B
Bellaire WB -- West of Fondren	17-B
Bellaire WB -- West of US 59	22-B
Beltway 8 Frontage Road SB -- North of US 59	1-D
Beltway 8 NB Beechnut Exit	3-C
Beltway 8 NB Beechnut Exit -- FR Before	3-C
Beltway 8 SB to US 59 WB	2-D
Bissonnet EB -- East of Country Creek	8-A
Bissonnet EB -- East of US 59	12-A
Bissonnet EB -- West of Country Creek	7-A
Bissonnet EB -- West of US 59	10-A
Bissonnet WB -- East of Country Creek	8-B
Bissonnet WB -- East of US 59	12-B
Bissonnet WB -- West of Country Creek	7-B
Bissonnet WB -- West of US 59	10-B
Clarewood EB -- East of Fondren	15-A
Clarewood EB -- West of US 59	24-A
Clarewood WB -- East of Fondren	15-B
Clarewood WB -- West of US 59	24-B
Club Creek EB -- East of Country Creek	9-A
Club Creek EB -- West of US 59	11-A
Club Creek WB -- East of Country Creek	9-B
Club Creek WB -- West of US 59	11-B
Country Creek NB -- North of Bissonnet	6-C
Country Creek SB -- North of Bissonnet	6-D
Country Creek SB -- South of Club Creek	5-D
Fondren NB -- North of Bellaire	16-C
Fondren NB -- North of US 59	20-C
Fondren NB -- South of Bellaire	19-C
Fondren NB -- South of US 59	21-C
Fondren SB -- North of Bellaire	16-D
Fondren SB -- North of US 59	20-D
Fondren SB -- South of Bellaire	19-D
Fondren SB -- South of US 59	21-D
I-10 EB M/L @ Gessner	----
I-10 WB M/L @ Gessner	----
Richmond EB -- East of Hillcroft	26-A
Richmond WB -- East of Hillcroft	26-B
US 59 EB to Beltway 8 NB	4-A
Westheimer EB -- East of Hillcroft	25-A
Westheimer WB -- East of Hillcroft	25-B
Westpark EB -- East of US 59	27-A
Westpark EB -- West of I-610	29-A
Westpark EB -- West of US 59	28-A
Westpark WB -- East of US 59	27-B
Westpark WB -- West of I-610	29-B
Westpark WB -- West of US 59	28-B

with direct access to these major retail centers were monitored in June and December of each year once the construction began. The Saturday and Sunday traffic volumes are a measure of the retail activity for those days.

Table 2 presents comparisons of the data collected on Saturday, September 7, 1991, with recent traffic studies. A detailed examination of the volumes observed at the Bellaire/Fondren intersection should provide an indication of any shifts in overall travel patterns near Sharpstown Mall. This comparison includes all traffic observed within the intersection as recorded by the automatic recording equipment. Summing the departure traffic demands within the intersection provides the following results: June 1991, 92,618 vehicles; September 7, 1991, 84,387 vehicles; and September 14, 1991, 87,524 vehicles.

A comparison of the studies conducted during Operation Big Switch with those completed the following week reveals that total traffic departures were observed to be 3.6 percent less. This small difference is insignificant and could be a result of normal fluctuations in daily traffic. Therefore, it can be stated that the freeway closure had limited impacts on the total traffic demands within the Bellaire/Fondren intersection, resulting in limited effects on retail sales.

Another comparison to measure impacts near Sharpstown Mall are traffic counts completed on Bellaire Boulevard on the east and west sides of the freeway. Total traffic demands (combined eastbound and westbound) west of U.S. 59 are as follows: June 1991, 51,729 vehicles; September 7, 1991, 49,017 vehicles; and September 14, 1991, 56,977 vehicles.

Using the June 1991 traffic demands as base volumes revealed a decline of 5.2 percent during the closure, but traffic was observed to increase by 10.1 percent the next Saturday. The following is a comparison of the traffic demands east of the freeway: June 1991, 32,204 vehicles; September 7, 1991, 37,279 vehicles; and September 14, 1991, 34,201 vehicles.

The June data were again used as the basis for comparison, and a 15.8 percent increase was observed during the operation and a 6.2 percent increase the next weekend. This indicates that the construction activities had a positive impact on the traffic on Bellaire Boulevard immediately adjacent to Sharpstown Mall.

Similar comparisons may be completed for traffic observed on Bissonnet Street, which provides access to Westwood Mall. Summing the data collected for Bissonnet east of County Creek (eastbound and westbound) results in the following: June 1991, 47,479 vehicles; September 7, 1991, 46,096 vehicles; and September 14, 1991, 46,451 vehicles.

A comparison with the June data indicates a 2.9 percent decrease during Operation Big Switch and a 2.2 percent decrease the next Saturday. These differences are insignificant and may be due mainly to daily fluctuations in traffic patterns.

On the basis of the limited comparisons made during this study, Operation Big Switch did not significantly affect Saturday traffic demands near the two regional shopping malls. Although traffic demands did differ slightly from those observed before and after the closure, these differences were not considered significant. The variations observed could have been caused by normal traffic variations as well as by altered traffic patterns because of the construction. No detailed comparisons of these traffic demands are included in this paper. However, traffic volumes collected during this period are presented in Tables 3 and 4.

ESTIMATES OF DIVERSION

Traffic studies were also completed at several locations near the corridor to measure diversion away from the freeway. The results of these studies are presented in Tables 5 and 6. These study sites were selected on the basis of expected diversion routes preferred by the public. No specific route was suggested to the public through the information program implemented before the freeway closure. Because of failures with traffic counting equipment, data were not available for all of these selected locations during Operation Big Switch.

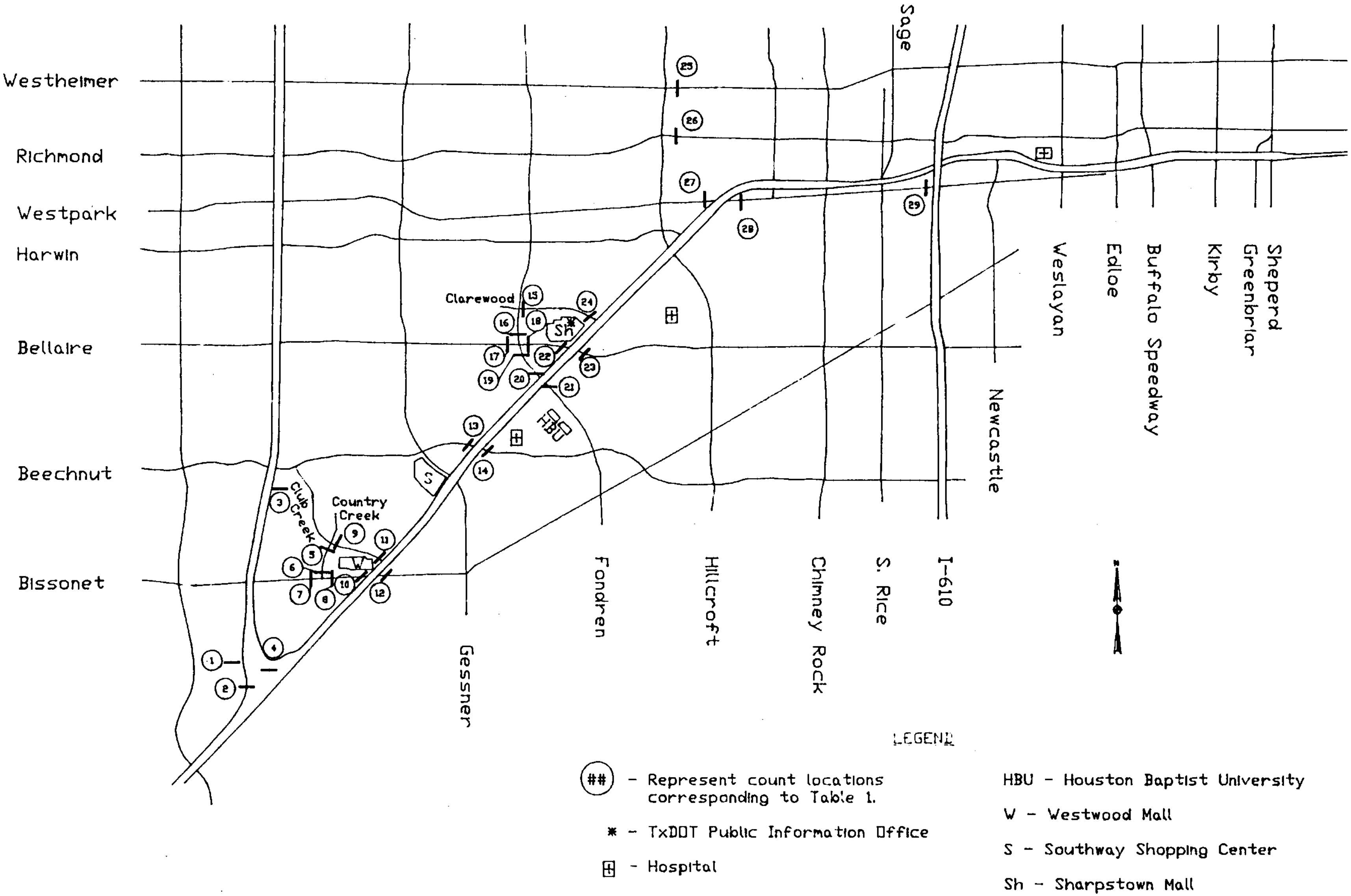


FIGURE 2 Count locations during Operation Big Switch.

TABLE 2 Comparison of 24-hr Saturday Traffic Volumes, U.S. 59 Southwest Freeway Corridor

Traffic Count Locations	Previous Traffic Studies Date	Volume	Studies During "Big Switch" Volume	% Change	Studies After "Big Switch" Volume	% Change
Beechnut EB -- East of US 59	Jun-91	10,620	19,393	N/A	N/A	N/A
Beechnut EB -- West of US 59	Jun-91	34,657	15,182	-7.84	16,473	-52.47
Beechnut WB -- East of US 59	Jun-91	12,045	12,784	N/A	N/A	N/A
Beechnut WB -- West of US 59	Jun-91	32,642	16,086	-4.48	16,841	-48.41
Bellaire EB -- East of Fondren	Jun-91	26,911	26,955	-5.79	28,611	6.32
Bellaire EB -- East of US 59	Jun-91	15,324	18,245	9.80	16,617	8.44
Bellaire EB -- West of Fondren	Jun-91	32,299	27,786	-20.23	34,831	7.84
Bellaire EB -- West of US 59	Jun-91	26,216	24,692	-18.37	30,249	15.38
Bellaire WB -- East of Fondren	Jun-91	24,412	N/A	N/A	28,006	14.72
Bellaire WB -- East of US 59	Jun-91	16,880	19,034	8.25	17,584	4.17
Bellaire WB -- West of Fondren	Jun-91	29,134	24,436	-4.60	25,613	-12.09
Bellaire WB -- West of US 59	Jun-91	25,513	24,325	-8.99	26,728	4.76
Beltway 8 Frontage Road SB -- North of US 59	Jun-90	7,172	N/A	N/A	10,940	52.54
Beltway 8 NB Beechnut Exit		N/A	5,518	1.45	5,439	N/A
Beltway 8 NB Beechnut Exit -- FR Before		N/A	20,191	12.91	17,882	N/A
Beltway 8 SB to US 59 WB		N/A	17,593	29.76	13,558	N/A
Bissonnet EB -- East of Country Creek	Jun-91	22,873	22,848	-2.16	23,353	2.10
Bissonnet EB -- East of US 59	Jun-91	23,042	22,770	5.16	21,652	-6.03
Bissonnet EB -- West of Country Creek	Jun-91	28,246	22,523	-2.05	22,995	-18.59
Bissonnet EB -- West of US 59	Jun-91	25,700	22,556	-6.80	24,203	-5.82
Bissonnet WB -- East of Country Creek	Jun-91	24,606	23,248	.65	23,098	-6.13
Bissonnet WB -- East of US 59	Jun-91	21,562	21,421	-.52	21,532	-.14
Bissonnet WB -- West of Country Creek	Jun-91	26,962	22,378	13.62	19,696	-26.95
Bissonnet WB -- West of US 59	Jun-91	26,733	23,603	-4.31	24,667	-7.73
Clarewood EB -- East of Fondren	Jun-91	11,769	4,417	-2.19	4,516	-61.63
Clarewood EB -- West of US 59	Jun-91	4,147	3,058	4.94	2,914	-29.73
Clarewood WB -- East of Fondren	Jun-91	7,016	8,049	N/A	N/A	N/A
Clarewood WB -- West of US 59	Jun-91	4,266	3,050	-44.49	5,495	28.81
Club Creek EB -- East of Country Creek	Jun-91	5,500	4,341	-18.97	5,357	-2.60
Club Creek EB -- West of US 59	Jun-91	5,751	4,659	-9.66	5,157	-10.33
Club Creek WB -- East of Country Creek	Jun-91	5,403	N/A	N/A	3,920	-27.45
Club Creek WB -- West of US 59	Jun-91	8,200	3,168	-14.19	3,692	-54.98
Country Creek NB -- North of Bissonnet	Jun-91	2,732	2,238	1.31	2,209	-19.14
Country Creek SB -- North of Bissonnet	Jun-91	1,870	1,548	-4.86	1,627	-12.99
Country Creek SB -- South of Club Creek	Jun-91	3,241	N/A	N/A	N/A	N/A
Fondren NB -- North of Bellaire	Jun-91	20,086	19,383	4.94	18,470	-8.05
Fondren NB -- North of US 59	Jun-91	16,491	13,800	43.76	9,599	-41.79
Fondren NB -- South of Bellaire	Jun-91	18,411	14,577	-10.82	16,345	-11.22
Fondren NB -- South of US 59	Jun-91	16,561	14,210	-32.29	20,987	26.73
Fondren SB -- North of Bellaire	Jun-91	20,257	17,922	-13.79	20,788	2.62
Fondren SB -- North of US 59	Jun-91	15,978	14,223	-12.52	16,258	1.75
Fondren SB -- South of Bellaire	Jun-91	16,487	13,613	-8.21	14,830	-10.05
Fondren SB -- South of US 59	Jun-91	15,661	18,392	17.59	15,641	-.13
I-10 EB M/L @ Gessner	Aug-91	82,210	85,654	-.84	86,377	5.07
I-10 WB M/L @ Gessner	Aug-91	80,048	81,198	-5.02	85,489	6.80
Richmond EB -- East of Hillcroft		N/A	19,368	13.79	17,021	N/A
Richmond WB -- East of Hillcroft	Jul-91	22,409	19,519	13.25	17,235	-23.09
US 59 EB to Beltway 8 NB	Jul-91	12,308	11,984	2.17	11,730	-4.70
Westheimer EB -- East of Hillcroft	Jul-91	36,974	52,099	21.06	43,034	16.39
Westheimer WB -- East of Hillcroft	Jul-91	34,872	50,044	7.65	46,488	33.31
Westpark EB -- East of US 59	Jun-91	12,717	26,740	76.48	15,152	19.15
Westpark EB -- West of I-610	Jul-91	15,103	28,109	103.72	13,798	-8.64
Westpark EB -- West of US 59	Jun-91	17,241	N/A	N/A	17,923	3.96
Westpark WB -- East of US 59	Jun-91	9,469	13,108	33.93	9,787	3.36
Westpark WB -- West of I-610		N/A	N/A	N/A	11,654	N/A
Westpark WB -- West of US 59	Jun-91	19,478	N/A	N/A	23,271	19.47

NOTE: % Change during "Big Switch" compares with studies completed the next week.
% Change after "Big Switch" compares with the previous traffic studies.

TABLE 3 Comparison of 24-hr Sunday Traffic Volumes, U.S. 59 Southwest Freeway Corridor

Traffic Count Locations	Previous Traffic Studies Date	Previous Traffic Studies Volume	Studies During "Big Switch" Volume	Studies During "Big Switch" % Change	Studies After "Big Switch" Volume	Studies After "Big Switch" % Change
Beechnut EB -- East of US 59	Jun-91	8,140	9,066	N/A	N/A	N/A
Beechnut EB -- West of US 59	Jun-91	24,619	12,521	-1.11	12,661	-48.57
Beechnut WB -- East of US 59	Jun-91	9,104	10,335	N/A	N/A	N/A
Beechnut WB -- West of US 59	Jun-91	23,130	13,621	-1.26	13,795	-40.36
Bellaire EB -- East of Fondren	Jun-91	18,831	19,824	-3.14	20,466	8.68
Bellaire EB -- East of US 59	Jun-91	12,392	14,356	20.93	11,871	-4.20
Bellaire EB -- West of Fondren	Jun-91	20,247	21,370	-15.45	25,274	24.83
Bellaire EB -- West of US 59	Jun-91	17,977	18,791	-12.03	21,361	18.82
Bellaire WB -- East of Fondren	Jun-91	17,612	19,286	-1.28	19,536	10.92
Bellaire WB -- East of US 59	Jun-91	12,964	14,160	11.94	12,650	-2.42
Bellaire WB -- West of Fondren	Jun-91	22,512	18,538	-6.79	19,889	-11.65
Bellaire WB -- West of US 59	Jun-91	18,448	18,526	-5.14	19,529	5.86
Beltway 8 Frontage Road SB -- North of US 59		N/A	N/A	N/A	8,550	N/A
Beltway 8 NB Beechnut Exit		N/A	6,322	31.76	4,798	N/A
Beltway 8 NB Beechnut Exit -- FR Before		N/A	16,263	13.17	14,371	N/A
Beltway 8 SB to US 59 WB		N/A	13,314	29.27	10,299	N/A
Bissonnet EB -- East of Country Creek	Jun-91	18,713	18,171	.67	18,050	-3.54
Bissonnet EB -- East of US 59	Jun-91	17,766	19,024	12.06	16,976	-4.45
Bissonnet EB -- West of Country Creek	Jun-91	20,233	17,829	.71	17,703	-12.50
Bissonnet EB -- West of US 59	Jun-91	16,569	17,928	-2.45	18,378	10.92
Bissonnet WB -- East of Country Creek	Jun-91	19,025	18,273	1.46	18,010	-5.34
Bissonnet WB -- East of US 59	Jun-91	16,283	16,780	2.58	16,358	.46
Bissonnet WB -- West of Country Creek	Jun-91	21,305	17,434	15.82	15,053	-29.35
Bissonnet WB -- West of US 59	Jun-91	19,545	18,470	-1.28	18,709	-4.28
Clarewood EB -- East of Fondren	Jun-91	6,508	2,822	.82	2,799	-56.99
Clarewood EB -- West of US 59	Jun-91	2,275	2,650	25.35	2,114	-7.08
Clarewood WB -- East of Fondren	Jun-91	4,442	5,947	N/A	N/A	N/A
Clarewood WB -- West of US 59	Jun-91	2,900	2,238	-31.71	3,277	13.00
Club Creek EB -- East of Country Creek	Jun-91	2,652	3,144	-12.59	3,597	35.63
Club Creek EB -- West of US 59	Jun-91	3,667	2,941	-11.50	3,323	-9.38
Club Creek WB -- East of Country Creek	Jun-91	3,443	N/A	N/A	2,706	-21.41
Club Creek WB -- West of US 59	Jun-91	4,908	2,189	-15.90	2,603	-46.96
Country Creek NB -- North of Bissonnet	Jun-91	2,137	1,836	6.62	1,722	-19.42
Country Creek SB -- North of Bissonnet	Jun-91	1,375	1,170	2.09	1,146	-16.65
Country Creek SB -- South of Club Creek	Jun-91	3,393	N/A	N/A	N/A	N/A
Fondren NB -- North of Bellaire	Jun-91	14,241	13,792	19.57	11,535	-19.00
Fondren NB -- North of US 59	Jun-91	9,945	6,367	7.53	5,921	-40.46
Fondren NB -- South of Bellaire	Jun-91	10,750	10,082	3.04	9,785	-8.98
Fondren NB -- South of US 59	Jun-91	10,657	10,188	-26.32	13,827	29.75
Fondren SB -- North of Bellaire	Jun-91	13,739	12,704	-3.79	13,204	-3.89
Fondren SB -- North of US 59	Jun-91	10,318	9,693	-6.59	10,377	.57
Fondren SB -- South of Bellaire	Jun-91	12,722	9,310	-.70	9,376	-26.30
Fondren SB -- South of US 59	Jun-91	11,540	13,286	28.92	10,306	-10.69
I-10 EB M/L @ Gessner	Aug-91	69,723	68,502	2.74	66,678	-4.37
I-10 WB M/L @ Gessner	Aug-91	67,242	65,249	-.86	65,818	-2.12
Richmond EB -- East of Hillcroft		N/A	12,888	19.51	10,784	N/A
Richmond WB -- East of Hillcroft	Jul-91	13,303	12,876	12.72	11,423	-14.13
US 59 EB to Beltway 8 NB	Jul-91	10,628	13,465	43.37	9,392	-11.63
Westheimer EB -- East of Hillcroft	Jul-91	26,842	39,607	30.87	30,265	12.75
Westheimer WB -- East of Hillcroft	Jul-91	25,870	37,146	17.73	31,553	21.97
Westpark EB -- East of US 59	Jul-91	10,472	22,619	97.89	11,430	9.15
Westpark EB -- West of I-610	Jul-91	9,029	24,783	182.75	8,765	-2.92
Westpark EB -- West of US 59	Jun-91	13,757	N/A	N/A	N/A	N/A
Westpark WB -- East of US 59	Jun-91	8,233	10,454	39.74	7,481	-9.13
Westpark WB -- West of I-610		N/A	N/A	N/A	7,032	N/A
Westpark WB -- West of US 59	Jun-91	17,021	N/A	N/A	N/A	N/A

NOTE: % Change during "Big Switch" compares with studies completed the next week.
% Change after "Big Switch" compares with the previous traffic studies.

TABLE 4 Comparison of 24-hr Weekday Traffic Volumes, U.S. 59 Southwest Freeway Corridor

Traffic Count Locations	Previous Traffic Studies Date	Previous Traffic Studies Volume	Week Before "Big Switch" Volume	Week Before "Big Switch" % Change	Week After "Big Switch" Volume	Week After "Big Switch" % Change
Beechnut EB -- East of US 59	Jun-91	14,609	12,448	N/A	N/A	N/A
Beechnut EB -- West of US 59	Jun-91	37,275	18,525	-1.13	18,737	-49.73
Beechnut WB -- East of US 59	Jun-91	16,196	16,984	N/A	N/A	N/A
Beechnut WB -- West of US 59	Jun-91	36,315	18,786	-2.22	19,213	-47.09
Bellaire EB -- East of Fondren	Jun-91	26,220	27,129	1.92	26,618	1.52
Bellaire EB -- East of US 59	Jun-91	16,676	17,898	.15	17,872	7.17
Bellaire EB -- West of Fondren	Jun-91	32,443	28,282	-10.29	31,525	-2.83
Bellaire EB -- West of US 59	Jun-91	25,058	26,782	-3.16	27,656	10.37
Bellaire WB -- East of Fondren	Jun-91	23,692	25,880	-3.52	26,823	13.22
Bellaire WB -- East of US 59	Jun-91	18,076	19,327	-.38	19,401	7.33
Bellaire WB -- West of Fondren	Jun-91	30,008	24,508	-4.47	25,656	-14.50
Bellaire WB -- West of US 59	Jun-91	23,694	24,789	-.08	24,809	4.71
Beltway 8 Frontage Road SB -- North of US 59	Jun-90	13,643	14,805	20.21	12,316	-9.73
Beltway 8 NB Beechnut Exit	Sep-90	6,133	6,365	-5.95	6,768	10.35
Beltway 8 NB Beechnut Exit -- FR Before	Sep-90	15,322	18,211	.42	18,134	18.35
Beltway 8 SB to US 59 WB		N/A	17,127	1.46	16,881	N/A
Bissonnet EB -- East of Country Creek	Jun-91	24,981	23,022	.64	22,876	-8.43
Bissonnet EB -- East of US 59	Jun-91	25,737	23,310	.38	23,222	-9.77
Bissonnet EB -- West of Country Creek	Jun-91	30,334	22,545	1.05	22,310	-26.45
Bissonnet EB -- West of US 59	Jun-91	24,836	23,423	-.17	23,464	-5.52
Bissonnet WB -- East of Country Creek	Jun-91	24,217	22,955	1.77	22,555	-6.86
Bissonnet WB -- East of US 59	Jun-91	23,052	21,589	-.57	21,712	-5.81
Bissonnet WB -- West of Country Creek	Jun-91	26,662	22,022	6.37	20,704	-22.35
Bissonnet WB -- West of US 59	Jun-91	26,012	23,884	.78	23,699	-8.89
Clarewood EB -- East of Fondren	Jun-91	9,414	4,153	10.78	3,749	-60.18
Clarewood EB -- West of US 59	Jun-91	2,833	4,723	86.68	2,530	-10.70
Clarewood WB -- East of Fondren	Jun-91	5,939	7,371	N/A	N/A	N/A
Clarewood WB -- West of US 59	Jun-91	4,257	3,059	-31.55	4,469	4.98
Club Creek EB -- East of Country Creek	Jun-91	6,102	3,835	-21.04	4,857	-20.40
Club Creek EB -- West of US 59	Jun-91	6,066	6,249	6.75	5,854	-3.49
Club Creek WB -- East of Country Creek	Jun-91	5,929	4,188	-1.83	4,266	-28.05
Club Creek WB -- West of US 59	Jun-91	8,024	4,189	-3.55	4,343	-45.87
Country Creek NB -- North of Bissonnet	Jun-91	2,859	2,395	1.14	2,368	-17.17
Country Creek SB -- North of Bissonnet	Jun-91	3,287	1,837	-1.55	1,866	-43.23
Country Creek SB -- South of Club Creek	Jun-91	3,317	3,873	N/A	N/A	N/A
Fondren NB -- North of Bellaire	Jun-91	20,096	16,952	-3.98	17,655	-12.15
Fondren NB -- North of US 59	Jun-91	18,926	13,482	43.26	9,411	-50.27
Fondren NB -- South of Bellaire	Jun-91	18,989	15,417	-.49	15,493	-18.41
Fondren NB -- South of US 59	Jun-91	16,433	14,252	-15.61	16,889	2.77
Fondren SB -- North of Bellaire	Jun-91	20,258	17,979	-5.76	19,078	-5.82
Fondren SB -- North of US 59	Jun-91	16,356	15,260	-4.42	15,965	-2.39
Fondren SB -- South of Bellaire	Jun-91	17,128	14,580	-.30	14,624	-14.62
Fondren SB -- South of US 59	Jun-91	14,394	17,897	7.52	16,646	15.65
I-10 EB M/L @ Gessner	Aug-91	99,247	91,030	-2.53	93,391	-5.90
I-10 WB M/L @ Gessner	Aug-91	94,911	89,412	-3.68	92,832	-2.19
Richmond EB -- East of Hillcroft	May-91	17,734	20,620	.02	20,616	16.25
Richmond WB -- East of Hillcroft	Jul-91	22,688	20,028	-3.73	20,805	-8.30
US 59 EB to Beltway 8 NB	Jul-91	19,355	15,329	-3.68	15,915	-17.77
Westheimer EB -- East of Hillcroft	Jul-91	41,644	48,264	-3.13	49,821	19.64
Westheimer WB -- East of Hillcroft	Jul-91	46,465	49,784	2.73	48,462	4.30
Westpark EB -- East of US 59	Jun-91	17,611	22,845	13.43	20,140	14.36
Westpark EB -- West of I-610	Jul-91	22,640	18,489	-8.45	20,195	-10.80
Westpark EB -- West of US 59	Jun-91	24,775	N/A	N/A	23,998	-3.14
Westpark WB -- East of US 59	Jun-91	12,343	12,458	7.41	11,599	-6.03
Westpark WB -- West of I-610	May-90	10,040	11,492	6.07	10,834	7.91
Westpark WB -- West of US 59	Jun-91	26,993	N/A	N/A	28,072	4.00

NOTE: % Change during "Big Switch" compares with studies completed the next week.
% Change after "Big Switch" compares with the previous traffic studies.

TABLE 5 Comparison of Saturday Traffic Demands Along Diversion Route

Diversion Route	Base 24-hr Volume	Volume during "Big Switch"	% Change
Beltway 8 FR SB - North of U.S. 59	10,940	N/A	N/A
Beltway 8 NB Beechnut Exit	17,882	20,191	12.91
Beltway 8 SB to U.S. 59 WB	13,558	17,593	29.76
I-10 EB M/L @ Gessner	86,377	85,654	- 0.84
I-10 WB M/L @ Gessner	85,489	81,198	- 5.02
Richmond EB -- East of Hillcroft	17,021	19,368	13.79
Richmond WB -- East of Hillcroft	17,235	19,519	13.25
Westheimer EB -- East of Hillcroft	43,034	52,099	21.06
Westheimer WB -- East of Hillcroft	46,488	50,044	7.65
Westpark EB -- East of U.S. 59	15,152	26,740	76.48
Westpark EB -- West of I-610	13,798	28,109	103.72
Westpark EB -- West of U.S. 59	17,923	N/A	N/A
Westpark WB -- East of U.S. 59	9,787	13,108	33.93
Westpark WB -- West of U.S. 59	11,654	N/A	N/A
Westpark WB -- West of U.S. 59	23,271	N/A	N/A

Only two of the assumed diversion routes experienced a reduction in traffic volume measured for the 24-hr period on Saturday. The main lane counts on I-10 Katy Freeway for the eastbound decreased by 0.8 percent, and westbound declined by 5.0 percent. This site was selected to determine the number of motorists who used I-10 as a detour around the closure. On the basis of these volumes, it may be concluded that that type of diversion did not occur.

Five of the fifteen sites studied indicated an increase in traffic demand in excess of 20 percent for the Saturday 24-hr period. The two highest increases were observed for eastbound travel along Westpark. This was expected because it was easily accessible from all major cross streets within the Southwest Freeway corridor. Eastbound Westpark east of the closed freeway increased by 76.5 percent, most likely as a result of motorists diverting from the frontage roads. The highest increase observed was for the same roadway west of the I-610 West Loop. This was most likely caused by a combination of vehicles from upstream Westpark and a volume of vehicles from Chimney Rock. Increases of 7.6 percent to 13.8 percent were observed at four of the study sites.

The best comparisons of the diversion from the freeway main lanes could be made by evaluating traffic counts completed along Westpark. However, because of problems with the equipment, data were not available for all six study sites. The problems were typically a result of road tubes that had been removed from the roadway surface. In some cases, the traffic counts malfunctioned in some manner. In order to have completed a better comparison, traffic counts should have been completed along the service roads along the freeway. However, the expected movement of construction equipment and uncertain public reaction did not allow for safe installation and monitoring of the equipment.

The best measure of diversion could have been obtained from traffic data collected by a permanent count station along the freeway. Unfortunately, data were not available at this

TABLE 6 Comparison of Sunday Traffic Demands Along Diversion Route

Diversion Route	Base 24-hr Volume	Volume during "Big Switch"	% Change
Beltway 8 FR SB - North of U.S. 59	8,550	N/A	N/A
Beltway 8 NB Beechnut Exit	4,798	6,322	31.76
Beltway 8 SB to U.S. 59 WB	10,299	13,314	29.27
I-10 EB M/L @ Gessner	66,678	68,502	2.74
I-10 WB M/L @ Gessner	65,818	65,249	- 0.86
Richmond EB -- East of Hillcroft	10,784	12,888	19.51
Richmond WB -- East of Hillcroft	11,423	12,876	12.72
Westheimer EB -- East of Hillcroft	30,265	39,607	30.87
Westheimer WB -- East of Hillcroft	31,553	37,146	17.73
Westpark EB -- East of U.S. 59	11,430	22,619	97.89
Westpark EB -- West of I-610	8,765	24,783	182.75
Westpark EB -- West of U.S. 59	N/A	N/A	N/A
Westpark WB -- East of U.S. 59	7,481	10,454	39.74
Westpark WB -- West of U.S. 59	7,032	N/A	N/A
Westpark WB -- West of U.S. 59	N/A	N/A	N/A

writing from that count site. Over-the-air reports from the traffic service agencies indicated that traffic throughout the area appeared to be lighter than normal.

PUBLIC INFORMATION CAMPAIGN

Throughout the duration of the construction, TxDOT maintained a public affairs office in the corridor (Figure 2). The office, located in the Sharpstown Mall, is easily accessible by the public, news media, and the construction contractors. The public affairs office carefully planned news releases concerning Operation Big Switch. Merchants in the corridor were also contacted before the release of the plan to the news media. The *Houston Chronicle* published a number of articles covering the operation (*1–7*), as did other print media.

The broadcast media also provided good coverage of the freeway closure. Traffic reporting services began mentioning the planned work several days in advance and advised motorists to seek alternative routes that weekend. Several radio stations announced the closure throughout the weekend. Houston television stations also covered the operation. The media reported light traffic throughout the weekend within the corridor. No major traffic congestion directly related to Operation Big Switch was reported.

SUMMARY AND RECOMMENDATIONS

On the basis of the results of the limited traffic studies completed and the positive results from the public, the implementation of Operation Big Switch was deemed a success. The activity involved the coordination of several construction contractors and government agencies. Assistance from the print and broadcast media was instrumental in obtaining cooperation from the public by selecting alternative routes to the closed freeway.

The construction of major freeways in most cases can be completed without major inconvenience to the public. However, the switching of traffic to new lanes normally requires some type of closure. In future instances, it is recommended that the following steps be completed to ensure a smooth operation. Each of these steps was implemented for this operation.

- A detailed review of existing corridor traffic is necessary to identify alternative routes and potential problem areas.
- Closure times must be selected for the least impact on the public while allowing adequate time for the contractor to complete the traffic switch.
- Early notification by public information to retail merchants in the corridor may serve to avert legal actions to halt the construction.
- Print and broadcast media should be involved to provide sufficient information to the public.
- All government agencies that may be affected by any freeway closure (police departments, hospitals, etc.) should be included in the planning process.
- Close coordination with all contractors involved is necessary. This includes the construction companies and all others, including traffic control and utilities.

If similar closure strategies are to be used for other construction projects, additional steps could be followed in the planning and implementation stages:

- Prepare complete documentation of all strategies discussed and implemented during the freeway closure.
- Provide real-time monitoring of traffic throughout the affected corridor, with emphasis on critical locations.
- Implement a temporary traffic control center to provide a focal point for information exchange. The center should have cellular telephone or radio contact with those doing the traffic monitoring and with the project supervisor. This center would only be needed during critical periods.
- Videotape the roadway closures. Videotapes should include all traffic control devices used for the operation. It is suggested that this be completed at selected time intervals through the duration of the operation to document that all devices have remained in place.

The preceding four steps were not included in Operation Big Switch. Even without these steps, however, the operation was a success and was completed without incident. The experiences gained during this effort have been used for similar (although smaller in duration and segment width) operations along the Southwest Freeway with similar success. The extensive public information campaign and early contact with the retail community were integral to each. This information will be useful in planning for comparable traffic switches on future projects.

REFERENCES

1. U.S. 59 To Be Closed. *Houston Chronicle*, Aug. 20, 1991.
2. Big Switch To Be Pulled on Southwest Freeway. *Houston Chronicle*, Sept. 5, 1991.
3. Big Switch To Go On . . . Weather Willing. *Houston Chronicle*, Sept. 7, 1991.
4. The Switch Is On. *Houston Chronicle*, Sept. 8, 1991.
5. Big Switch On I-59 Pulled Off Without A Hitch. *Houston Chronicle*, Sept. 9, 1991.
6. Southwest Drivers Say it Was Smooth but Slow. *Houston Chronicle*, Sept. 10, 1991.
7. Operation Big Switch a Success Thanks to Many. *Houston Chronicle*, Sept. 20, 1991.

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

Estimation of Delays to Boats and Vehicular Traffic Caused by Moveable Bridge Openings: An Empirical Analysis

YOUSSEF DEHGHANI, PAUL B. ARNOLD, AND RICHARD L. PEREIRA

The paper describes an interactive and simple queuing model developed to evaluate potential delays to both vehicular and vessel traffic caused by openings and closures of a draw bridge. The queuing procedures were developed to evaluate the proposed replacement alternatives (i.e., fixed-span bridge, tunnel or moveable bridge with 55 ft (16.77 m) vertical clearance) to the existing S.E. 17th Street draw bridge across the Intracoastal Waterway (ICWW) in Ft. Lauderdale, Florida. Currently, excessive delays are experienced by vehicular and vessel traffic using the S.E. 17th Street draw bridge and the ICWW, respectively. Queues to both the vehicular and vessel traffic were estimated and analyzed using a variety of factors ranging from bridge operating characteristics and available boat holding capacity in the ICWW to forecasted vehicle and vessel traffic. The queuing procedures are demonstrated in the paper mostly via examples for the sake of simplicity in presentation. The queuing procedures presented in the paper provided useful information, such as hours of delay to vessel and vehicular traffic, which was used to evaluate the proposed replacement facilities. The queuing analysis also provided useful and appropriate guidance for changing the historical 15-min bridge opening cycle to a 30-min time-saving bridge opening scheme.

An interactive and simple queuing model developed to evaluate potential delays to both vehicular and vessel traffic caused by openings and closures of a draw bridge is described in this paper. Necessary data for the empirical analyses were collected in relation to operation of the existing S.E. 17th Street draw bridge across the Intracoastal Waterway (ICWW) in Ft. Lauderdale, Florida. The existing bascule bridge provides 25 ft (7.62 m) of vertical clearance and it is located between two signalized intersections that are less than 1 mi (1.67 km) apart.

Because of the excessive delays to both vessel and vehicular traffic, the Florida Department of Transportation (FDOT) has embarked on evaluation of the following alternatives for replacement of the existing draw bridge: (a) a high-level, fixed-span bridge; (b) a tunnel; and (c) a higher-level, moveable bridge.

For the queuing analysis presented in the paper under the moveable bridge option, both vessel and vehicle queues were analyzed on the basis of a variety of factors, from bridge operating characteristics to forecasted vessel and vehicle traffic. For the fixed-span bridge and tunnel options, it was assumed that the overall performance of the two signalized intersections would control the net traffic flow capable of traveling on S.E. 17th Street. Therefore, the number of lanes for a fixed-span bridge or a tunnel by itself, relative to the proposed improvement schemes for the two intersections, could not necessarily be an issue. It was also assumed that any queue build-up would take place before either intersection.

Y. Dehghani and P. B. Arnold, Parsons Brinckerhoff Quade & Douglas, Inc., 999 Third Avenue, Suite 801, Seattle, Wash. 98104-4099. R. L. Pereira, Florida Department of Transportation, 780 S.W. 24th Street, Ft. Lauderdale, Fla. 33315.

VESSEL AND VEHICULAR TRAFFIC DATA

Vessel Traffic Patterns

Some information regarding the existing vessel traffic was available from the bridge tender's logs. These data showed that the bridge is opened approximately 43 times a day. This information did not provide data on the height of vessels or the duration of bridge openings—critical pieces of information needed for the analysis of different bridge height options. To provide the needed information, a vessel height survey was conducted during the peak season in April 1991. The vessel survey provided detail information on the number and height of vessels passing under or through the bridge during each opening cycle observed from 9:00 a.m. to 6:00 p.m. The survey was conducted on Tuesday, Saturday, and Sunday. The duration of the bridge opening for each cycle was also recorded.

The analysis of the boat traffic from the survey indicates that (a) the boat traffic is heavier during the weekends and has peaking characteristics similar to that of general traffic and (b) vessels that are 55 or 65 ft (16.77 or 19.82 m) high appeared to use the ICWW continuously throughout the weekend survey day. Therefore, for the fixed-span bridge option, the clearance seems to be an issue if vessels 65 ft (19.82 m) and taller are to be accommodated through the ICWW.

Boat traffic forecasts are based on the evaluation of historical data for the study area and interviews with local residents involved in the marine industry. Vessels registered in the area as well as those using the S.E. 17th Street Causeway are increasing at a rate of 5 to 6 percent per year. This rate includes boats of all sizes. The vessel type distribution from the FDOT Bridge Opening Logs for an average month in 1986 indicates that 43 percent of the vessels were motorized and the remaining 57 percent were sailing vessels. For the purpose of queuing analysis it is assumed that the number of sailing vessels, with mast heights of more than 45 ft (13.72 m), would experience a lower growth rate than that of power boats. Therefore, an annual growth rate of 3 percent seems to be reasonable, although it might result in an optimistic set of boat forecasts for 2010. Interviews with residents involved in the marine industry indicated that an annual growth rate of 1 to 3 percent is reasonable. Results of the queuing analysis presented in this paper are based on 3 percent annual growth rate in boat traffic. Year 2010 (2050) forecast of boat traffic is summarized in Table 1.

General Traffic Patterns

The S.E. 17th Street corridor containing the ICWW is a well-established urban area. The daily traffic volume in 1991 on S.E. 17th Street was about 42,000 annual average daily traffic (AADT). General traffic is forecasted to increase to 48,000 AADT by 2010/2050 and beyond.

QUEUING PROCEDURES AND DELAY ANALYSIS

Both vehicle and vessel queues were analyzed under the 55 ft moveable bridge replacement option for the current year and year 2010. In addition to the existing 15-min bridge opening cycle, a 30-min bridge opening option also has been considered for the queuing and delay analyses. The operation of the existing bascule bridge or any future moveable bridge has great impact on the level of service on and near the facility. The limited vessel holding capacity and the impact on traffic resulting from a bridge opening required that both vessel traffic and vehicle traffic be analyzed simultaneously. For the simple queuing analysis described here, both vessel and vehicle queues were analyzed on the basis of a variety of factors ranging from bridge operating characteristics to forecasted vessel and vehicle traffic. A discussion of the methodology and results of the queuing analysis follows.

Average vessel crossings per minute were calculated on the basis of peak hour volumes from the 1991 boat survey. An analysis of the boat survey data reveals the following characteristics of vessels passing under the S.E. 17th Street Bridge:

- Weekend boat traffic was more than three times higher than weekday traffic,
- About 10 percent of weekend and 4 percent of weekday vessels that passed under the S.E. 17th Street Bridge were more than 65 ft (19.82 m) tall, and
- About 1 percent of weekend and 1.5 percent of weekday vessels that passed under the S.E. 17th Street Bridge were more than 85 ft (25.91 m) tall.

Vessel queues were calculated on the basis of the current 15-min bridge opening scheme as well as a 30-min bridge opening option for 25-ft (7.62-m) bascule bridge and a proposed 55-ft moveable bridge. A 50-ft (15.24-m) clearance was assumed for the 55-ft (16.77-m) bridge to provide a buffer zone between the top of a vessel's mast and the bottom of the bridge structure. It was assumed that all boat or vehicular backup dissipates during every bridge opening and closure. The existing operating scheme is such that the bridge stays open until all boats in the queue pass through.

Estimation of Holding Capacity for Marine Vessels

The number of vessels that can hold safely, both north and south of the bridge, was established using various site-specific

TABLE 1 Summary of 2010 (2050) Boat Traffic Forecasts

Time of Day	WEEKEND DAY: Low Estimate (1% per Year) < = 44' (13.4m)	> =45' (13.7m)	Total	WEEKEND DAY: High Estimate (3% per Year) < = 44' (13.4m)	> =45' (13.7m)	Total	WEEKDAY: Low Estimate (1% per Year) < = 44' (13.4m)	> =45' (13.7m)	Total	WEEKDAY: High Estimate (3% per Year) < = 44' (13.4m)	> =45' (13.7m)	Total
9-10	17	22	39	22	29	51	5	2	7	6	3	9
10-11	16	22	38	21	29	50	6	0	6	8	0	8
11-12	26	11	37	35	14	49	11	1	12	14	2	16
12-1	24	24	48	32	32	64	8	6	14	11	8	19
1-2	18	16	34	24	21	45	17	8	25	22	11	33
2-3	38	35	73	51	46	97	13	4	17	18	5	23
3-4	43	18	61	58	24	82	7	1	8	10	2	12
4-5	20	23	43	27	30	57	8	8	16	11	11	22
5-6	11	5	16	14	6	20	0	2	2	0	3	3
Total	213	176	389	284	231	515	75	32	107	100	45	145

facts in combination with certain assumptions. Safe holding areas were established as approximately 200 ft × 1,000 ft (60.98 × 304.88 m) north of the bridge and 200 ft × 1,100 ft (60.98 × 335.37 m) south of the bridge. In order to determine the anticipated holding areas, the following factors were taken into consideration: (a) depths within the ICWW, (b) the position of the turning basin for the port area and that smaller vessels must stay clear, and (c) sight distance to the bridge (observation of the boats holding indicates that boats will stay as close to the bridge as possible while waiting).

The number of boats that can hold within the safe area was determined using the following assumptions.

First, average length for boats holding is 45 ft (13.72 m). This assumption was verified through review of the boat survey data collected in April, 1991. At this time, approximate boat lengths were recorded for all vessels passing under the bridge during an opening.

Second, "shorter" vessels such as power boats are presently passing through even when the bridge is closed.

Third, boats require at least 4 times their length and 6 times their width to stay clear of others while holding. The figures in this assumption were determined from 4 days of observation in the bridge vicinity (April 1991 boat survey) and personal experience. Note that the information from the Marina Design Standards (MDS) appeared to be inappropriate for estimation of the holding area. Use of the MDS appears to be appropriate for sizing the parking areas for the boats and not necessarily for the vessels that are temporarily holding for a bridge opening. Therefore, use of the MDS would have resulted in an unrealistically high number of boats that could not be safely held on either side of the bridge. A more conservative estimate of holding capacity for boats was used to reflect the impacts of currents and the reduction in navigation ability while the boat is sitting motionless (this is especially true for larger vessels) and to take into consideration shorter vessels passing through the queue.

Using these assumptions, the number of boats that can be safely held on either side of the bridge are as follows: for the north side of the S.E. 17th Street Bridge, 11 boats; for the south side of the S.E. 17th Street Bridge, 11 to 12 boats.

Queuing Analysis of Boat Traffic

The daily distribution of the 1991 boat survey data indicated a high concentration of boat traffic during 1 hr of either the morning or afternoon peak period. Therefore, the queuing analysis was conducted for only 1 hr instead of using blocks of time during the peak period. To compensate for any underestimation of delay due to this particular assumption, values for daily instead of peak period average service time were used. The boat survey identified a weighted (by vessels' heights) daily average service time of 0.98 min (as opposed to a peak average of 0.50 min) per vessel during the weekend and 2.45 min per vessel for the weekday.

The projected number of vessels in the average peak hour queue was multiplied by the overall daily weighted average vessel service time (estimated from the boat survey) to determine the average duration of bridge opening during the peak hour. The bridge survey identified a weighted daily average service time of 0.98 min per vessel during the weekend and 2.45 min per vessel for weekdays. These different service times probably result from the lower vessel volumes on weekdays. The same amount of time is needed to raise and lower the bridge regardless of the number of vessels passing underneath. The lower number of weekday vessels allocates this time to fewer vessels, thus increasing the average service time (minutes per vessel crossing). With only a few exceptions, the minimum bridge opening time was 5 min. To reflect actual operating characteristics in the analysis, 5 min was used as the minimum bridge opening time. Because many of the bridge openings during the weekday were to allow 5 vessels or fewer to pass underneath, this sample was not used to calculate bridge opening duration. Instead, the weekend average service time of 0.98 min per vessel was used to calculate both weekend and weekday bridge opening duration. This service time includes the time for opening and closing the bridge. Calculated bridge opening times were used when the projected vessel queues resulted in estimated bridge openings greater than 5 min.

The queuing analysis indicates that the bridge opening time is, for the most part, the same when one to five vessels pass underneath. This means that during times of low vessel traffic, such as the weekday morning peak period, the duration of each bridge opening will be the same for both the existing bridge and the 55-ft (16.77-m) bascule bridge option [i.e., no-build versus a 55-ft (16.77-m) moveable bridge]. The frequency of bridge openings would be reduced with the 55-ft (16.77-m) moveable bridge option. Data from the bridge survey indicate that currently during the morning peak hour, two vessels more than 45 ft (13.72 m) in height can be expected to pass underneath the S.E. 17th Street bridge. During the afternoon peak hour, seven vessels were counted with a height exceeding 45 ft (13.72 m).

The vessel queues during the weekday peak hours in 2010 (2050) will not reach capacity under the current 15-min operating scenario or 30-min bridge opening scheme. Weekend vessel queues are at or near capacity during the current afternoon peak operating scheme, as shown in Table 2. Weekend vessel queues would be at or near capacity for the existing 15-min bridge opening cycle in 2010 under a 55-ft (16.77-m) bridge replacement option (Table 2) using 3 percent per year growth in boat traffic. Weekend vessel queues are expected to increase by 100 percent of the existing holding area capacity under the 30-min bridge opening option both in 1991 and 2010, as demonstrated in Table 3.

Average vessel delay and total vessel delay for the peak hour was calculated on the basis of the existing 15-min bridge opening cycle, a 30-min bridge opening option, the vessel queue, and the service rate. Results for 1991 and 2010 (2050) under a 55-ft (16.77-m) bridge replacement option are summarized in Tables 2 and 3.

Queuing Analysis of Vehicle Traffic

The existing vehicle queues are about 1,000 to 1,500 (304.88 to 457.32 m) ft behind the two intersections during the peak hour. Vehicle queues were calculated based on the existing and forecasted length of bridge openings. One result of using a minimum opening time was that vehicle queues per bridge opening for the 25-ft and 55-ft (7.622-m and 16.77-m) bridge

TABLE 2 Peak Season Vessel Delay Analysis (15-min Bridge Opening Scenario)

Year	15-Minute Bridge Operating Scheme	Vessel Queue	Total Vessel Delay (in minutes)	Peak "Hour" Delay 15 min. Cycle X 4 (in minutes)	Daily Vessel Delay (in hours)
25' (7.6m) Bridge					
1991	Weekday	3	27	108	9
1991	Weekend	11**	131	524	34
2010 (2050)	Weekday	5	45	180	15
2010 (2050)	Weekend	20*	476	1904	92
55' (16.7m) Bridge (With 45-Foot (13.73m) Effective Clearance)					
2010 (2050)	Weekday	3	27	108	9
2010 (2050)	Weekend	11**	131	524	34

* Exceeds maximum vessel holding capacity.

** Vessel queue at holding capacity.

Note: Daily delay was calculated by converting four 15-minute bridge cycles into an hourly volume, taking into account the bridge opening duration, and then dividing by the peak hour factor of .15 derived from the boat survey data.

during the weekday a.m. and p.m. peak hours were identical, even though vessel volumes were not. The actual number of bridge openings during the peak hour will be less for the 55-ft (16.77-m) bridge, especially during the morning peak hour. Data from the bridge survey indicate that currently during the weekday a.m. peak hour, one vessel more than 50 ft (15.24 m) high can be expected to pass S.E. 17th Street. During the weekday p.m. peak hour, four vessels taller than 55 ft (16.77 m) were counted.

Actual 1991 and forecasted 2010 peak hour traffic was converted to vehicle arrivals per minute to determine the length of the vehicle queue on the basis of the estimated duration of the bridge opening. The base year 1991 and 2010 (2050) p.m. peak hour traffic volumes were used to determine peak hour vehicle traffic crossing the bridge. Both vessel and vehicle queues for 1991 and 2010 (2050) during the weekday p.m. peak hour and the weekend p.m. peak hour are presented in Tables 4 and 5 for the 15-min and 30-min bridge opening cycles, respectively.

Because the weekday peak hour bridge opening duration is the same for both the existing bridge and the 55-ft bridge, the vehicle queues per bridge opening would be the same for either option. The frequency of bridge openings and the associated vehicle queues will be reduced with the 55-ft bridge.

Average and total vehicle delay were calculated for the different bridge options on the basis of the length of the bridge

TABLE 3 Peak Season Vessel Delay Analysis (30-min Bridge Opening Scenario)

Year	30-Minute Bridge Operating Scheme	Vessel Queue	Total Vessel Delay (in minutes)	Peak "Hour" Delay 30 min. Cycle X 2 (in minutes)	Daily Vessel Delay (in hours)
25' (7.6m) Bridge					
1991	Weekday	6	102	204	19
1991	Weekend	22*	546	1092	71
2010 (2050)	Weekday	11**	214	428	35
2010 (2050)	Weekend	41*	1399	2798	133
55' (16.7m) Bridge (With 45-Foot (13.73m) Effective Clearance)					
2010 (2050)	Weekday	6	102	204	19
2010 (2050)	Weekend	22*	546	1092	71

* Exceeds maximum vessel holding capacity.

** Vessel queue at holding capacity.

Note: Daily delay was calculated by converting two 30-minute bridge cycles into an hourly volume, taking into account the bridge opening duration, and then dividing by the peak hour factor of .15 derived from the boat survey data.

TABLE 4 Peak Season Vessel and Vehicle Queues (15-min Bridge Opening Scenario)

Year	15-Minute Bridge Operating Scheme	Vessel Queue	Vehicle Queue	
			Westbound	Eastbound
25' (7.6m) Bridge				
1991	Weekday	3	88	69
1991	Weekend	11**	176	139
2010 (2050)	Weekday	5	98	78
2010 (2050)	Weekend	20*	358	283
55' (16.7m) Bridge (With 45-Foot (13.73m) Effective Clearance)				
2010 (2050)	Weekday	3	98	78
2010 (2050)	Weekend	8	143	113

* Exceeds maximum vessel holding capacity.

** Vessel queue at holding capacity.

opening (which is determined by the vessel queue) and the time it takes for the vehicle queue to dissipate. The delay associated with the vehicle queue was calculated on the basis of the length of the vehicle queue, the speed of the roadway, and the capacity of the roadway.

For the purpose of illustrating the method used to determine vessel and vehicle queues and delays, the following example shows the calculations step by step:

Calculation of Queues and Delays

The queue and delay procedures are summarized in the following steps:

1. Calculate vessel queue;
2. Determine bridge opening time required to clear vessel queue;
3. Calculate vehicle queue on the basis of hourly traffic and duration of bridge opening;
4. Calculate vessel delay on the basis of bridge cycle length and time required to clear the queue; and
5. Calculate total vehicle delay on the basis of duration of bridge opening and time required to clear the queue, including queue dissipation.

Example of Queue Length Estimation

Step 1

The vessel queue is determined by the bridge cycle length, currently 15 min between openings, and average hourly vessel traffic. For the base year (1991), the weekend p.m. peak vessel traffic during the hour from 2 to 3 p.m. was 45 vessels per hour. This translates to 0.75 vessels per minute arriving

TABLE 5 Peak Season Vessel and Vehicle Queues (30-min Bridge Opening Scenario)

Year	30-Minute Bridge Operating Scheme	Vessel Queue	Vehicle Queue	
			Westbound	Eastbound
25' (7.6m) Bridge				
1991	Weekday	6	103	81
1991	Weekend	22**	352	299
2010 (2050)	Weekday	11**	212	167
2010 (2050)	Weekend	41**	733	579
55' (16.7m) Bridge (With 45-Foot (13.73m) Effective Clearance)				
2010 (2050)	Weekday	5	98	78
2010 (2050)	Weekend	17**	286	226

* Exceeds maximum vessel holding capacity.

** Vessel queue at holding capacity.

at the S.E. 17th Street Bridge. A 15-min bridge cycle forces 11 vessels to queue up before the next bridge opening.

Step 2

The vessel survey indicated that the weighted average vessel service flow rate (duration of bridge opening divided by number of vessels that pass underneath) was 0.98 min per vessel for the weekend. A queue of 11 vessels would then result in a bridge opening duration of 10.8 min.

Step 3

The number of westbound and eastbound 1991 p.m. peak hour vehicles traveling on the S.E. 17th Street Bridge are 2,103 and 1,661, respectively. This weekday peak hour traffic estimate was converted to weekend peak hour estimate using a factor (the weekend p.m. peak is 0.93 of the weekday p.m. peak) derived from a comparison of the weekday and weekend peak hour bridge counts conducted in March 1991. The resulting weekend p.m. peak hour (2 to 3 p.m.) vehicle traffic estimates used in this example are as follows: westbound 1,956 and eastbound 1,545. Similar weekend volumes for 2010 (2050) are as follows: westbound 2,190 (i.e., 2,355 × .93) and eastbound 1,730 (i.e., 1,860 × .93).

1991 peak hour (weekend) vehicle traffic is then converted to vehicle arrivals per minute. The vehicle queue is calculated as the number of vehicles arriving at the bridge per minute multiplied by the duration of the bridge opening.

In this example, the queue length for 1991 westbound weekend traffic is calculated as follows (see Table 4):

32.6 vehicles per minute × 10.8 min (5 min for weekday)
= 352 vehicles, or 176 per lane

The queue length for 1991 eastbound weekend traffic is calculated as follows (see Table 4):

25.8 vehicles per minute × 10.8 min (5 min for weekday)
= 278 vehicles, or 139 per lane

Example of Delay Estimation

Step 4: Vessel Delay per Bridge Opening Cycle

Vessel delay is a function of time waiting for the bridge to open and the time spent clearing the queue. Assuming vessels arrive randomly at the bridge, the average vessel delay as a result of the bridge cycle would be one-half of the cycle length, or, in this case, 7.5 min. The average vessel delay resulting from the vessel queue would be one-half of the duration of the bridge opening, or 5.4 min per vessel [2.5 min. per vessels for weekday (5.0 × 0.5)] minus the time it would normally take to pass under the bridge (.98 min). Total vessel delay per bridge cycle is calculated as the sum of the bridge opening cycle and queue delays multiplied by the number of vessels in the queue.

[(Bridge opening cycle delay × # of boats per cycle)
+ (queue clearance delay × # of boats per cycle)]
= total boat delay per bridge cycle

For a 1991 weekend, vessel delay is calculated as follows (see Table 2):

(7.5 min × 11 boats)
+ [(5.4 min − .98 min) × 11 boats] = 131 boat min

For a 1991 weekday, vessel delay is calculated as follows (see Table 2):

(7.5 min 3 boats)
+ [(2.5 min − .98 min) × 3 boats] = 27 boat min

Step 5: Total Vehicle Delay

Vehicle delay was estimated by applying a bottleneck concept developed by Adolf May (*1*). A bottleneck (in this case, a draw bridge) on a roadway may be represented by the behavior of a queue during one cycle of a traffic signal. This method assumes that vehicles arrive randomly at the bridge in spite of being interrupted by the two intersections at either end of the bridge. This seems to be a reasonable assumption because the bridge opening cycle was so much greater than the cycle at the intersections. When the bridge is open, it probably does not matter whether the arriving vehicles would stop at the intersections or at the bridge because the intersections are not far from the bridge.

May's bottleneck model is formulated as follows:

q = average arrival rate of traffic (vehicle per minute) upstream of the bottleneck;
s = saturation flow rate or capacity [vehicle per minute—1,850 vehicles per hour per lane (*2*)] of uninterrupted flow;
sr = flow rate (vehicles per minute) at bottleneck during blockade (zero when bridge is open to boat traffic);
r = duration of blockade (bridge opening time in minutes);
to = time for queue to dissipate after the blockade is removed (in minutes); and
tq = total elapsed time from start of blockade (bridge opening) until free flow resumes [$r + to$ (minutes)].

The duration of the queue is calculated in Equation 1:

$$tq = r\,(s - sr) \,/\, (s - q) \qquad (1)$$

The number of vehicles affected is calculated in Equation 2:

$$N = q \times tq \qquad (2)$$

The average number of minutes of vehicle delay is calculated in Equation 3:

$$d = r\,(q - sr) \,/\, 2q \qquad (3)$$

Total vehicle minutes of delay are calculated in Equation 4:

$$D = r \times N / 2 \quad (4)$$

These equations have been used to estimate total vehicle delays. For example, for 2010 p.m. peak weekend operation under a 15-min bridge opening scheme, queue duration, average vehicle delay, and total vehicle delay are calculated as follows.

For queue duration in minutes, Equation 1 is used. The following equations are for 2010 westbound weekend traffic:

$$s = 1{,}850 \times 2 \text{ (lanes)} / 60 = 61.7 \text{ vehicles/minute}$$

$$q = 2{,}355 \text{ (weekday vph)} \times .93 = 2{,}190 \text{ vph, or}$$

$$q = 2{,}190 / 60 = 36.5 \text{ vehicles/minute}$$

$$r = 8 \text{ vessel queue} \times .98 \text{ min service time} = 7.84 \text{ min (5 for weekday operation)}$$

$$tq = 7.84\,(61.7 - 0) / (61.7 - 36.5) = 19.20 \text{ min of queue duration}$$

The duration of queue for bridge opening is 7.84 min. The amount of time necessary to dissipate the entire queue is 19.20 − 7.84 = 11.36 min.

The following equations are for 2010 eastbound weekend traffic:

$$q = 1{,}728 / 60 = 28.8 \text{ vehicles/minute}$$

$$tq = 7.84\,(61.7 - 0) / (61.7 - 28.8) = 14.70 \text{ min of queue duration}$$

The duration of queue for bridge opening is 7.84 min. The amount of time necessary to dissipate the entire queue is 14.70 − 7.84 = 6.86 min.

The average vehicle delay in minutes is calculated using Equation 3:

$$d = 7.84 / 2 = 3.92 \text{ min}$$

because $sr = 0$ for both westbound and eastbound (2.5 for weekday).

The total number of vehicles affected is calculated using Equation 2. The following equation shows the number of vehicles for westbound weekend traffic:

$$36.5 \times 19.20 = 701 \text{ vehicles}$$

The following is the equation for eastbound weekend traffic:

$$28.8 \times 14.7 = 423 \text{ vehicles}$$

Total vehicle delay is calculated using Equation 4. For 2010 westbound weekend traffic, the delay is as follows:

$$7.84 \times 701 / 2 = 2{,}748 \text{ min}$$

For 2010 eastbound weekend traffic, the delay is as follows:

$$7.84 \times 423 / 2 = 1{,}658 \text{ min}$$

The calculation of queue duration indicated that under most circumstances the queue will dissipate during the required 15-min bridge cycle.

SUMMARY FINDINGS AND CONCLUSIONS

The queuing procedures presented in this paper provided useful information for evaluation of the proposed replacement facilities for the existing 25-ft (7.62-m) moveable bridge from the traffic operation standpoint. Obviously, if the elimination of delays to vehicular and vessel traffic is the only criterion by which to judge the proposed replacement facilities, the tunnel would be the superior option. Comparably, an 85-ft (25.91-m), fixed-span bridge would be a viable option if ves-

TABLE 6 Total Daily Delay Comparison Analysis for Average Peak Season Weekday (Delay Due to Bridge Openings)

Alternative	Cycle	1991 Vehicle Hours	1991 Vessel Hours	2010/2050 Vehicle Hours	2010/2050 Vessel Hours
55' (16.77m) Bascule Bridge	15-min	na	na	1,196	9
	30-min	na	na	933	19
25' (7.62m) Bascule Bridge	15-min	946	9	1,196	15
	30-min	724	19	2,710	35*
Tunnel	15-min	na	na	0	0
	30-min	na	na	0	0
Fixed-Span Bridge (65' or 85') (19.82m or 25.91m)	15-min	na	na	na	na
	30-min	na	na	na	na

* Under this scenario the vessel queue would be at holding capacity.
na = not applicable

TABLE 7 Total Daily Delay Comparison Analysis for Average Peak Season Weekend Day (Delay Due to Bridge Openings)

Alternative	Cycle	1991 Vehicle Hours	1991 Vessel Hours	2010/2050 Vehicle Hours	2010/2050 Vessel Hours
55' (16.77m) Bascule Bridge	15-min	na	na	3,636	34*
	30-min	na	na	8,582	71**
25' (7.62m) Bascule Bridge	15-min	2,865	34*	8,970	92**
	30-min	6,656	71**	18,577	133**
Tunnel	15-min	na	na	0	0
	30-min	na	na	0	0
Fixed-Span Bridge (65' or 85') (19.82m or 25.91m)	15-min	na	na	na	na
	30-min	na	na	na	na

* Under this scenario the vessel queue would be at holding capacity.
** Under this scenario the vessel holding capacity would be exceeded.
na = not applicable

sels with mast heights of 85 ft (25.91-m) were eliminated. The existing and projected daily boat traffic mast height distributions indicate that about 1 percent of the boats using the ICWW require more than 85 ft (25.91 m) of clearance during the weekends. On weekdays, about 1.5 percent of the boats appear to require this amount clearance.

Summary findings from the queuing and delay analysis are presented in Tables 6 and 7 for an average weekday and weekend day operation, respectively. Hours of delay to vessel and vehicular traffic were used in the economic analysis to rank the proposed replacement facilities to the existing moveable bridge. Furthermore, the analysis provided useful guidance for a more efficient operation of the existing bridge. As shown in Tables 6 and 7, a reduction of about 22 percent in vehicular traffic delays is expected under the 30-min bridge opening scheme for the weekdays relative to the 15-min scheme. The existing bridge operation was recently changed from the 15-min opening cycle to a 30-min scheme. Initial observations appear to confirm the findings from the queuing analysis.

ACKNOWLEDGMENTS

Materials presented in this paper are solely the views and opinions of the authors and do not necessarily represent the official policy of FDOT. The authors would like to thank FDOT staff and Scheda Ecological Associates for their cooperation and constructive input during the course of this study.

REFERENCES

1. *Traffic and Transportation Traffic Engineering Handbook,* 2nd ed. Prentice Hall, Englewood Cliffs, N.J., 1982, pp. 467–469.
2. Parsons Brinckerhoff, *Level of Service Manual for developing Generalized LOS Tables.* Florida Department of Transportation, March 1992.

Publication of this paper sponsored by Committee on Methodology for Evaluating Highway Improvements.

Evaluation of the Spatial Distribution of Activity Center Parking Facilities

RANDY MACHEMEHL AND DAVID MILLAR

Many existing and proposed activity centers, such as research complexes, university campuses, and commercial and industrial centers, have large numbers of employees, clients, and visitors who drive automobiles and compete for desirable parking spaces. Most drivers tend to base the desirability of parking spaces on their proximity to an ultimate destination; that is, they attempt to minimize walking distances. As the activity center grows, additional parking facilities must be added; however, locations for new parking facilities that will minimize walking distances for all or selected groups of users are not easily selected. Decisions on the best locations for additional parking facilities for a large activity center are, therefore, difficult. An algorithm describing traveler choices of available activity center parking spaces was implemented in a simulation model and applied to a typical case study. Survey data describing actual traveler parking choices and walking distances were collected and compared with simulation predictions before the simulation was used in the decision process.

Many existing and proposed activity centers, such as research complexes, university campuses, and commercial and industrial centers, have large numbers of employees, clients, and visitors who drive automobiles and compete for desirable parking space. Most drivers tend to base the desirability of parking spaces on their proximity to an ultimate destination; that is, they attempt to minimize walking distances. If an activity center is spatially large, any random sample of arriving drivers will likely have many potential destinations and parking opportunities. Drivers destined for several different buildings within the center may compete for the same parking space in one parking facility, and several drivers destined for one building may compete with others for space in several different parking facilities. As the activity center grows, additional parking facilities must be added; however, locations for new parking facilities that will minimize walking distances for all or selected groups of users are not easily selected. Decisions on the best locations for additional parking facilities for a large activity center are, therefore, difficult. An algorithm describing traveler choices of available activity center parking spaces was implemented in computer code as a simulation model and applied to a typical case study. Survey data describing actual driver parking choices and walking distances were collected and compared with simulation predictions before the simulation was used in the decision process.

R. B. Machemehl, Department of Civil Engineering, University of Texas, Austin, Tex. 78712. D. Millar, WHM Engineering Consultants, Inc., 2717 Rio Grande, Austin, Tex. 78705.

JOHNSON SPACE CENTER CASE STUDY

The National Aeronautics and Space Administration's (NASA's) Johnson Space Center (JSC) in Houston is a typical example of a large activity center with multiple employment sites and parking facilities. The central portion of JSC is called the mall area and is the employment site for roughly 7,000 people. As the mall developed over the last 3 decades, locations of new buildings and parking facilities were controlled by a master planning process that did not attempt to quantify parking-related walking distances.

Faced with concerns about parking availability and walking distances and anticipating expansion of the existing work force, JSC officials commissioned a study of parking and access conditions for the entire JSC. Principal questions to be answered by the study were the following: Is there a shortage of parking spaces? What are current walking distances? If additional parking spaces are needed, where should they be constructed?

The first two questions were answered through primary data collection, including traffic and parking accumulation counts and two user surveys. These data indicated the current total supply of parking spaces is slightly greater than the peak accumulated demand. Walking distances reported by survey respondents were large, with a mean of almost 800 ft and a 90 percentile approaching .25 mi.

With current peak parking demands only slightly less than the available supply, anticipated work force expansion of 1,000 to 1,500 people would clearly create the need for more parking facilities. However, many options were available for expanding the parking space supply. These included many small or few large facility expansions that could be located many different places. The definition of "best" recommended expansion was determined to be that with the largest positive impact on walking distances per dollar of facility cost. To estimate the effect on walking distances of the many options and combinations, a robust methodology was needed.

An algorithm describing the traveler's decision process in choosing a parking space with developed and implemented in a computer simulation model. Development of the algorithm and simulation model is described next.

PARKING SPACE SELECTION CRITERIA

Employees driving to work at JSC or another activity center choose a parking location on the basis of several criteria. Like most commuters, however, their primary consideration is probably the proximity of the available parking space to their work sites, or, in other words, their walking distance. However, only in rare cases can commuters walk the straight line distance from their parked automobiles to their work sites because of obstructions, including other parked automobiles, buildings, trees, lakes, and permitted street crossing locations. Therefore, the simulation process was designed to use a rectangular distance computed as the sum of the absolute values of the differences of the X and Y coordinates of parking facilities and building work sites.

Most, if not all, commuters would likely prefer to choose a parking space in the facility closest to their work site. However, one parking facility may be closest, or best, by the walking distance criterion, for several work sites. The combined parking demands for these work sites may exceed the capacity of that one facility. Therefore, some drivers simply cannot select the closest, or best, choice. Further, two or more parking facilities may differ in walking distance to a given work site by only a small amount. Assuming that all drivers destined for that work site would chose the marginally closest facility would be unreasonable, especially if the nearly equidistant parking areas are large.

The simulation process sequentially assigned small increments of parking demand, associated with each work site, to the most likely available parking facilities. Assigning all demand to the marginally closest facility would exemplify both problematic situations described in the previous paragraph. The algorithm implemented here uses a probability of drivers selecting each facility that is inversely related to the walking distance raised to an exponent. This means that two facilities that are nearly equidistant from a work site will have nearly equal probabilities and will therefore receive nearly equal parking assignments. It also means that some parking demand is not assigned to the closest facility, but this is reasonable, considering human variability and parking facility spatial size.

The increment of parking demand from each destination site assigned to each parking facility at each simulation step could be identified as A_{ij} and is determined by the following relationship:

$$A_{ij} = aB_iq_{ij}$$

where

a = 1/number of simulation increments,
B_i = parking space demand for Building i
= number of Building i automobile travelers, or automobile occupancy, and
q_{ij} = $(1/D_{ij}^P)/\Sigma_{j=1}^n (1/D_{ij}^P)$
= probability of travelers destined for Building i selecting Parking Facility j during this simulation step

where

D_{ij} = $\text{ABS}(Y_i - Y_j) + \text{ABS}(X_i - X_j)$
= sum of absolute values of differences of respective cartesian coordinates for Building i and Parking Facility j,
P = exponent of rectangular walking distance, and
n = number of parking facilities.

As each parking demand increment is added to any parking facility, the assigned demand is compared with the facility capacity, and if the whole increment or any part causes the assigned quantity to exceed the capacity, the excess is withheld until the next simulation step at which probabilities are revised. Additionally, after each increment of parking demand is allocated to available parking facilities during the incremental assignment process, probabilities are recomputed. At every incremental stage of the simulation, every available (unfilled) parking facility has a nonzero chance of receiving drivers from all work sites. The magnitude of the probability for more distant facilities compared with those closer to the work site depends on the relative rectangular distances and the exponent to which the distance has been raised.

WALKING DISTANCE EXPONENT

The magnitude of the exponent for distance effectively simulates the degree to which drivers respond to walking distance. As the exponent for rectangular distance increases, differences in walking distance produce greater allocation probability differences. In an area like the JSC mall, where many parking facilities have similar walking distances for any one work site, a small magnitude exponent means that drivers for each work site would be allocated to many different facilities. That is, drivers are not sensitive to walking distance. As the exponent increases, differences in walking distances among alternative parking facilities produce greater sensitivity or greater assignment probability differences. Effects of increasing the exponent are shown in Figure 1, where the numbers of parking facilities to which drivers are allocated are plotted against the walking distance exponent magnitude.

The figure indicates that as the exponent increases from 3 to 9, sensitivity of drivers to walking distances increases dramatically and the number of facilities receiving parking allocations correspondingly decreases. However, as the exponent is increased above 9, little additional sensitivity is gained. On the basis of this sensitivity study and analyses of the JSC mall user surveys, a value of 9 was tentatively selected for the walking distance exponent.

INCREMENTAL STEP SIZE

The magnitude of the parking demand increment allocated during each successive simulation step is also important. The number of drivers allocated from each work site to each parking facility during each simulation step is the product of this

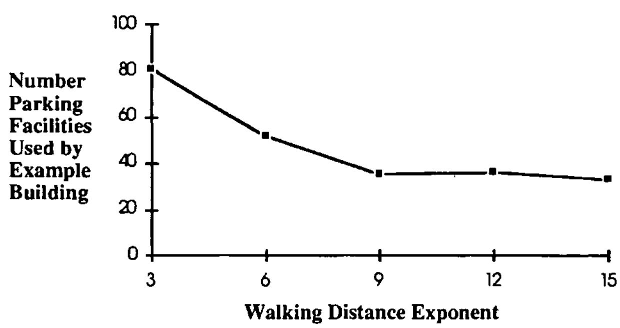


FIGURE 1 Simulated number of parking facilities used by drivers for one JSC mall building versus walking distance exponent.

step size (expressed as a decimal percentage), the probability associated with each parking facility and the work site total parking demand. The maximum step size must produce a number, through this multiplication, that is less than the capacity of the smallest parking facility. For the JSC mall area, a step increment of 0.01 is small enough to satisfy this criterion and results in a maximum of 6 or 7 drivers being allocated from each large work site during each simulation step. Sensitivity analyses of the step size for the JSC mall indicate that values smaller than 1 percent did not significantly improve the allocation accuracy.

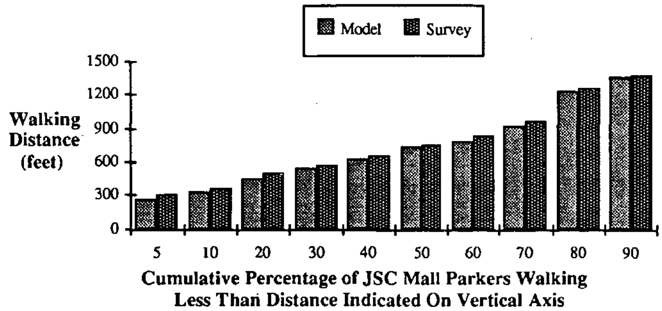


FIGURE 2 Comparison of survey- and simulation-derived mall area walking distances.

JSC MALL AREA DESCRIPTION FOR SIMULATION ANALYSES

Like other behavioral models, the accuracy of the parking simulation model improves as the data describing sources and sinks are disaggregated. That is, smaller spatial descriptions of work sites and parking facilities produce a more realistic simulation. Therefore, current work sites in the JSC mall area were described as 51 separate entities, each with coordinates and parking demand. Parking facilities were disaggregated to form 97 separate parking areas.

Current total parking space demand in the mall area was estimated at 6,429, and total available spaces were counted at 7,089. The demand total was developed through vehicle accumulation in JSC estimated from hourly counts of all entering and exiting traffic and work site employment figures. These data sources yielded an estimated vehicle occupancy of 1.1 persons per vehicle.

Additionally, surveys of civil service and contractor employees in the mall area were conducted during April and May 1991. A total of 612 persons responded to the survey, for a response rate of 71 percent, which is phenomenal for this type of data-acquisition process. In addition to a number of opinion-oriented questions, respondents indicated the locations of their respective work and parking sites by marking each on a mall area map, which was part of the survey instrument. Observations of walking paths from parking facility to work sites confirmed the assumption that the density of buildings in the mall generally requires those paths to follow the legs of right triangles instead of the hypotenuse. Therefore, walking distances were calculated from survey results using this path characteristic.

COMPARISON OF SIMULATION AND SURVEY WALKING DISTANCES

The survey data were used as the basis for a simulation model validation process. Comparative frequency distributions for simulation model and survey based mall area walking distances are shown in Figure 2.

Comparisons of mean and 90th and 99th percentile walking distances produced by simulation and survey are presented in Figure 3. As in the previous figure, agreement between the simulation and survey data is good.

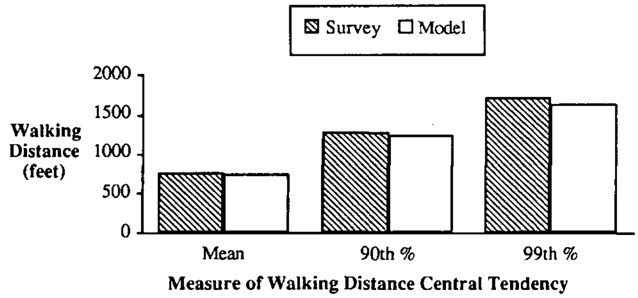


FIGURE 3 Comparison of survey and simulation values of mall area walking distances.

In addition to the visual comparisons of the model and survey walking distances, differences between the two were tested using the nonparametric method of the Kolmogorov-Smirnov two-sample test (*1*). The null hypothesis that the simulation and survey walking distances were drawn from the same population could not be rejected at a 0.2 or higher confidence level. On the basis of the results of both the visual and statistical comparisons, the simulation procedure was accepted as being valid. A second survey and comparison of simulation model and actual walking distances further confirmed this conclusion.

APPLICATIONS

The simulation technique was used to examine the potential effects on walking distances of a series of parking facility additions and modifications. In addition to the rather extreme walking distances for many current employees, the situation was further complicated by a planned increase in JSC employment. Many options for additional surface parking facilities around the periphery of the mall area were available, as were several potentially desirable parking structure sites. A multitude of options including combinations of both surface and structures were compared. The simulation methodology provided a convenient means of evaluating the effects of each alternative on employee walking distances. A recommended program of improvements was finally developed and featured a mixture of surface parking facility expansions, carpooling, and conventional transit options.

SUMMARY

A computer simulation-based methodology for evaluating the effects of alternative parking facility locations on walking distances in an activity center has been developed. The technique has been tested using actual survey data from NASA's JSC in Houston. Following verification of the procedure, it has been used to develop a program of parking facility improvements for the JSC mall area.

REFERENCE

1. S. Siegel. *Nonparametric Statistics for the Behavioral Sciences*. McGraw-Hill, New York, N.Y., 1956.

Publication of this paper sponsored by Committee on Parking and Terminals.

Parking Requirements for Transit-Oriented Developments

THOMAS J. HIGGINS

Local transportation and land use planners are attempting increasingly to develop parking requirements (both minimum and maximum requirements) to encourage transit use and avoid excess parking supply. Planners are focusing particular attention on transit-oriented developments in proximity to transit where tight parking supply, good pedestrian access to transit, and dense development are aimed at increasing transit use. This paper presents a method for setting parking requirements for office, commercial, and industrial developments in proximity to transit stations and stops. The method presented relies on annual employee transportation surveys of the kind typically required under trip-reduction ordinances. These ordinances are now present, or soon will be, in many urban areas and are the result of air quality regulations, traffic management regulations, or both. The method of deriving parking requirements is demonstrated using employee survey data from the city of San Diego. The method derives a range of estimates for parking demand in proximity to transit stops on the basis of high and low use of transit and other alternatives to solo driving, as revealed in the employee survey data. The author draws implications for maximum and minimum parking requirements in San Diego and suggests general cautions in applying the method and areas for further research to improve results from the method.

Localities are increasingly interested in the issue of encouraging transit use through land use policies. Strategies being considered and implemented include locating office developments or housing near transit stations providing convenient pedestrian and bicycle access to transit, revising zoning codes to encourage more density and multiple uses in proximity to transit, and limiting parking supply and locating parking facilities to encourage transit use. For example, the county of Sacramento and city of San Diego, California, as well as the city of Portland, Oregon, are encouraging transit-oriented developments (TODs) in proximity to transit. According to guidelines adopted by Sacramento County (*1*), the purpose is to develop a link between transit and land use "to result in an efficient pattern of development that supports a regional transit system and makes significant progress in reducing traffic congestion and air pollutants."

Parking requirements in local codes are a key issue in planning TODs. To the extent that greater proportions of employees in developments near transit lines and stations use transit compared with employees at comparable developments further from transit, employee demand for parking ought to be less and parking requirements ought to be less. The area around transit stops and stations where lesser parking requirements might be considered is related to how far commuters will walk to transit stations. Generally, the distance is no more than a few blocks, although it all depends on the quality of transit service, typical weather, and perceived risks in walking. Figure 1 shows the cumulative percent of transit users walking to trolley and bus transit in San Diego. Here, weather, safety, and transit service combine to encourage transit use. The biggest bulk of transit users walk less than four blocks to access transit (*2*).

K.T. Analytics, Inc., 885 Rosemount Road, Oakland, Calif. 94610.

PARKING REQUIREMENT ISSUES

One way to develop parking requirements for zoning codes, whether for TODs or other areas, is to base them on periodic surveys of actual parking demand across different land uses (commercial, industrial, residential). One source of such data is ITE. ITE periodically publishes results of local parking demand studies for various land uses. However, the ITE survey results suggest considerable variation in demand by community, even for the same land uses. It appears that parking demand depends on many variables unique to localities and development sites. Local parking surveys, if well executed, can be more accurate than national studies, but still cannot provide lasting predictions of parking demand. The number of cars traveling to and from any building is a function of many variables:

- Particular tenants,
- Price of parking and gasoline,
- State of the economy,
- Proximity to transit service,
- Attractiveness of on- versus off-street parking, and
- Regulations requiring employers to implement traffic-reduction programs.

Even if parking code requirements based on demand studies reflect true parking demand for a period of time, the match is sure to change as the determinants of parking demand vary.

Parking requirements eventually will err on the short side or the long side of actual parking demand, so which way is best to err? Given that the purpose of TODs is to encourage transit use, requirements should be set to encourage transit use. According to the results of at least one recent study, limited parking supplies encourage transit use (*3*). The result of erring on the short side of parking demand may be spillover. For example, if employees find insufficient long-term parking off street and are not attracted to transit or carpooling, they may park in neighborhoods or parking areas designated for shoppers. Thus, if parking requirements are set on the tight side of expected demand, guards against spillover need to be

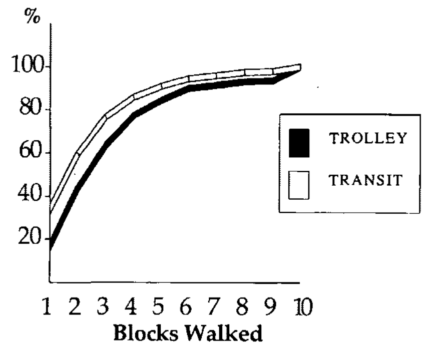


FIGURE 1 The walk to transit.

considered. Two guards are neighborhood resident preferential parking programs to discourage commuters parking on street and short-term parking zones (1 or 2 hr) or parking meters to discourage commuter parking in areas intended for shoppers.

SETTING PARKING REQUIREMENTS FOR TODS

Not only are parking demand surveys unlikely to reflect parking demand as conditions underlying demand change, such surveys are costly and time-consuming. A full-blown parking demand survey involves space and car counts, license plate turnover studies, and considerable data entry and analysis. Often, localities find surveys sufficiently demanding to contract the task to consulting companies. Here again, time is required to develop and issue a request for proposals, review proposals, select the winner, and negotiate a contract.

For some localities, employee mode-share surveys may offer a preferred alternative to parking demand surveys in setting parking requirements for TODs. Employee surveys assessing proportions of solo drivers, carpool users, transit patrons, and walkers may be used to deduce parking demand without the need for counting cars. Furthermore, annual employee surveys at employment sites are required by a growing number of local trip-reduction ordinances. Consequently, the survey data are never very dated, and no new survey instruments or data collection procedures are needed to develop parking demand estimates. The only requirement is a sample of employees drawn from employment sites in close proximity to transit. Preferably, the sample should include employers representing the usual breakdowns in parking codes: office, commercial, and industrial.

Table 1 shows how employee survey information may be used to arrive at parking demand estimates at employment sites near transit. The data in the table are based on a city of San Diego 1991 employee survey carried out under trip-reduction ordinance requirements. To arrive at a set of employers for the analysis, city staff drew a sample of employers from the data base of employees by employment site and assigned each employer to a matrix by proximity to transit (within and outside .25 mi of a transit trunk line) and land use (office, commercial, and industrial). Employers were drawn at random and assigned to the matrix cells. This procedure ensures that all the variables bearing on mode shares of employees are equally represented across the cells. Possible confounding variables include employer size, a particular transportation demand management (TDM) program encouraging transit and parking pricing. (In the particular illustrative sample, employers in the central business district (CBD) were excluded because parking demand and code requirements there were the subject of a separate study and different policies.)

Specific land uses were selected to reflect likely uses in TODs and to avoid uses with unusual levels of parking demand. For example, office use includes professional services, utility, and city and county, but not hospital and post office. Commercial includes retail, market, and discount, but excludes hotel, bank, and entertainment.

Table 1 involves three steps to arrive at parking demand:

1. Part 1 of the table arrays employee mode share ranges at the sample employment sites. For the sample of employers by each land use type (27 cases in all), the lowest and highest percent mode share was entered into Part 1 of the table, except for obvious outlyers. Solo shares then make up the balance after all alternative mode shares are subtracted from 100 percent. This high-low approach ensures the widest possible range of transit use, and other alternative mode use provides the basis for the parking demand analysis.
2. Part 2 of the table translates these mode shares into high and low parking demand cases. High use of transit, carpools, vanpools, walking, and drop offs translates into the least solo driving and parking demand. This part of the table also contains estimates of parking demand in addition to employee parking demand. Specifically estimated are visitor parking associated with office and industrial uses and shopper demand associated with commercial use.
3. Finally, Part 3 of the table arrays the total parking demand estimated in Part 2 by a range of employee densities found in the land uses for San Diego. The resulting demand expressed in parking spaces per 1,000 ft^2, is the typical ratio found in parking codes.

Certain important assumptions provide the basis for the table:

- Vehicle occupancies: carpool occupancy is assumed to be 2.5 per car, vanpool occupancy is 11 per van.
- Absenteeism, night shifts, and early arrivals and departures: 10 percent reduction for absenteeism and 5 percent for night shifts and early arrivals and departures (*4*).
- Visitor parking: for industrial uses, peak-period visitor rates range from .05 to .2 per employee, so .1 is used, with an 85 percent drive-alone rate (*5*). Visitor parking demand for commercial use is assumed to be the same rate as for industrial use. For office, daily visitors range from .14 to 1.0 per employee, so .5 per employee is assumed. Also assumed is daily turnover of 4 and 85 percent drive alone for visitors (*4, 6*).
- Shopper parking: Studies of shoppers show large downtown retail stores draw a peak weekday demand of about 5.0 shoppers per 1,000 ft^2. Weekend peak shopper demand may exceed weekday demand by 20 to 30 percent; weekend holiday demand exceeds these levels (*4*, p. 103, 123). Commercial retail in the scope of the study (convenience, retail, discount) outside the CBD will attract less than this level, perhaps 3.0 on weekdays and 4.0 to 5.0 on weekends. At 4.0 to 5.0 maxi-

TABLE 1 Parking Space Demand by Land Use and Employee Densities

	Land Use					
	OFFICE		COMMERCIAL		INDUSTRIAL	
1. Hi-Lo Alternative Mode Use	LO	HI	LO	HI	LO	HI
Modes						
Transit	0	16.4	0	7.6	3.1	11.3
Carpool	2.5	20.2	0	10.3	9.8	16.1
Vanpool	0	1.3	0	2.7	0	.4
Walk, Drop, Cycle	0	13.9	1.5	27.7	4.4	9
Solo drive	97.5	48.2	98.5	51.7	82.7	63.2
Total	100	100	100	100	100	100
2. Parking Required						
Per 100 Employees						
Transit	.00	.00	.00	.00	.00	.00
Carpool	1.00	8.08	.00	4.12	3.92	6.44
Vanpool	.00	.12	.00	.25	.00	.04
Solo drive	82.88	40.97	83.73	43.95	70.30	53.72
Shoppers	.00	.00	148.75	119.00	.00	.00
Visitors	10.63	10.63	8.50	8.50	8.50	8.50
Total	94.50	59.79	240.98	175.81	82.72	68.70
3. Parking Demand						
By Employee Density						
	Parking Demand Per 1000 Sq. Ft.					
Employees/1000 Sq. Ft.						
4.0	3.78	2.39	9.64	7.03	3.31	2.75
3.5	3.31	2.09	8.43	6.15	2.90	2.40
3.0	2.84	1.79	7.23	5.27	2.48	2.06
2.5	2.36	1.49	6.02	4.40	2.07	1.72
2.0	1.89	1.20	4.82	3.52	1.65	1.37
1.5	1.42	.90	3.61	2.64	1.24	1.03

mum and 2.0 employees per 1,000 ft^2 (densities in San Diego for neighborhood and community shopping range from 1.0 to 3.0 employees per 1,000 ft^2) (*7*), shoppers per employee range from 2.0 to 2.5. The higher figure is used to create the most parking demand in the low alternative mode case in Table 1; the lower figure is used to create a lower range in the high alternative mode case. In downtowns, about 50 percent of shoppers walk in (*4*, p. 103). They are residents or commuters already parked elsewhere and generating no additional parking demand. Assume only 30 percent walk in for cases in the study sample. Of the remaining 70 percent coming in cars, assume 85 percent are drivers, the rest passengers.

Figure 2 graphically displays the range of parking demand results from Part 3 of Table 1.

CONCLUSIONS AND RECOMMENDATIONS

By creating their own Table 1 based on repeated annual employee surveys, localities can derive guidelines for parking

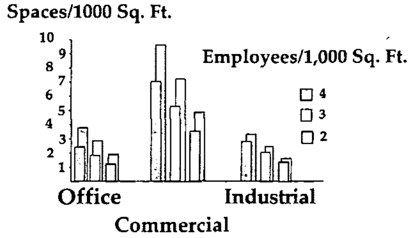


FIGURE 2 High and low parking demand by land use and employee density.

requirements in proximity to transit stops and stations. For localities looking to revise parking minimums or develop maximum parking requirements, the table will suggest possible limits on the minimums and maximums across ranges of employee densities for office, commercial, and industrial uses. The following conclusions and guidelines for San Diego (non-CBD) illustrate how the particular parking demand analysis applies to one locality.

Office

- Current policy: City engineering guidelines for local discretionary projects specify a minimum of 3.33 spaces per 1,000 ft^2, the same as required by the city code for commercial office classification.
- Results of the analysis: Parking demand ranges from 2.4 to 3.8 spaces per 1,000 ft^2 at a density of 4.0 employees per 1,000 ft^2. This density is typical of offices in the study area, except corporate offices in which densities are closer to 3.0 persons per 1,000 ft^2 (*7*).
- Recommendations: The analysis suggests a minimum of 2.0 spaces per 1,000 ft^2 and a maximum of 4.0 per 1,000 ft^2 would be a reasonable guideline for general office use. For corporate offices, a maximum of 3.0 per 1,000 ft^2 is recommended. If and where alternative mode use approaches 50 percent (some CBD employers with aggressive TDM programs may be applications), a maximum of 2.5 spaces per 1,000 ft^2 would be reasonable at usual employee densities. For comparison purposes, the ITE design standard for general office buildings outside downtowns is a minimum of 3.3 spaces per 1,000 ft^2 (*4*, Table 6-30).

Commercial

- Current policy: City engineering guidelines for local discretionary projects specify a minimum of 5.0 spaces per 1,000 ft^2. The city code for neighborhood commercial classification specified is the same amount, 5.0 per 1,000 ft^2. However, retail uses under the community commercial code applicable to "older established communities" (Section 101.0427) are required to provide only a minimum of 1.25 spaces per 1,000 ft^2.
- Results of the analysis: Peak weekend (nonholiday) parking demand ranges up to 7.0 spaces per 1,000 ft^2 at the highest employee density (3.0 employees per 1,000 ft^2) and the lowest alternative mode use. Probably the most realistic assumption falls between the extremes, where employee densities are a little less than 3.0 and solo driving shares are less than 98 percent.
- Recommendations: A minimum of 3.0 per 1,000 ft^2 and a maximum of 6.0 per 1,000 ft^2 is suggested. For comparison purposes, a recent national survey of localities finds most localities specify a minimum of 5.0 per 1,000 ft^2 for retail, convenience, grocery, and hardware stores (*8*).

Industrial

- Current policy: City engineering guidelines for local discretionary projects specify 2.5 per 1,000 ft^2. The city code for M-L1 (assembly, fabrication, design, and development) specifies a minimum of 3.33 spaces per 1,000 ft^2. The city code for M-1P (assembly, distribution, fabrication, testing, and repair) for industrial parks specifies .67 space per employee on the shift with the most employees. At densities of 2.0 to 3.0 employees per 1,000 ft^2, this ratio translates to 1.3 to 2.0 spaces per 1,000 ft^2 of development. In short, code and policy appear to require between 1.0 and 3.3 spaces per 1,000 ft^2.
- Results of the analysis: Parking demand ranges from 1.0 to 2.9 spaces per 1,000 ft^2, up to a maximum light industry density of 3.5 employees per 1,000 ft^2. Typically, employee density at light industry, assembly, and distribution would be no more than 3.0 employees per 1,000 ft^2. At this employee density and assuming least use of alternative modes, the most parking demand expected would be 2.5 spaces per 1,000 ft^2.
- Recommendations: The analysis suggests a minimum of 1.0 space per 1,000 ft^2 and a maximum of 3.0 spaces per 1,000 ft^2 would be a reasonable guideline for industrial uses of the kind in the study and possible for TODs. If and where alternative mode use approaches 40 percent (60 percent solo) or employee densities are 3.0 persons per 1,000 ft^2 or less, a maximum of 2.5 spaces per 1,000 ft^2 would be reasonable. For comparison, most localities require minimums of 1.3 to 2.5 spaces per 1,000 ft^2 (*8*).

Summary

Office

- A minimum of 2.0 spaces per 1,000 ft^2, and a maximum of 4.0 per 1,000 ft^2;
- For corporate offices, a maximum of 3.0 per 1,000 ft^2; and
- If and where alternative mode use approaches 50 percent, a maximum of 2.5 spaces per 1,000 ft^2 (at usual employee densities).

Commercial

- A minimum of 3.0 per 1,000 ft^2, and a maximum of 6.0 per 1,000 ft^2.

Industrial

- A minimum of 1.0 space per 1,000 ft^2, and a maximum of 3.0 spaces per 1,000 ft^2; and
- If and where alternative mode use approaches 40 percent or employee densities are 3.0 persons per 1,000 ft^2 or less, a maximum of 2.5 spaces per 1,000 ft^2.

Application Considerations

The parking recommended requirement guidelines must be applied with reason and caution. Three important considerations are as follows:

- The importance of site variables. As found in some of the sample cases for San Diego, a building may be close to transit, but there may be barriers to transit access. Highways, waterways, or other developments may be such barriers. Thus, expected transit use may be lower than for other comparable developments close to transit without such barriers.
- Handling peak holiday demand. The guidelines for commercial parking demand are derived for peak weekend demand, but not for holiday demand. Therefore, an important consideration is the degree to which holiday demand is to be accommodated by on- versus off-street parking.
- Accounting for shift changes in industrial uses. The guidelines do not assume industrial work shifts will create overlapping demand. If such overlap is expected, higher-than-recommended maximum parking supply may be required. However, another alternative is to encourage staggered shifts such that first shift employees leave early enough to permit their parking spaces to be used by the second shift. Another option is to encourage development of areas to allow employees to be dropped off by family members, thereby reducing overall parking demand. An excellent, though dated, review of industrial parking demand and issues can be found in work published by ITE (*9*).

Another important consideration is employee density. As Table 1 indicates, parking demand is quite sensitive to employee density. Application of the guidelines can be fine-tuned by better data on densities for applicable land uses. Localities should monitor periodically employee densities for various land uses to derive the most appropriate parking guidelines. Additionally, other guidelines could be developed for specific uses not included here. For example, the guidelines for commercial use apply to general retail, grocery, discount, and the like, but not regional shopping centers, banks, entertainment, restaurants, or hotels.

Continued monitoring of other variables will improve application of the guidelines. Key variables include those used in deriving Table 1:

- Mode shares (often monitored by annual survey under TDM programs),
- Number of visitors and shoppers per employee, and
- Proportion of walk-in shoppers, shopper mode of travel, vehicle occupancy, and volume of shoppers in normal versus holiday periods.

Finally, planners attending to parking for TODs should guard against the possibility of spillover parking. Although the parking guidelines proposed here are not overly restrictive compared with expected parking demand in proximity to transit, there is always the possibility that maximum requirements will be too tight relative to demand for a particular site or project. Furthermore, parking demand may increase as a result of variables outside the control of any locality. Falling gasoline prices, changes in the economy, and a decline in transit service due to cuts in state or federal funding are only some of the possible variables. Therefore, planners are well advised to consider neighborhood preferential parking as one guard against spillover commuter parking and short-term parking controls (meters or timed zones) to reduce the chances of commuter parking in areas intended for shoppers.

ACKNOWLEDGMENT

The author gratefully acknowledges the support of the city of San Diego for the study reported in this paper. However, all findings and conclusions are strictly those of the author.

REFERENCES

1. *Transit-Oriented Development Design Guidelines*. Calthorpe Associates, San Francisco, Calif., Nov. 1990.
2. 1985 On Board Survey. Metropolitan Transit Development Board of San Diego, Calif., 1985.
3. *The 1987 Evaluation of Transportation Management Programs*, Final report. Seattle Commuter Services, City of Seattle, Wash., 1987.
4. R. Weant and H. Levinson. *Parking*. Eno Foundation, Westport, Conn. 1990.
5. J. Goldsteen. Parking Standards and Requirements: Update, Summary and Literature Review. In *Strategies To Alleviate Traffic Congestion*, Proc., ITE 1987 Conference, 1988.
6. *Office Building Parking Demand Study for City of Walnut Creek*. DKS Associates, April 1982.
7. *Brief Guide of Vehicular Traffic Generation Rates for the San Diego Region*. San Diego Association of Governments, Calif., Jan. 1990.
8. D. Bergman. *Off Street Parking Requirements*. Report 432. American Planning Association, Washington, D.C., 1991.
9. *Parking Facilities for Industrial Plants*. ITE, Washington, D.C., Sept. 1969.

Publication of this paper sponsored by Committee on Parking and Terminals.

Conceptual Framework To Study the Effectiveness of Employer Trip-Reduction Programs

WALDO LOPEZ-AQUERES

Policy makers throughout the United States increasingly rely on employer-sponsored trip-reduction programs to reduce air pollution and traffic congestion. Despite the popularity of these programs, only a small number of studies have been undertaken to evaluate their performance. This paper presents a conceptual framework for a more rigorous study of employer trip-reduction programs and their expected emission and traffic reduction impacts. Implications of the practical application of the framework and data requirements are also discussed.

The number and variety of government mandated trip-reduction programs have increased significantly during the last 10 years. This trend reflects a growing recognition by policy makers that trip-reduction programs do work and that they are more likely to be implemented if required by law. A recent survey conducted in the San Francisco Bay Area indicates that the majority of employers who have implemented trip-reduction programs have done so to comply with government regulations (*1*). Limited evidence suggests that trip-reduction programs are more effective when initiated through government regulation than through private voluntary participation (*2–4*). Policy instruments, such as local ordinances and regional rules, provide overall direction to these programs by identifying program goals and objectives, issuing administrative guidelines to ensure uniformity in program development and implementation, establishing performance standards, and outlining specific actions to enforce compliance and prevent early program termination.

Federal and state air quality and congestion management legislation has helped accelerate the growth of employer trip-reduction programs. Under federal and some state rules, urban areas that fail to meet air quality and mobility standards are required to control the number of vehicle trips and vehicle miles traveled (VMT). As of 1990, 52 active and proposed trip-reduction ordinances had been identified in six states; 42 of them had originated in California (*5*). The 1987 regional ridesharing rule adopted by the South Coast Air Quality Management District (SCAQMD), the air pollution control agency responsible for improving air quality in Los Angeles, Orange, and Riverside counties and the nondesert portion of San Bernardino county, is the first regional regulatory program of its kind in the United States. This regional rule, known as Regulation XV, directs employers with 100 or more employees at a work site to develop and implement trip-reduction programs for employees arriving to work between 6:00 a.m. and 10:00 a.m., Monday through Friday. Employers subject to Regulation XV must file a trip-reduction plan with SCAQMD every other year. To be approved, the plan should have the potential to attain a policy-prescribed average vehicle ridership (AVR), which may range from 1.75 passengers per vehicle in downtown Los Angeles to 1.3 in sparsely populated areas of the South Coast Air Basin (SCAB).

Transportation Programs, South Coast Air Quality Management District, 21865 Copley Drive, Diamond Bar, Calif. 91765-0933.

In spite of the increasing popularity and applicability of employer trip-reduction programs, the evaluation of these programs remains scarce. Evaluative studies conducted to date are primarily descriptive, rely heavily on data from case studies, and place too much emphasis on outcome indicators, such as the number of trips reduced and modal shares (*6,7*). With the exception of work by Giuliano et al. (*8*), little effort has been made to systematically analyze the relative effects of various trip-reduction strategies while controlling for confounding factors (*4,9*). From a policy perspective, the most significant shortcoming found in the literature is the lack of a formalized conceptual framework linking the context and constraints of employer trip-reduction programs with expected outcomes. Thus, given that these programs are not implemented in a vacuum and that they constitute a first attempt to change driving behavior on a large scale, a more comprehensive research approach should be used to assess their effectiveness.

OBJECTIVES

An attempt is made in this paper to provide a minimum conceptual framework that may be helpful for a more rigorous study of employer trip-reduction programs and their expected emission and traffic reduction impacts. On the basis of ridesharing research conducted in the past, the major components and variables of the framework are outlined and the relationship between them is suggested. The proposed framework should improve the understanding of the relationship between program outcomes and the determinants of such outcomes and how the determinants of the outcomes relate to one another and to the desired objectives. Such an understanding may provide fertile ground for more effective public action. In addition, the empirical validation of some of its components should be useful in (a) identifying effective program options, (b) assessing the potential of alternative trip-reduction plans, and (c) determining which strategies work best in different environments.

METHODOLOGY

In the evaluation of public programs, two types of variables must be considered: (a) outcome variables, which are output-type indicators or dependent variables, and (b) independent or analytic variables, including program or policy variables, which can be manipulated by decision makers, and antecedent or control variables, which represent the context and constraints of the program (*10,11*). An understanding of the role of these variables is essential to maximizing program impacts.

In this paper, the trip-reduction literature, especially as it applies to factors affecting ridesharing behavior, will be placed within the research perspective outlined previously. Many of the variables included in the framework have been identified in the work of Kuzmyak and Schreffler (*7*); Wachs (*12*); Hwang and Giuliano (*13*); Lopez-Aqueres, Siwek, and Peddada (*14*); Stevens (*15*); Bhat, Schofer, and Kopelman (*16*); and the Urban Mass Transportation Administration (UMTA) (now FTA) (*6*). The discussion, however, does not rely on an exhaustive review of the literature. Summarizing all the relevant work here would be a difficult undertaking and would obviously make this paper deviate from its main purpose.

OVERVIEW OF THE FRAMEWORK

The basic components of the framework are (a) public policy, (b) employer factors, (c) travel mode characteristics, (d) employee attributes, (e) employee mode choice, and (f) program impacts (Figure 1). In general, independent variables are found in components (a) through (d). Dependent variables are included in components (e) and (f). According to the hypothesized causal links depicted in the model, independent variables can assume a dependent role as well. Program and antecedent variables are identified with the letters P and A, respectively.

Public policy may affect the performance of trip-reduction programs indirectly by influencing employer factors (e.g., program options), travel mode characteristics (e.g., cost), or employee attributes (e.g., household income). Employer factors include program resources (i.e., company revenues diverted to implement the trip-reduction plan), management commitment, program options (i.e., trip-reduction strategies incorporated into the plan), labor-management agreements, work site location, and employer size, as measured by the number of employees. Employee attributes include personal values (e.g., altruistic feelings), occupation, commuting distance, and household characteristics.

The next framework component is travel mode characteristics. As hypothesized in the model, this component determines employee mode choice and program outcome. Travel behavior theory indicates that the cost, travel time, convenience, comfort, privacy, and safety associated with each commuting alternative are of much concern to the employee and to most travelers in general (*12*). As shown in Figure 1, changing travel mode characteristics is an intermediate but fundamental step to influence employee mode choice and program outcome. Employers must rely on their trip-reduction plans to change travel mode characteristics and, ultimately, employee modal choice.

Employee attributes and mode characteristics jointly determine employee mode choice. The various modes identified

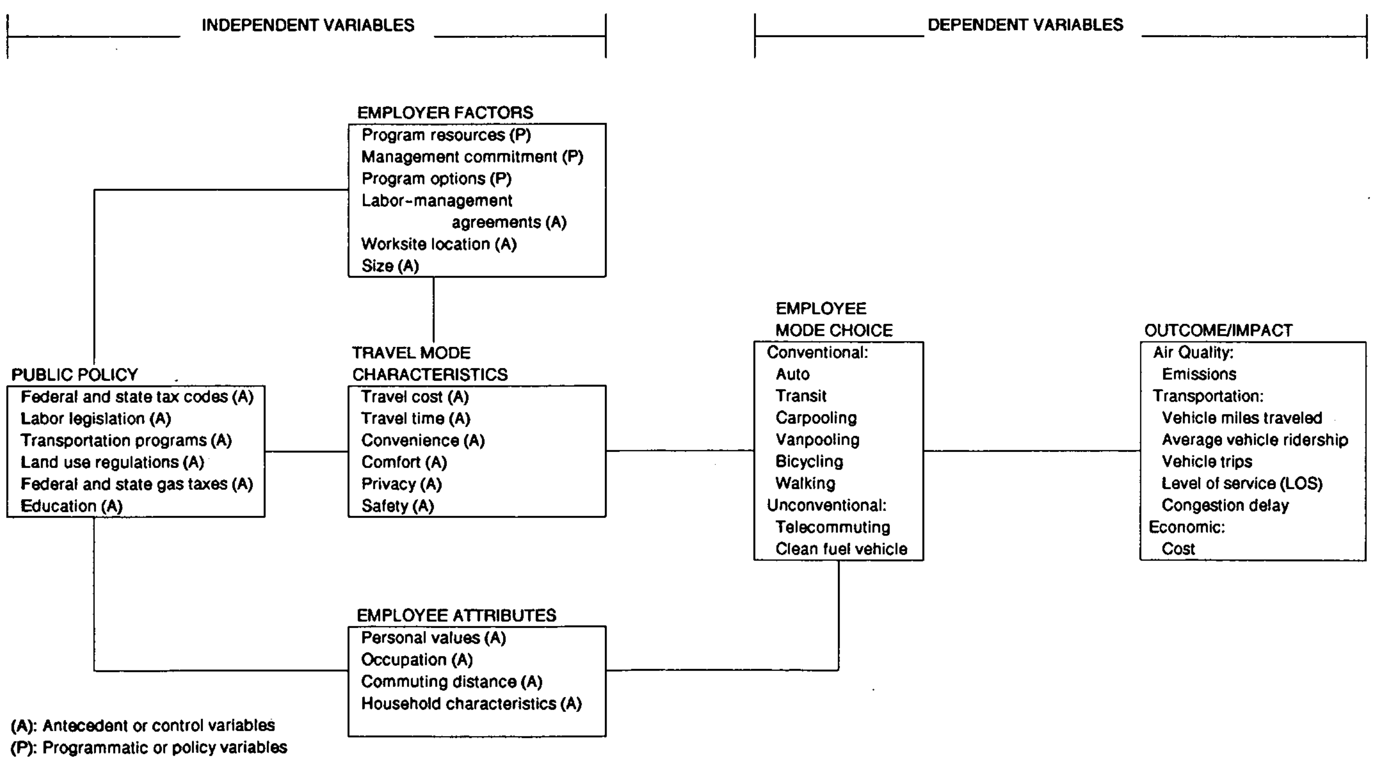


FIGURE 1 Framework to study the effectiveness of employer trip-reduction programs.

in the framework incorporate conventional (e.g., transit) and unconventional (e.g., telecommuting) forms of commuting to work.

The last framework component is the outcome of the trip-reduction program, which depends directly on mode choice and indirectly on the remaining components of the framework. Which particular component, or variables, may exert the greatest influence on modal choice and, ultimately, on program performance, is an important policy question that has to be settled on empirical grounds.

CONCEPTS AND VARIABLES

Public Policy

Specific public policies or government regulations that can have a significant impact on program outcomes include federal and state tax codes, labor legislation, transportation programs, land use regulations, federal and state gasoline taxes, and education. These variables provide the policy context within which the trip-reduction program is implemented.

Federal and State Income Tax Codes

Some specific aspects of the federal tax code promote driving alone while discouraging the use of public transportation. This situation is a result of the way in which employee benefits have been taxed for individual and corporate taxpayers. Until recently, federal regulations exempted employee parking benefits from personal income taxation and allowed businesses to claim the cost of employee parking as a tax deductible business expense. In contrast, employee transit subsidies exceeding $21 per month were subject to income tax (*16*). As a result, employers have favored paid parking over transit subsidies.

Recent federal legislation, however, has raised the transit subsidy exempt from personal income taxation from $21 to $60. The 1992 Comprehensive Energy Policy Act allows employers to provide employees with a nontaxable $60 per month subsidy for the use of public transportation or vanpooling, with an inflationary adjustment allowed every year. In addition, it limits the amount of employee parking that employers may claim as a business deduction to $155 per employee per month. This new policy reduces the cost of public transportation and vanpooling, as well as the employer's incentives to subsidize parking. Commuter associations have worked for years to change the law to eliminate the tax advantages of driving alone over the use of public transportation (*17*). In California, while employer subsidies for mass transit, carpooling, and vanpooling are exempted from income taxation, subsidies for walking or bicycling continue to be taxed as ordinary income.

Labor Legislation

Federal and state labor legislation specifying the conditions for which overtime must be paid may prevent employers from using compressed workweek schedules more extensively. Essentially, these overtime rules preclude employees from accumulating overtime hours that they may use at some future date as compensatory time. Although most administrative, executive, and managerial personnel are exempted from these government statutes, federal legislation (such as The Walsh-Healy Act, The Contract Work Hours and Safety Standards Act, and The Fair Labor Standards Act) requires payment of overtime to hourly employees who work more than 8 hr per day or 40 hr per week (*18,19*). California has one of the strictest laws regulating working hours and overtime pay. In California, however, hourly employees who work more than 8 hr per day are allowed to accumulate overtime hours, provided the employer has formally adopted a 4-day workweek schedule (*18*). Other things being equal, adoption of a 4-day workweek schedule, in which the employee works 40 hr in 4 days, would reduce the number of work trips by 20 percent.

Transportation Programs

The provision of urban transportation services is a government responsibility. Federal, state, and local governments control much of the resources to finance the supply of local transportation alternatives. The long-standing federal policy to use Interstate highway program funds almost exclusively to finance highway construction and maintenance has favored the use of automobile commuting over less polluting and congesting transportation possibilities, such as commuter rail and buses. The 1991 Intermodal Surface Transportation Efficiency Act has modified such a practice by authorizing the use of federal highway funds to finance transit capital projects, carpool projects, pedestrian walkways, and other transportation control measures identified in the Federal Clean Air Act (*20*). Shifting the policy focus from road building to transportation demand management could indirectly enhance the effectiveness of employer trip-reduction programs by increasing the supply of local transit services and stimulating carpooling, walking, and bicycling as means of traveling to work.

State transportation resources allocated to the development of high-occupancy vehicle (HOV) lanes have been shown to enhance the performance of trip-reduction programs indirectly by stimulating carpooling. For example, the establishment of HOV lanes in Orange County, California (*21*), and Minneapolis, Minnesota (*7*), has led to higher carpool formation. Savings in commuting time made possible by traveling in the HOV lane may entice employees to carpool more often (*13*).

Land Use Regulations

Land use decisions by local governments can also affect mode choice and travel behavior in different ways. First, the type and intensity of land use specified in the city's general plan may indirectly influence the quantity and type of transportation alternatives available to commuters. City areas zoned for low residential or employment density become automobile dependent because they cannot be efficiently served by traditional means of public transportation, such as mass transit. Second, the segregation of land uses by district contributes to the spatial mismatch between the location of housing and employment (*22*). Communities with sharp job-housing imbalances encourage solo driving by creating excessive travel and long commutes. Separation of land use activities also fosters additional employee travel during the day for personal or business reasons. Finally, but not less important, the liberal parking specifications of some local jurisdictions make it more difficult for trip-reduction programs to succeed. The policy of many cities to underprice parking space in public lands, primarily on streets, encourages the use of single-occupancy vehicles (SOVs) and undermines public and private efforts to stimulate transit use or carpooling.

Federal and State Gasoline Taxes

Other public policies, such as federal and state gasoline taxes, can influence employee modal choice and the effectiveness of trip-reduction programs by affecting the cost of commuting. Economists have generally supported increases in gasoline taxes to discourage the use of SOVs. This relationship was indirectly tested during the 1970s, when higher gasoline prices caused by the higher petroleum prices charged by the Organization of Petroleum Exporting Countries led automobile commuters to switch to carpooling and public transportation. Today, however, lower gasoline prices are making carpooling less attractive. In 1991, for example, gasoline prices in the United States were about 12 percent lower than in 1981 (*23*). Further, compared with the United Kingdom, France, Japan, and Italy, gasoline prices in the United States are three to four times lower (*24*). Thus, depending on specific tax rates levied, federal and state gasoline taxes could reinforce or undermine the goal of employer-sponsored trip-reduction programs.

Education

This variable is included in the framework more for its potential than for its actual effect on the success of trip-reduction programs. Education is an invaluable tool to convey the importance and necessity of trip reduction to employees and to the public in general. Commuters know little about the social cost of the journey to work. Although most everyone is aware of the visible effects of smog, few understand and recognize the long-term harmful, and sometimes deadly, effects of air pollution (*25*). Consumer education can go a long way to raise public awareness of the subtle effects of air pollution and the necessity to improve air quality. Unfortunately, although there is a wealth of technical data linking air pollution with human health, there has not been a comprehensive public education effort to communicate this knowledge to the community. Elementary and high schools, as well as colleges and universities, could become the focal point to educate youngsters and their families on the health risks of air pollution and on the benefits to be attained by changing commuting behavior.

Employer Factors

Factors included in this component can have a major influence on the performance of the trip-reduction plan. Whereas program resources, management commitment, and program options are within the employer's control if not precluded in regulations, labor-management agreements, work site location, and employer size are not.

Program Resources

Program resources are the labor, capital, and monetary rewards that the employer devotes to implement the trip-reduction plan. Company revenues diverted to plan implementation depend on the time spent by the employee transportation coordinator (ETC) to prepare, promote, and monitor the program; the office space occupied by the ETC; the passenger vans or minibuses purchased or leased by the employer to transport employees; and the financial outlays to promote ridesharing and subsidize alternatives to solo driving. Resources allocated to the program are more limited for some employers than for others, and they may vary with the number of employees and the types of incentives offered.

Data collected by UMTA (now FTA) (*6*) on suburban employers indicate that small-scale efforts to reduce work trips might cost from $10,000 to $20,000 per year for employers with fewer than 500 employees and from $30,000 to $60,000 for employers with more than 1,000 employees. On the other hand, the cost of comprehensive ridesharing programs might vary from $30,000 to $60,000 per year for employers with fewer than 500 employees and from $100,000 to $250,000 for employers with more than 1,000 employees. Costs are generally higher for large companies because their programs usually include vanpool and shuttle services.

A recent study based on a sample of 39 trip-reduction plans filed with SCAQMD shows that the average yearly cost of developing and implementing a trip-reduction plan is about $29,000, or $70 per employee (*26*). For employers of different sizes, the cost varies as follows:

Employer Size	*Total Cost*	*Cost Per Employee*
100–199	$13,400	$70
200–500	$28,100	$86
500 +	$34,300	$50

More recently, and based on a larger sample of 1,100 trip-reduction plans submitted to SCAQMD, the annual average cost of program implementation in SCAB was estimated at $105 per employee (*27*). Nonetheless, a validity study of 17 cases, conducted shortly thereafter, revealed that 10 of these companies had overstated their program costs, some by as much as 380 percent (*28*).

The studies by Commuter Transportation Services and Ernst & Young found no connection between resources devoted to the program and its performance, as measured by the AVR attained by the employer. This is an important finding, suggesting that although some employers may spend relatively more on plan implementation, higher expenditures do not guarantee program success.

Management Commitment

A key element in the performance of employer-sponsored trip-reduction plans is management interest (*3*) or commitment to the program. Experience suggests that support from top company officials is critical in developing and sustaining an effective ridesharing program. On the other hand, if management is not fully supportive of the program, is unsure of its value, or is skeptical of government regulation, program outcomes may fall short of the goal. At present there are no criteria to distinguish employers who are fully committed to the program from those who, in evaluation research terms, "ritually comply" (*29*) or try to conform with all the legal provisions of the regulation but make little effort to reach the stated goal. Cases of ritual compliance are also difficult to identify because most trip-reduction regulations do not have mandatory performance standards and employers only need to show a "good faith effort" to accomplish the policy-prescribed goal. The anticipated effects of the trip-reduction program can also be influenced by the person primarily responsible for its implementation. Incentives that could be effective in the hands of an experienced and highly motivated ETC may not be as effective when implemented by a less experienced or less motivated ETC.

Program Options

In general, employers rely on incentives and disincentives to discourage automobile commuting. Incentives usually include various kinds of compressed workweek schedules, telecommuting or working at home, financial and nonfinancial rewards for ridesharing, employer-sponsored carpool and vanpool programs, guaranteed ride home programs, and preferential parking for carpoolers. The influence of some of these incentives on AVR has been confirmed by two recent studies. On the basis of an analysis of 1,100 trip-reduction programs, Giuliano et al. (*8*) found that AVR increases are associated with the presence of various types of financial incentives for carpooling, riding transit, walking, and bicycling; provision of guaranteed rides home; orientation of new employees; and recognition of ridesharers in the company newsletter. This research, however, did not rank these incentives in order of importance. The other study, which relies on data from 5,593 trip-reduction programs, revealed that although carpool and transit subsidies affect AVR and changes in AVR in the expected direction, the explanatory power of these variables is low (*30*).

A well-known disincentive that employers could use to affect commuting behavior and program effectiveness is to charge employees for parking. Employee-paid parking increases the cost of automobile commuting, forcing the employee to use more economical travel alternatives. Various case studies have consistently shown that the number of automobiles driven to work is significantly reduced when employers stop subsidizing employee parking (*31,32*). Lower parking fees among employers subject to Regulation XV have been found to correlate with lower AVRs (*30,33*).

Despite all the accumulated evidence on the negative effect of employer-paid parking on modal choice, private and public sector firms continue to subsidize parking. In Southern California, 93 percent of all commuters do not have to pay for parking (*34*). In SCAB, as many as 92 percent of employers subject to Regulation XV still provide free parking to their employees (*33*). In addition to the detrimental effects on carpooling and transit use, employer-paid parking requires large expenditures by employers. According to a study conducted in 1987, employers in Los Angeles County spent between $1.3 and $1.7 billion to subsidize parking (*35*). In Southern California, parking expenditures per firm could range from $26,000 to $377,000, and the average annual subsidy per parking space could vary from $50 per space in the San Bernardino and Riverside county areas to $389 in downtown Los Angeles (*36*). If adjusted for inflation, the current value of these numbers would be much higher.

Employers also face the task of marketing the program options and fine-tuning the incentives to get employees to change their commuting habits. This process may take longer for some employers than for others. Altering employees' commuting behavior requires time to experiment with various types of incentives and overcome employees' resistance to abandon their cars. After all, the automobile has been dominant for more than 50 years, and this dominance is not likely to change overnight. In addition, employers also confront obstacles over which they have little or no control. Examples include travel patterns associated with some employee occupations (e.g., social workers and auditors) and locational constraints (e.g., poor access to public transportation). These factors also limit the types of incentives that employers can offer in their trip-reduction plan.

Labor-Management Agreements

Employers may not be able to use certain trip-reduction strategies because they may violate labor-management agreements. For example, substitution of parking benefits for a transportation allowance may not be possible without first renegotiating the labor-management contract. Another trip-reduction strategy that may require labor management negotiations is compressed workweek schedules. Some labor organizations, for example, have been known to oppose compressed workweek schedules on the grounds that a longer workweek may cause loss of overtime pay, as well as employee fatigue, which may eventually result in health and safety problems. Other unions have been supportive of compressed workweek schedules because of the potential benefits (e.g., improvement of employee morale, decrease in absenteeism, and reduction of employee turnover) that these programs may generate (*18*).

Work Site Location

Specific features associated with the location of the work site may enhance or hinder the effectiveness of the trip-reduction program. They include employment clustering and proximity to public transit.

Multiemployer centers, or the concentration of small employers, are less likely to encourage ridesharing than single-employer centers (*6,15*). It is suggested that rideshare participation is lower at multiemployer centers because the organization of a ridesharing program among various smaller companies is more difficult and requires greater coordination than at a single company (*13*).

Proximity to public transit is another locational factor that may affect the success of employer trip-reduction programs.

Considerable evidence exists to support the notion that accessibility to public transit networks reduces the use of SOVs. Employees working in places located in or near downtown areas of large cities rely on public transportation more than employees working for companies located in suburban communities, where public transportation is practically nonexistent and parking is usually free (*6,13,37*).

Employer Size

Studies indicate that ridesharers are more likely to work for large employers (*15,38,39*). Trip-reduction programs are more successful at larger employers with a smaller proportion of professional occupations (*40*). This association is traced to the greater availability of potential ridesharers found in a larger labor pool (*13*).

Employee Attributes

Employee attributes that may affect mode choice, and ultimately the performance of trip-reduction programs, include personal values, occupation, commuting distance, and household characteristics.

Personal Values

Personal values are largely shaped by sociopsychological influences (such as culture, social class, family and group influence, personality, etc.) acquired through learning and experience. In general, and depending on how strong these personal values are, the employee may have a higher or lower disposition to change his commuting behavior. For example, altruistic feelings (e.g., a desire to improve air quality) and attraction to other carpool members have been found to correlate positively with carpooling (*15*).

Hwang and Giuliano (*13*) found that although the attraction factor is positively correlated with carpooling, freedom to drive alone and the perceived negative status associated with being a driver or a passenger in a carpool may prevent people from ridesharing. Overcoming employee resistance to ridesharing arising from personal values is one of the biggest challenges that employers and public decision makers still have to face. However, the connection between personal values and travel mode is not altogether clear and is difficult to ascertain empirically (*12,41*).

Employee Occupation

Because of the special needs associated with certain occupations, ridesharing could be more difficult for some employees. The need to make daily visits to clients or customers located in different parts of the city reduces the employee's chance to rideshare or use public transportation. Irregular work schedules and part-time employment also make rideshare matching particularly difficult. Management and professional occupations appear to have lower carpool propensity than blue collar occupations (*15*). The relationship between occupation and ridesharing is sometimes attributed to the higher rate of automobile ownership and lower susceptibility to commuting costs found among professional employees (*13*).

Commuting Distance

Reviews of several studies indicate that ridesharers are more likely to have longer home-to-work trips than solo drivers (*13,15,38*). It is not clear, however, what specific factors induce individuals with longer commuting trips to join carpool programs at a higher rate. Apparently, the cost savings of sharing the ride in a long commute outweigh the inconveniences of carpooling (e.g., time spent to pick up and drop off carpool passengers) (*13*).

Household Characteristics

Household income has long been used in transportation demand models to predict modal split, primarily the commuter's choice between travel by automobile and public transit. Nevertheless, there is insufficient evidence to provide an understanding of how household income may affect the choice among alternative commuting modes other than SOVs. It is possible that household income, occupation, and work schedules interact in subtle ways to influence the employee's modal choice and propensity to use different transportation alternatives. Other household characteristics, such as family size, may also affect employees' commuting behavior. The presence of small children in the household may create child care responsibilities requiring different travel patterns.

Travel Mode Characteristics

Employees, and commuters in general, are fairly rational in deciding which particular travel mode to use. They generally perceive each travel mode as having different characteristics and distinctive benefits and costs. Travel mode characteristics usually identified in the transportation literature are cost, travel time, convenience, comfort, privacy, and safety (*12*). The trip-reduction plan, especially the program options, becomes the tool to modify the benefits and costs associated with each commuting mode.

Excluded from the employee selection of a travel mode are the social costs (e.g., the costs of accidents, traffic congestion, environmental damage, and health effects) of the various commuting travel alternatives. Thus, although ridesharing reduces the cost of commuting through fuel savings and wear and tear on automobiles, the exclusion of social costs continues to make the use of SOVs the preferred alternative for the majority of travelers. Employers, however, could partially eliminate the apparent advantage of SOVs over carpooling or the use of public transit if they were to give some serious thought to the option of charging for parking. California has enacted legislation requiring employers who subsidize parking to provide employees with the option of receiving a parking subsidy or an equivalent cash allowance. The rationale behind this legislation is that employees who do not value employer-paid parking very highly will choose the cash allowance and stop driving their cars to work (*31*). Employers could also outweigh most advantages attributed to SOVs if they were to pay more attention to the home-based telecommuting option and use it more extensively, but, according to the *Los Angeles Times* (*42*), employers remain skeptical of this idea.

Employee Mode Choice

Employee mode choice is the first manifestation of the impact of the trip-reduction program. As presented in the framework, the employee's choice of a particular mode is a function of the combined effects of the various framework components already discussed. Conventional transportation alternatives identified in this component are automobile (or light duty truck), transit, carpooling, vanpooling, and walking. The two unconventional or less traditional alternatives listed are telecommuting and vehicles powered by methanol, natural gas, or electricity.

Outcomes or Impacts

To date, most studies of employer trip-reduction programs have used modal shares (e.g., proportion of employees who carpool) (*6,7*) and AVR (*8*) to gauge program success. These indicators, however, do not reflect accurately the emission reduction and transportation benefits expected from these programs.

The selection of performance measures, or outcome indicators, of trip-reduction programs should be dictated by the program objectives. Programmatic efforts aimed at reducing air pollution call for quantifying emission reduction benefits. Vehicle emissions are a function of vehicle type and year. Older vehicles, for example, pollute significantly more than newer ones. In general, larger engines also emit more air pollution than smaller ones.

In addition, vehicles release different levels of air pollution during three phases of vehicle operation: the cold start phase, the running phase, and the evaporative phase. Cold start emissions are generated when the vehicle engine and catalytic converter are operating cold. Running exhaust emissions occur after the vehicle engine is warmed up and depend on vehicle speed and the number of miles driven. Evaporative emissions are released when the vehicle engine is turned off and the gasoline remaining in the carburetor evaporates. Cold start and evaporative emissions are not affected by distance traveled, but running emissions are.

Thus, reliable estimates of emission reduction benefits brought about by changes in AVR or travel mode would normally require information on the number of cold starts and VMT before and after implementation of the trip-reduction program. Two employers with the same number of work trips could have quite different impacts on mobile source emissions depending on the number of trips made during the regular work day and VMT. Further, in quantifying the emission benefits of specific trip-reduction options, such as telecommuting or the 4-day compressed workweek, it would be important to know whether the commuting vehicle that remains at home is used to make other trips.

If increasing mobility is the program goal, the number of trips reduced, VMT, or level of service (LOS) during morning and evening rush hours may be used as performance indicators. The LOS concept is favored by traffic engineers, and it reflects five different levels of traffic conditions ranging from Level A (free flow) to Level F (gridlock). Using LOS to assess the traffic impacts of trip-reduction programs would be a complex undertaking because it would require measuring traffic volume, speed, and travel time.

CONCLUSIONS AND IMPLICATIONS

This paper has suggested a conceptual framework to study the effectiveness of employer trip-reduction programs. The model illustrates the complexity of the environment in which employer trip-reduction programs operate and the rather large number of variables that may impinge on program performance. The description is, at best, a tentative one. Although other variables could be added, the ones included in the framework deserve priority.

The Framework Components

From a programmatic standpoint, the effect of program resources, management commitment, and program options are most relevant. The absence of any relationship between resources allocated to the trip-reduction program and AVR attained indicates that larger expenditures by employers may not necessarily translate into program success, and lesser expenditures sometimes may be more effective in achieving the objectives of the trip-reduction plan. Although experience indicates that management commitment can make a difference in terms of program success, the specific actions, or behavior, that underlie such a concept remain largely unknown and may be ascertained only by placing greater emphasis on the "nuts and bolts" of the system or the evaluation of program effort. One way to ensure greater management commitment is to introduce mandatory performance standards in the trip-reduction regulation, along with penalties for failing to meet the policy-prescribed goal. This option, however, is likely to generate strong political opposition.

Regarding the impact of specific program options, financial incentives and parking charges keep reappearing in the literature as promising options to change commuting behavior. The analysis conducted to date, however, has yet to provide any definite clues regarding which particular incentives and disincentives are likely to produce the largest effect on program outcome. This has been partly attributed to data limitations, especially inadequate measures and lack of information on control variables (*8,30*). Depending on its proximity to public transportation, work site location has been shown to affect program performance as well.

Although remaining largely beyond the employer's influence, making employee attributes part of a comprehensive evaluation may help decision makers establish a more direct and explicit link between these antecedent variables (e.g., personal values, occupation, commuting distance, and household characteristics such as automobile ownership) and program outcomes. Having this knowledge may lead to better market segmentation and thus more appropriate targeting of incentives and promotional activities among company employees.

Although from an operational standpoint it may be difficult to fully integrate the public policy component into the framework, its presence may remind us that existing public policies can create favorable or unfavorable conditions to the success of employer-sponsored trip-reduction programs. Reducing the adverse effects of some of these public policies on ridesharing, or enhancing their favorable impacts, would require greater political coordination between transportation and air quality planners. A good example of the long-term payoff of this kind of activity is the new provision of the Comprehensive Energy Policy Act, which raises the transit subsidy exempt from income taxation from $21 to $60 per employee, a threefold increase. It took years of organized political action to make federal income taxation policy less biased toward ridesharing.

To evaluate program impacts more conclusively, the performance or outcome indicators should reflect more accurately the emission or traffic reduction benefits expected from these programs. Nevertheless, given the complexity of the environment in which employer trip-reduction programs are carried out and the enormous challenge of changing commuter behavior, it would be unrealistic to hope for significant results during the first few years of program implementation (*43*). As pointed out in the evaluation research literature, the more complicated and intricate the environment in which public programs operate, the longer the time span required to observe program impacts (*29*).

Information Requirements

Making the framework explicit calls for the development of an information system to improve the evaluation of trip-reduction programs and their effectiveness. An adequate system should be designed for local use, and it should serve the needs of employers and public decision makers.

In the first place, it should provide specific information to facilitate assessment and testing of the impact of program and antecedent variables on outcomes. A data collection form or questionnaire could be used to gather most of the information from employers. Employer data should include detailed program costs and company size. Rating schemes could be developed to assess management commitment and ETC attitude toward the trip-reduction program. Equally important would be to assess the experience of the ETC and the time devoted to implement the program.

The types of incentives and disincentives, their costs, and the number of employees affected would be critical to the information system. Also included should be the work site location and its accessibility to public transportation. Employers could provide information on employee attributes, such as occupation, commuting distance, travel behavior, and household characteristics. It would also be helpful to obtain some indication of employee satisfaction with the type and variety of incentives offered and with the way management is implementing the trip-reduction program. In addition, the system should include more valid measures of air quality and transportation impacts.

To maintain its usefulness and preserve its policy relevance, such an information system must have certain properties. First, it must have some safeguards to control the quality of the data and ensure their integrity. Second, it must be flexible. Information collected, for example, should be periodically revised in order to discard useless or irrelevant data. Finally, it must have some stability (i.e., key definitions used in the system should not be changed too often because longitudinal analysis would not be possible).

Developing this type of information system may not be as costly as the data requirements may suggest. Many localities and air pollution control districts requiring the implementation of employer trip-reduction programs already collect a significant amount of information for administrative purposes. In addition, data collection costs could be substantially reduced by using carefully selected samples of employers and employees. Thus, to the extent that the new information collected would be supplementing an existent system, the additional cost of data gathering would probably not be high. The benefits, however, would be the creation of a more reliable data base to assess and improve program effectiveness.

ACKNOWLEDGMENT

The author thanks Catherine Wasikowski, John Reimers, Sarah Siwek, Charles Blankson, Carlos Gonzalez, and Antonio Thomas for their comments and is especially grateful to Silvia Keefe for her editorial suggestions.

REFERENCES

1. JHK & Associates. *Cost-Effectiveness Study of TSM Measures in Suburban Settings.* Prepared for the City of Pleasanton and FTA, San Francisco, March 1992.
2. K. Orski. Evaluating the Effectiveness of Travel Demand Management. *Institute of Transportation Engineers Journal,* Vol. 61, No. 8, Aug. 1991, pp. 14–18.
3. E. Ferguson. Evaluation of Employer-Sponsored Ridesharing Programs in Southern California. In *Transportation Research Record 1280,* TRB, National Research Council, Washington, D.C., 1990, pp. 59–72.
4. E. Schreffler and J. Kuzmyak. Trip Reduction Effectiveness of Employer-Based Transportation Control Measures: A Review of Empirical Findings and Analytical Tools. Presented at 84th Annual Meeting and Exhibition of the Air and Waste Management Association, Vancouver, British Columbia, 1991.
5. R. T. Dunphy and B. C. Lin. *Transportation Management Through Partnerships.* The Urban Land Institute, Washington, D.C., 1990.
6. *An Assessment of Travel Demand Approaches at Suburban Activity Centers* (First Report). Urban Mass Transportation Administration, Office of Technical Assistance and Safety, U.S. Department of Transportation, July 1989.
7. J. R. Kuzmyak and E. Schreffler. *Evaluation of Travel Demand Management to Relieve Congestion.* Report FHWA-SA-90-005. FHWA, U.S. Department of Transportation, 1990.
8. G. Giuliano, M. Hwang, and Wachs. *Mandatory Trip Reduction in Southern California: First Year Results.* School of Urban and Regional Planning, University of Southern California, Los Angeles, Jan. 1992.
9. T. Higgins. Monitoring and Evaluating Employer Based Demand Management Programs. In *Transportation Research Record 1321,* TRB, National Research Council, Washington, D.C., 1991.
10. L. Rutman. Planning and Evaluation Study. In *Evaluation Research Methods: A Basic Guide* (L. Rutman, ed.). Sage Publications, Beverly Hills, Calif., 1977, pp. 13–38.

11. K. Land. Social Indicator Models: An Overview. Unpublished manuscript. Russel Sage Foundation and Columbia University, New York, 1972.
12. M. Wachs. Policy Implications of Recent Behavioral Research in Transportation Demand Management. *Journal of Planning Literature,* Vol. 5, No. 4, May 1991, pp. 333–341.
13. K. Hwang and G. Giuliano. *Review of the Literature on the Determinants of Ridesharing, Working Paper No. 1.* Evaluation of SCAQMD's Regulation XV Project. School of Urban and Regional Planning, University of Southern California and University of California Transportation Center, Los Angeles, July 1990.
14. W. Lopez-Aqueres, S. Siwek, and R. Peddada. An Overview of Regulation XV—Trip Reduction Program: Preliminary Impact Assessment on Emission Reduction. Paper presented at 84th Annual Meeting and Exhibition of Air and Waste Management Association, Vancouver, British Columbia, 1991.
15. W. F. Stevens. Improving the Effectiveness of Ridesharing Programs. *Transportation Quarterly,* Vol. 44, No. 4, Oct. 1990, pp. 563–578.
16. C. Bhat, J. Schofer, and F. Koppelman. Actions to Ameliorate Suburban Congestion: A Method-Based and Action-Based Classification. Paper presented at 71st Annual Meeting of the Transportation Research Board, Washington, D.C., 1992.
17. *Rideshare Tax Facts.* Commuter Transportation Services, Inc., Los Angeles, Calif., 1990.
18. *Variable Work Hours Implementation Guide.* Commuter Transportation Services, Inc., Los Angeles, Calif., undated.
19. Transportation Research Board. *Alternative Work Schedules: Impacts on Transportation.* NTIS No. PB81-199820. Prepared for FHWA, U.S. Department of Transportation, 1980.
20. *ISTEA (Intermodal Surface Transportation Efficiency Act of 1991) Southern California Regional Workshop.* Southern California Association of Governments, Los Angeles, 1992.
21. G. Giuliano, D. Levine, and R. Teal. Impact of High Occupancy Vehicle Lanes on Carpooling Behavior. *Transportation,* Vol. 17, No. 2, 1990, pp. 159–177.
22. R. Cervero. Unlocking Suburban Gridlock. *Journal of the American Planning Association,* Vol. 52, No. 4, 1986, pp. 389–406.
23. *ACTNOW.* News Release. Association of Commuter Transportation, Washington D.C., Oct. 28, 1992.
24. Meet the Metro. *Los Angeles Times,* June 7, 1992, p. 13.
25. Smog: The Silent Killer. *Los Angeles Times,* Nov. 26–30, 1989.
26. J. Stewart, R. Young, A. Ho, et al. *What Price Success? Regulation XV Trip Reduction Plans: Investment Patterns and Cost-Effectiveness.* Commuter Transportation Services, Inc., Los Angeles, Calif., 1992.
27. Ernst & Young. *SCAQMD Regulation XV Cost Survey.* Irvine, Calif., Aug. 1992.
28. Ernst & Young. *AQMD Survey Follow-Up.* Irvine, Calif., Nov. 1992.
29. P. Rossi, F. Howard, and S. Wright. *Evaluation: A Systematic Approach.* Sage Publications, Beverly Hills, Calif., 1979.
30. Development of Tools for Phase II Regulation XV Ministerial Plan Review Process. Status report (unpublished). COMSIS. Los Angeles, Calif., Oct. 14, 1992.
31. D. Shoup and R. Willson. Employee Paid Parking: The Problem and Proposed Solution. *Transportation Quarterly,* Vol. 46, No. 2, April 1992, pp. 169–192.
32. R. Willson, D. Shoup, and M. Wachs. *Parking Subsidies and Commuter Mode Choice: Assessing the Evidence.* Graduate School of Architecture and Urban Planning, University of California, Los Angeles, July 31, 1989.
33. W. Lopez-Aqueres and C. Wasikowski. *Relationship Between Employer-Paid Parking and Average Vehicle Ridership Among Employers Affected by Regulation XV.* South Coast Air Quality Management District, Diamond Bar, Calif., 1992.
34. *The State of the Commute.* Commuter Transportation Services, Inc., Los Angeles, Calif., 1991.
35. J. Simon and A. Woodhull. *Parking Subsidization and Travel Mode Choice.* Southern California Rapid Transit District, Los Angeles, Aug. 1987.
36. *Costs and Benefits of Ridesharing to Employers.* Commuter Transportation Services, Inc., Los Angeles, Calif., 1985.
37. A. Pisarski. *Commuting in America.* Eno Foundation for Transportation, Westport, Conn., 1987.
38. R. Booth and R. Waksman. Analysis of Commuter Ridesharing Behavior at Five Urban Sites. In *Transportation Research Record 1018,* TRB, National Research Council, Washington, D.C., 1985, pp. 33–40.
39. Crain and Associates. *Summary of Demand Management Programs.* Menlo Park, Calif., Dec. 1986.
40. *Transit and Parking: Public Policy.* Urban Mass Transportation Administration, U.S. Department of Transportation, 1990.
41. Charles River Associates. *On the Development of Traveler Attitude-Behavior Interrelationships, Volume 1.* Report DOT-TSC-RSPA-78-14.I. U.S. Department of Transportation, 1978.
42. New Technology Opens Door for More Workers to Stay at Home. *Los Angeles Times.* Aug. 29, 1990, p. 7.
43. *Transportation Performance Standards of the California Clean Air Act.* California Air Resource Board, Sacramento, April 1991.

Publication of this paper sponsored by Task Force on Transportation Demand Management.

Transportation Demand Management Cost-Effectiveness Model for Suburban Employers

DEBORAH A. DAGANG

Ordinances requiring employers and business complexes to reduce the number of commute trips arriving at the employment site by implementing transportation demand management (TDM) measures have been enacted in more and more cities in the last few years. Local trip-reduction ordinances are now a requirement in California to comply with the legislatively mandated Congestion Management Program. Although employers are required to comply with various ordinances, there may be little guidance provided to them other than a listing of possible strategies. This paper reports on a project performed for the City of Pleasanton, California, to develop a methodology to evaluate the cost-effectiveness of employer-based TDM measures in suburban settings. Pleasanton was the first city in the United States to adopt a comprehensive TDM ordinance, in October 1984, and has served as a model for many other communities throughout the nation. The methodology developed in this study was applied in a Lotus 1-2-3 spreadsheet-based model so that it is readily accessible to employers and staff at local agencies who may be inexperienced with using computers. Site-specific information for a given work site may be entered into the model, and the relative cost-effectiveness of up to 18 TDM measures may be evaluated. This is an extremely useful tool for employers to evaluate the potential cost-effectiveness of TDM measures. To demonstrate the use of the TDM Cost-Effectiveness Model, the model was tested for characteristics that represented a variety of suburban employers in the San Francisco Bay Area.

Many local jurisdictions throughout the United States are implementing trip-reduction ordinances (TROs) as a method to alleviate traffic congestion and improve air quality. In California, local TROs are a requirement of the legislatively mandated Congestion Management Program. These TROs are often aimed at employers in an effort to affect the commute trip, which is considered the easiest trip to influence because of its consistent origin, destination, and time of travel. Transportation demand management (TDM) measures are likely to be the key implementation tool required by the TRO or used by the employer to meet the requirements of the TRO. In addition to TROs, the Federal Clean Air Act requires that areas that are classified as severe or extreme implement an employer trip-reduction rule, which relies on the implementation of TDM measures.

Although employers are required to comply with various ordinances and rules to reduce travel to their work site, little guidance, other than a listing of possible strategies, may be provided to them. A significant amount of information is available in the transportation literature regarding the effectiveness of various TDM measures; however, employers may not know about or have direct access to this information. Of the literature that is available, the majority of the studies performed have focused on successful programs that have been implemented in urban areas and do not address cost-effectiveness. Although this information is useful to the general transportation community, it is not useful to an individual employer trying to determine what will happen at a particular work site. In addition, many employers affected by these ordinances are located outside urban centers in the surrounding suburban communities, and therefore, what will be effective for them may be quite different.

This paper reports on a project performed for the City of Pleasanton and FTA to develop a methodology to evaluate the cost-effectiveness of employer-based TDM measures in suburban settings. The purpose of this study was to provide information to employers on a site-specific basis to assist them in determining which TDM measures are the most cost-effective. The focus on suburban employers reflects the different travel-related characteristics of suburban areas as compared with most urban areas. For example, urban areas are more likely to be characterized by high employee densities and direct transit service. The TDM Cost-Effectiveness Model is an analytical tool developed in a user-friendly spreadsheet format to provide employers with a method to evaluate the cost-effectiveness of potential TDM measures that reflected their site-specific characteristics.

The suburban areas examined in the San Francisco Bay Area include a wide range of transportation service characteristics that are likely to have an impact on the effectiveness of TDM measures. Eight transportation environments were defined to represent various combinations of transportation service characteristics, such as availability of transit, employment density, and cost of parking. The combination of factors that define each transportation environment is provided in Table 1. The factors identified are those likely to influence travel behavior. Not included are factors that describe the employer, such as work force composition, although this could also be included. In a general sense, the availability of transportation service characteristics that would encourage TDM measure use decreases as the number for the transportation environment increases.

To make the methodology developed for this study transferrable to a variety of suburban communities and to ensure that it is readily accessible to employers and staff at local agencies who may be inexperienced computer users, it was

JHK & Associates, 2000 Powell Street, Suite 1090, Emeryville, Calif. 94608.

TABLE 1 Description of Transportation Environments

	Transportation Environment							
	1	2	3	4	5	6	7	8
Bus/Shuttle Service	X	X	X		X	X		
Rail/Express Bus Service	X	X			X			
HOV Lanes	X			X			X	
Employment Density > 3,000 within 1 mile	X	X	X	X	X			
Employee Paid Parking	X	X						
Pedestrian/Bicycle Amenities	X	X	X	X	X			

applied in a LOTUS 1-2-3 spreadsheet. Fifteen employer-based TDM measures were evaluated in this study and included in the spreadsheet-based model. A description of each of the measures is provided next.

- *Commute information program.* Provision of information to employees on alternatives to driving alone, such as transit routes and schedules, ridematching services, and location of bicycle paths. Information may be posted on a bulletin board or be distributed to employees through new-employee packets, a company newsletter, or personal delivery.
- *In-house ridematching services.* Employees who are interested in carpooling or vanpooling provide information to a transportation coordinator on their work hours, availability of a vehicle, and place of residence. The transportation coordinator then matches employees who can reasonably rideshare together.
- *Transit pass subsidies.* For employees who take transit to work on a regular basis, the employer pays for all or part of the cost of a monthly transit pass.
- *Employee transportation coordinator.* The employee transportation coordinator is an individual responsible for administering and implementing the organization's commute alternatives program. These duties may be full-time or included with the individual's other duties for the organization, depending on the requirements of the program.
- *Home-based telecommuting.* Employees perform their regular work duties at home instead of commuting to the work site. The employee may telecommute full time, or commute to work on some days and telecommute on others.
- *Compressed workweeks.* Employees work their regularly scheduled number of hours in fewer days per week. The two most common forms are (a) 4/40—4 10-hr days per week and (b) 9/80—80 hr over 9 days in 2 weeks.
- *Reduction of employer-subsidized parking.* The portion of the cost of parking that is paid for by the employer is reduced, and the employee pays an increased cost for parking. The existing subsidy may be in the form of payments for the parking places to a third party (such as a parking garage) or may be included in the building or office lease.
- *Preferential parking for carpools and vanpools.* Certain parking spaces (usually those closest to employee entrances) are reserved for carpools and vanpools, parking costs are reduced for carpool or vanpool members, or both.
- *Bicycle lockers and showers.* Secure lockers or racks for bicycle storage, shower facilities, or both are provided for those who bicycle to work. These facilities could also be used by those who walk to work.
- *Guaranteed ride home.* A company-owned or leased vehicle or taxi fare is provided in the case of an emergency for employees who carpool, vanpool, or use transit.
- *Shuttle to transit stations.* A shuttle is provided for employees to nearby transit stations that are not within walking distance of the employment site.
- *Vanpool program.* A vanpool program organizes employees who live near each other into single vans for the trip to work. The employer also assists in the acquisition of the van and pays for its operating and maintenance cost.
- *Reduction of parking supply.* The number of parking spaces available to employees may be reduced by leasing fewer spaces or converting a portion of the parking lot into other uses.
- *Direct monetary incentives for use of alternative transportation.* The employer provides a monetary bonus to employees who commute to work by a mode other than driving alone.
- *Transportation allowance.* The employer provides an amount to the employee each month to be used for commute costs. The employee is also charged for parking at the work site, and the allowance usually equals this cost for parking. It is then up to the employee's discretion whether to spend the transportation allowance on parking, or to keep a portion of it by using a less expensive mode of commuting to work.

DATA COLLECTED

To provide a basis for the evaluation of employer-based TDM measures in suburban settings, a number of data collection methods were used. These included a review of the literature, an employer survey questionnaire administered to employers in suburban areas throughout the San Francisco Bay Area, and a review of existing data bases with information on employer-based programs. A brief description of each of these is provided here.

Before the development of the employer survey questionnaire and the development of the cost-effectiveness methodology, a review of local and national literature was performed. The literature review was focused on experiences of suburban employers, with emphasis placed on the reported costs and effectiveness of the implemented measures. However, most of the sources reviewed provided descriptions of successful programs and had relatively little cost information. The scarcity of cost data reported in the literature reflects that this is a relatively new area of emphasis, although an important one. The data collected in the employer survey for this study is a significant addition to the literature on the costs incurred by the suburban employer in implementing TDM measures.

A survey was conducted of suburban employers in the San Francisco Bay Area. First, more than 100 firms with commute alternatives programs were identified to participate in the employer survey. A letter was sent to each of these firms to describe the purpose of the study and to elicit their cooperation in the employer survey. Approximately three-quarters of the firms agreed to participate, and a lengthy questionnaire was mailed to acquire characteristics of the firm and its commute alternatives program. Detailed questions regarding the costs associated with a variety of TDM measures were included. Some employers were not able to complete and return the questionnaire, and a few others were still in the process of implementing their program. For the completed surveys received, a detailed summary of the responses is provided in the report *Summary of Employer Survey Responses*. The survey results are based on the responses from 58 employers, representing a range of transportation service characteristics and employer sizes. In general, no assumptions were made about the employers who did not respond to a particular question. Most of the employers were not able to provide detailed cost information on the TDM measures that they had implemented. In follow-up conversations with the employers, it was found that the primary reason for this was that much of the cost data were not tracked separately from other operating costs. For example, the labor cost associated with providing the TDM measures to the employees was often not identified because the employer viewed this as a cost already incurred (i.e., the employee performing this function was already employed).

To supplement the data collected through the literature review and the employer surveys, two existing data bases with information on employer-based programs were reviewed. The existing programs are for areas that are a mixture of urban and suburban locations. These data bases were the South Coast Air Quality Management District's Regulation XV employer trip-reduction plan data base and the Pima Association of Governments Travel Reduction Program employer plan data base. Primarily, this information was used to provide guidance on the expected effectiveness of the TDM measures.

COST-EFFECTIVENESS METHODOLOGY

Each of the 15 employer-based TDM measures affect travel in different ways and have different cost characteristics. For these reasons, a single approach to calculating their cost-effectiveness was not adequate, and an individual set of equations was developed for each TDM measure. The characteristics that make each TDM measure unique are reflected in the variables chosen to evaluate its cost-effectiveness.

Where possible, calculations for the estimated trip reduction from the implementation of the TDM measure were developed. Unfortunately, few of the employers that responded to the employer survey were able to provide baseline information that would have allowed an analysis of the impact of the TDM measures on travel behavior. Calculations for the estimated trip reduction were developed, therefore, only for those measures for which sufficient information in the literature existed on factors that affect travel. For the remaining measures, the user must derive an estimate of the expected trip reduction outside of the model. In these cases, it is recommended that some sensitivity testing be performed on this variable. The measures for which trip reduction was calculated are the following:

- Transit pass subsidies,
- Home-based telecommuting,
- Compressed work hours,
- Reduction of employer-subsidized parking,
- Bicycle lockers and showers,
- Direct monetary incentives for use of alternative transportation, and
- Transportation allowance.

The next step was to determine the appropriate cost variables to include. First, a number of cost categories were identified to differentiate the impact of the cost variables. These categories are described next.

- *Annual labor cost.* The total amount spent on labor in a year for a TDM measure. This is a fully-burdened labor cost; that is, it includes employee benefits and other overhead costs as appropriate. Program administration costs fall into this category.
- *Annual capital cost.* The cost of capital facilities and equipment, such as vehicles purchased and bicycle lockers installed, amortized over the expected life of the facilities and equipment.
- *Annual direct operational cost.* The annual cost incurred to perform any operational tasks required for the TDM measure. An example of this type of cost is the amount spent on transit passes.
- *Annual overhead cost.* The annual overhead cost incurred for the TDM measure. For example, extending hours of operation to accommodate the longer days for compressed workweeks may result in increased energy usage for lights, computers, and the like.
- *Annual cost savings.* The annual savings that the employer may realize as a result of implementing the measure. The reduction in parking spaces that the employer leases would be included in this category.
- *Total daily cost.* This cost is calculated by summing each of the first four categories of costs, subtracting the cost savings, and dividing by the average number of work days in a year.

All of the costs are the incremental costs to the employer over those that would have already been expended. In many cases, the ability to calculate costs if the TDM measure is implemented in a variety of manners is included in the cost variables identified. For example, a company may provide a guaranteed ride home program by paying for a taxi, providing a company-owned vehicle, or providing a company-leased vehicle. Any one or a combination of these options may be evaluated, and the costs for the options not included must be set to zero.

Two measures of cost-effectiveness were estimated within the methodology: cost per daily trip reduced and cost per peak-period trip reduced. In both of these cost-effectiveness measures, total daily cost is the cost variable used.

The results from the evaluation of each measure are independent of each other. Caution should be used in directly combining the results from more than one measure because the implementation of multiple measures may affect their total effectiveness. For example, individuals who would have participated in a vanpool program or a program to subsidize transit passes would have to choose between the two programs if they were both offered. Therefore, the net effect of implementing these two measures together would likely be less than the sum of their individual effects.

IMPLEMENTATION OF TDM COST-EFFECTIVENESS MODEL

A LOTUS 1-2-3 spreadsheet-based analytical tool was developed to make the cost-effectiveness methodology accessible to employers and staff of local agencies so that it could be applied on a site-specific level. The TDM Cost-Effectiveness Model requires only a rudimentary knowledge of LOTUS spreadsheets, and a user's guide has been developed that provides users with step-by-step instructions for operation of the model.

An important consideration in developing this model was that it not operate as a "black box," that is, that the user does not input values and receive results without access to any of the intermediate steps. The model takes the user through a series of steps that includes viewing any intermediate results and allows the user to view the components of individual calculations. This approach has the following advantages:

- The user is aware of the impact of any assumptions made;
- Each step in the methodology may be followed by the user;
- It is possible to review intermediate results to verify their reasonableness; and
- A more sophisticated user may review the calculations and assumptions and modify them to make them even more site-specific, if so desired.

An additional advantage of the spreadsheet-based model is that it makes sensitivity testing relatively simple. When new data are input into the model, it takes only a few seconds for results to be calculated. The user can easily and quickly perform sensitivity testing by varying one or more variables in the model and viewing the change in results.

To operate the model, the user first inputs descriptive information about the transportation characteristics of the areas being analyzed by selecting one of the eight transportation environments and entering characteristics that affect many or all of the TDM measures (e.g., total number of employees, percent of commute trips in the peak period). For each of the characteristics, referred to as spreadsheet-wide defaults, the user has the choice of using default values included in the model or entering site-specific values. The default values were estimated on the basis of the literature review and employer survey and included in the model so that employers without extensive data available can still make use of this model. For each of the 15 TDM measures, the user must input a number of variables, some of which have defaults specified. With this input, the cost-effectiveness of the TDM measure may be calculated. A summary of the procedure followed in the model is illustrated in Figure 1, and an example of the inputs required and the results for the TDM measure Transit Pass Subsidies is provided in Figure 2. The results reported by the model are as follows:

- Reduction in daily trips,
- Reduction in peak-period trips,
- Average daily cost,
- Cost per daily trip reduced, and
- Cost per peak-period trip reduced.

The model has been designed so that it may be revised easily. As more suburban employers implement TDM measures and document their results, it may be desirable to update the equations and default values included in the TDM Cost-Effectiveness Model. Changes of this sort could easily be made without altering the general structure of the model. To the user, there would likely be no difference in model operation.

SAMPLE APPLICATION

Using the data collected on suburban employers and the costs associated with TDM measures, the TDM Cost-Effectiveness Model was used to evaluate each of the 15 TDM measures. The findings presented in this section are for a base model

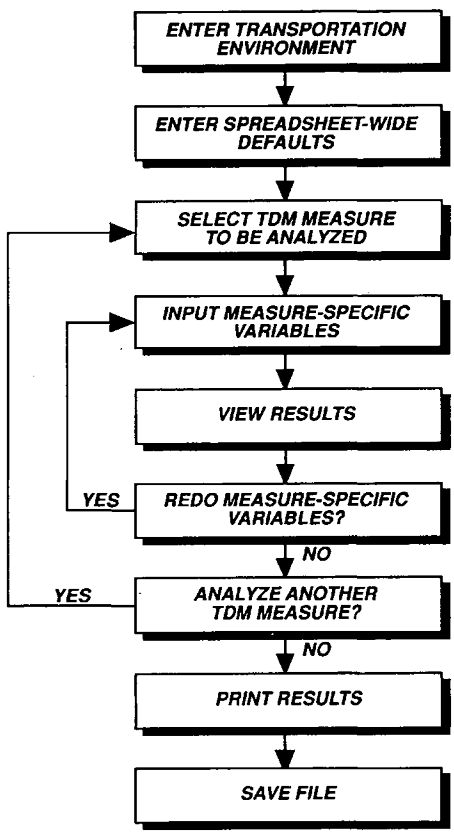


FIGURE 1 TDM cost-effectiveness model procedures.

TDM #3 Transit Pass Subsidies		
Is this TDM measure:		
- appropriate for the transportation environment		Yes
- being evaluated in this run? (Yes=1, No=0)		1
User-Defined Inputs		
percent of employees that currently use transit		3.1%
reduction in leased parking spaces		2
annual program administration cost		$2,250
monthly transit pass subsidy		$30.00
number of pass subsidies provided		16
Inputs With Default Values		
annual overhead cost of program accounting		$0
Default Value	$0	
User Override	$0.00	
cost of a monthly transit pass		$30.00
Default Value	$30.00	
User Override	$0.00	
% of employees offered transit subsidy		100.0%
Default Value	100.0%	
User Override	0.0%	
% of transit ridership that equals the trip reduction		80.0%
Default Value	80.0%	
User Override	0.0%	
Cost-Effectiveness of TSM Measure		
$/daily vehicle commute trip reduction		$4.63
$/peak-period vehicle commute trip reduction		$5.79
Travel Calculations		
average daily reduction in vehicle commute trips		6
Cost Calculations		
annual labor cost		$2,250
annual capital cost		$0
annual direct operational cost		$5,686
annual overhead cost		$0
annual cost savings		$911
average daily cost		$28

- Cells for User Input

FIGURE 2 Sample TDM measure inputs and results.

alternative that was defined using as inputs average values obtained from the employer survey to represent a suburban employer in the San Francisco Bay Area. These values may vary significantly from one employer to the next; therefore, it is recommended that these results be used to demonstrate the application of the model and to describe issues that arise in the analysis of the cost-effectiveness of employer-based TDM measures. To determine which measures to implement, the model should be applied for the specific site that is developing a commute alternatives program.

The base model alternative is referred to as Alternative 1A. The specification of the TDM measures for Alternative 1A combined the use of values obtained from the surveys, default values, and estimations of the likely impact of the TDM measures on travel. In general, values other than the default values were only used if there was some evidence obtained from the employer survey. A general description of each TDM measure evaluated for Alternative 1A is provided next. These descriptions are not meant to be representative of the preferred or likely measure as actually implemented.

- *Commute information program.* The program includes the development and dissemination of written materials describing alternative commute modes for traveling to work. As a general estimate, the program is assumed to encourage 5 percent of the employees to use an alternative commute mode. A general assumption used throughout the TDM measures, unless stated otherwise, is that the reduction in leased parking spaces is one-quarter of the average daily reduction in vehicle commute trips, or one-half of the number of vehicles that arrive at the work site. This assumes that employers are likely to be cautious about reducing the amount of parking available.
- *In-house ridematching services.* A computer-based ridematching service in which individuals interested in carpooling or vanpooling submit information on their residence location, work start and end times, and other factors. The average daily reduction in vehicle commute trips was calculated assuming that 10 percent of the employees would be encouraged to rideshare, and that the average size of the carpools and vanpools would be 2.5 persons per vehicle. Therefore, the reduction in trips accounts for the fact that trips are still made by the carpool and vanpool vehicles.
- *Transit pass subsidies.* Provision of a $30 per month transit pass subsidy to all employees by an employer with a current transit share of 3.1 percent. For this program, a cost is incurred for all transit pass users, not just new transit riders.
- *Employee transportation coordinator.* The provision of an individual in the organization whose responsibility it is to coordinate all TDM activities.
- *Home-based telecommuting.* Employees are allowed to work at home 1 day a week. This measure is offered to all employees, and, based on the participation rates in the employer survey, 4.6 percent of the employees participate in the program. It is assumed that the employee is provided with computer hardware and software and that telecommunications are paid for by the employer.
- *Compressed work hours.* For this alternative, employees are allowed to work 4 10-hr days each week and have the fifth day off from work. This measure is offered to all employees and, based on the results from the employer survey, 23.3 percent of the employees participate in the program. Because these employees are now at work for 11 hr a day instead of 9 hr, assuming 1 hr for lunch, the commute trip either to or from work will occur outside the peak period.
- *Reduction of employer-subsidized parking.* The monthly subsidy provided by the employer for parking is the difference between the monthly cost of leasing a parking space and the amount that the employee pays per month for parking. For this alternative, the subsidy is removed and all employees are required to pay $40 a month for parking.
- *Preferential parking for carpools and vanpools.* Parking spaces near the entrances to the building are reserved for carpools and vanpools, and signs are installed indicating this restriction. The average daily reduction in vehicle commute trips was calculated assuming that 8 percent of the employees would be encouraged to rideshare and that the average size of the carpools and vanpools would be 2.5 persons per vehicle.
- *Bicycle lockers and showers.* For this alternative, bicycle lockers and showers are installed to encourage 1 percent of employees who commute less than 6 mi to bicycle to work. No additional costs are incurred for maintaining the lockers and showers.
- *Guaranteed ride home.* For this alternative, the employer will pay the cost of a taxicab ride home in the case of an emergency in the middle of the day or if the employee is required to work late and misses his or her bus, carpool, or

vanpool home. It is estimated that the provision of this program will encourage another 2 percent of the employees to use alternative transportation modes.

- *Shuttle to transit stations.* If the employment site is located too far from the transit station for employees to walk, the employer provides two shuttle vehicles that operate between the nearest transit station and the work site. The costs for this program include the cost of the personnel operating the shuttle, maintenance of the employer-owned shuttle vehicles, and insurance coverage. The analysis assumed that an additional 5 percent of the employees would be encouraged to use transit.
- *Vanpool program.* For this alternative, the employer provides a vanpool program for its employees that includes the administration required to organize the vanpools. For this program, the employer purchases three vans and must pay insurance coverage and maintenance for the vans. The analysis assumed that approximately 7 percent of the employees would be encouraged to participate in the vanpool program.
- *Reduction of parking supply.* For this alternative, the employer reduces the constrained parking supply by 12 spaces, either by restriping or by using the designated area for some other purpose. The one-time cost for this reduction is assumed to be $5,000.
- *Direct monetary incentives for use of alternative transportation modes.* For all employees who commute to work by any mode other than driving alone, a monthly bonus payment is provided by the employer in the amount of $35 a month.
- *Transportation allowance.* For this alternative, all employees receive monthly transportation allowances of $40 each that they may use to pay their transportation costs at their discretion. If a transportation mode is used that costs less than $40 a month, the employee keeps the difference. A parking charge is also imposed that approximately equals the $40 a month allowance.

The cost-effectiveness for each measure was estimated for all trips reduced and for peak-period trips reduced. A summary of the results calculated for Alternative 1A is provided in Table 2 and illustrated for selected measures in Figure 3. For Alternative 1A, the most cost-effective measure for all trips and for peak-period trips was the reduction of employer-subsidized parking. A key reason why this measure is cost-effective is that there is a net income to the employer as a result of collecting parking fees from those who do not participate in the measure. Also, the economic incentive to not drive alone is a strong one when employees are faced with a charge for parking. Even when this alternative was evaluated under the assumption that the employer does not pay any lease costs for parking (as described later in this paper), reduction of employer-subsidized parking is the most cost-effective measure and results in a cost savings. Of course, the political difficulty of implementing such a measure is not accounted for in this analysis, especially for a suburban employer who may have acres of parking area and would have a difficult time justifying the parking charge to its employees. Unfor-

TABLE 2 Results of Cost-Effectiveness Analysis: Alternative 1A

TDM Measure	Average Daily Cost per Daily Trip Reduced	Ranking	Average Daily Cost per Peak-Period Trip Reduced	Ranking
Commute Information Program	$0.42	7	$0.53	7
Ridematching Services In-House	-$0.23	4	-$0.28	3
Transit Pass Subsidies	$4.63	13	$5.79	13
Employee Transportation Coordinator	$5.15	14	$6.44	14
Home-Based Telecommuting	$100.87	15	$126.09	15
Compressed Work Hours	-$0.59	3	-$0.01	5
Reduction of Employer-Subsidized Parking	-$6.48	1	-$8.10	1
Preferential Parking	$0.15	6	$0.18	6
Bicycle Lockers and Showers	$4.40	12	$5.50	12
Guaranteed Ride Home	-$0.14	5	-$0.18	4
Shuttle to Transit Stations	$3.84	9	$4.80	9
Vanpool Program	$4.04	11	$5.06	11
Reduction of Parking Supply	-$0.87	2	-$1.09	2
Direct Monetary Incentives	$4.02	10	$5.02	10
Transportation Allowance	$1.01	8	$1.26	8

Note: Ranking among measures with a negative cost per trip reduced may be misleading and should all be considered highly cost-effective.

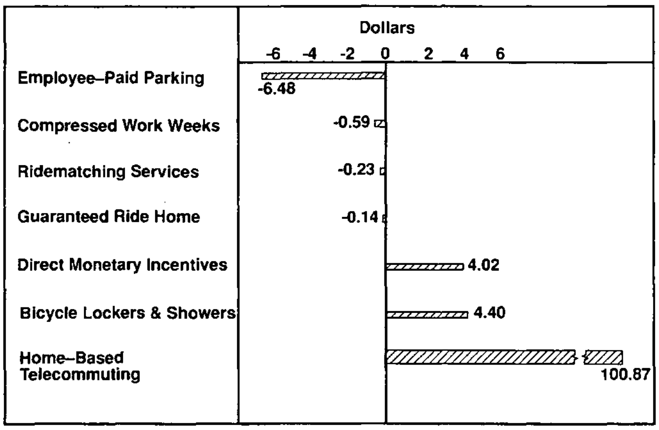


FIGURE 3 Daily cost per trip reduced: selected TDM measures.

tunately, many employees expect free parking as a benefit of their job, and it will take some cooperative effort on the part of public agencies and the employers to dispel this notion.

Four other measures were estimated to result in an overall cost savings to the employer per trip (daily or peak period) reduced. These measures were in-house ridematching services, compressed work hours, guaranteed ride home, and reduction of parking supply. Each of these measures does not require a great deal of monetary investment by the employer, and a cost savings is experienced as a result of the reduction of parking spaces that the employer must lease.

The least cost-effective measure for Alternative 1A is home-based telecommuting, for both total trips and peak-period trips. The primary reason for this is that it is assumed that a significant amount of computer and telecommunications equipment is required for the employee to telecommute, and this cost is proportional to the number of employees who telecommute. Also, only two trips a week are reduced for each employee who participates in the program. What this indicates is that telecommuting is an expensive option if significant capital investment is required; however, telecommuting would be more cost-effective if employees could work at home without a great deal of equipment-based support. As would be expected, those measures that include some sort of payment by the employer to the employee (transit pass subsidies, direct monetary incentives, and transportation allowance) are in the bottom half of cost-effectiveness rankings.

As indicated in Table 2, the relative cost-effectiveness of each of the TDM measures does not vary between daily trips and peak-period trips for those measures that have a positive cost per trip reduced. There is some difference in the ordering for the cost savings per trip reduced; however, this is misleading because it is a result of the cost savings being spread over a greater trip reduction. It should not be interpreted, therefore, that somehow compressed workweeks are more cost-effective for reducing total trips than for peak-period trips. Instead, this is an anomaly of evaluating the cost-effectiveness of measures that increase income to the employer.

The cost-effectiveness of a TDM measure would be expected to be greatly influenced by certain characteristics of the employer and of the measure as it is implemented. Various model alternatives, or scenarios, were tested in the TDM Cost-Effectiveness Model to determine the sensitivity of the cost-effectiveness estimation to different employer and TDM measure characteristics. The ability to perform sensitivity analysis on individual variables is an important and useful aspect of the model.

To test the sensitivity of the results to employer characteristics, the TDM measures defined for Alternative 1A were applied for seven other alternatives, Alternatives 1B through 1H. There were four variables that were varied among the alternatives to describe the employer, and each of these for Alternatives 1A through 1H are listed in Table 3. Alternative 1B represents an employer that is similar to Alternative 1A but that charges an average of $50 a month for parking. For this alternative, the TDM measure of reducing the employer-subsidized parking supply does not apply because no parking subsidy is offered. A smaller increase in the daily parking fee is also evaluated for the TDM measure of providing transportation allowances. Alternatives 1C though 1G vary only in the number of employees at the work site. Each of the inputs correlated to employer size, such as number of telecommuting employees, is increased or decreased to maintain its relative proportion. Alternative 1H is the same as Alternative 1A, with the exception that the employer does not pay a monthly lease cost for the parking spaces, that is, the employer owns the land.

Sensitivity testing was then performed on the definition of the TDM measures themselves in Alternatives 2 through 4, which used the employer description for Alternative 1A as the basis. A listing of the inputs for each of the alternatives and the results by alternative are not provided in this paper because of space limitations, although the conclusions presented reflect this portion of the analysis.

TABLE 3 Employer Characteristics for Model Alternatives 1A Through 1H

	Alternative							
	1A	1B	1C	1D	1E	1F	1G	1H
Transportation Environment	5	2	5	5	5	5	5	5
Number of Employees at Worksite	240	240	50	100	500	1,000	2,000	240
Daily Parking Charge at Employer-Provided Facility	$0	$2.38	$0	$0	$0	$0	$0	$0
Monthly Cost of a Leased Parking Space	$40	$50	$40	$40	$40	$40	$40	$0

CONCLUSIONS

The TDM Cost-Effectiveness Model developed represents a significant step forward in the evaluation of the cost-effectiveness, instead of just the effectiveness, of employer-based TDM measures in suburban settings. This model is available to employers and will assist them in determining which TDM measures are the most cost-effective for their work site. An important aspect of the model is the extent to which an employer may enter site-specific information that will have a direct impact on the cost-effectiveness calculations. For those employers that may not have access to the entire range of data required to operate the model, default values have been estimated for many of the variables and are included in the model.

A significant amount of data collection was performed in support of the methodology development. The literature review summarized in this report examined the costs and effectiveness of TDM measures that had been implemented by suburban employers. As was expected, there was much more information of the description of the particular measure implemented and on the program effectiveness than there was on program costs. One of the key goals of the employer survey administered to suburban employers throughout the San Francisco Bay Area was to supplement this cost data. There was a great deal of variation among the employers regarding the amount of cost data that they were able to provide. A few employers had the costs associated with their program well documented and were able to provide complete information. Most employers, however, were only able to give general cost information on a few measures, and even then did not necessarily know all of the costs for that measure. Where cost information was not reported, confidentiality was not the issue; instead, it was a matter of the employers having kept sufficient records to allow them to distinguish the costs associated with individual measures or the program as a whole. The cost data provided do provide some insight, however, into the costs associated with the implementation of TDM measures.

From the employer surveys, a significant amount of information was collected regarding the implementation of the TDM program itself and the characteristics of the transportation services available to the employees of each organization. Although this information is only representative of those who responded to the survey, it does provide a good background on the factors that affect program design and implementation. The data obtained through the employer survey performed for this study was also supplemented with an evaluation of two data bases that contain information on employer-based TDM programs.

The cost-effectiveness of each of the TDM measures was evaluated using the TDM Cost-Effectiveness Model. A variety of model alternatives were tested to determine which measures were the most cost-effective and which variables affect their cost-effectiveness. Before applying the findings of this report to a particular employment site, the assumptions made regarding the measure's impact on the average daily trip reduction should also be reviewed for their reasonableness compared with the particular situation being evaluated. Because there are so many possible combinations of employer and measure characteristics, it is best to run the TDM Cost-Effectiveness Model for the individual employer using site-specific data. Some general observations regarding the cost-effectiveness evaluation of the TDM measures follow.

- The most cost-effective measure for each alternative to which it is applicable is the reduction of employer-subsidized parking. This is primarily because the employer collects parking fees from employees who continue to drive to work.
- For Alternative 1A, which represented average employer and TDM measure characteristics, four other measures were estimated to result in an overall cost savings to the employer per trip reduced: in-house ridematching services, compressed work hours, guaranteed ride home, and reduction of parking supply.
- The least cost-effective TDM measures are home-based telecommuting, primarily because of the cost of the computer and telecommunications equipment, and measures that require a payment by the employer to the employees: transit pass subsidies, direct monetary incentives, and transportation allowances.
- Relative cost-effectiveness is not significantly affected by whether the effectiveness measure is daily trips or peak-period trips.
- As employer size increases, the measures become more cost-effective because fixed costs are spread over a larger number of employees and there is a greater savings because of the reduction of leased parking spaces.
- If employers with 500 or more employees implement the same TDM measures implemented by employers with 240 employees, two additional measures result in cost savings: commute information program and preferential parking. This is primarily because of the increased reduction in leased parking spaces.
- For an employer that charges its employees for parking, there are no TDM measures that result in a cost savings because the employer does not experience a direct cost savings when the number of parking spaces used is reduced. This is also true for employers that do not pay a monthly lease cost for parking spaces, with the exception of reduction of employer-subsidized parking.
- Despite the higher cash outlay by the employer, an increased monetary incentive from $35 to $50 a month is predicted to result in a slight increase in this measure's cost-effectiveness.
- When a compressed work hour program is implemented in which employees have an extra day off every 2 weeks instead of every week, the cost-effectiveness of the measure is reduced, however, the employer continues to experience an overall cost savings.
- Even by decreasing the reduction of the employer-subsidized parking by half, this measure remains one of the most cost-effective.
- If bicycle lockers and no showers are provided, and the same level of participation remains the same, this measure becomes highly cost-effective and results in a cost savings. This effect is greatly amplified if it is assumed that bicycles would be ridden to work for 10 percent of the trips less than 6 mi. This is not an unreasonable assumption in areas with flat terrain, temperate climates, and other bicycle amenities, such as bicycle lanes, in the surrounding area.

It should be noted that these findings are based on a technical analysis only and do not to take into account other factors, such as acceptability to unions, which may also affect an employer's decision regarding which measure(s) to implement.

AREAS FOR FUTURE RESEARCH

There is still a great deal to be learned as more suburban employers implement TDM measures. A list of areas in which future research or updates to the TDM Cost-Effectiveness Model would be worthwhile follows:

- Collect more detailed information on the costs associated with implementing TDM measures. For existing programs, this could be accomplished by visiting the employer and interviewing various members of the staff, including the employee transportation coordinator, a human resources representative, someone involved in facility operations, and a representative from the accounting department. For future programs, some guidance could be provided to the employer for how to accurately track costs related to measure implementation.
- Collect additional baseline information to evaluate the effectiveness of TDM measures. Before implementing TDM measures, survey employees to determine the baseline mode split and average vehicle occupancy.
- Customize the TDM Cost-Effectiveness Model to account for differences that would result from different transportation environments. With additional baseline information, some of these impacts could be determined. Then, instead of using estimates of the average daily trip reduction as an input to the model, equations could be included in the model to estimate this value.
- Develop calculations for additional TDM measures and include them in the TDM Cost-Effectiveness Model.
- Collect data and apply the model in other suburban areas of the country to determine possible geographical impacts on the cost-effectiveness of TDM measures.

Some of these data may become available over time as more local jurisdictions pass TROs that require data reporting by the employer. An effort must be made, however, to keep these data up-to-date and to consider cost-effectiveness when evaluating them.

ACKNOWLEDGMENTS

This study was funded by FTA and the City of Pleasanton, California, with contributions from a number of Pleasanton employers. A great deal of assistance was provided by RIDES for Bay Area Commuters, Inc., in the conduct of the employer surveys and by the two subcontractors on the project, Transportation Management Systems and Sierra Research, Inc. Special thanks to Gail Gilpin, Transportation Systems Manager for the City of Pleasanton, for her support and contributions throughout the study.

Publication of this paper sponsored by Task Force on Transportation Demand Management.

U-PASS: A Model Transportation Management Program That Works

MICHAEL E. WILLIAMS AND KATHLEEN L. PETRAIT

On September 30, 1991, the University of Washington, in cooperation with the Municipality of Metropolitan Seattle, implemented U-PASS, one of the most comprehensive transportation demand management programs in the United States. The U-PASS program was developed in response to campus and community concerns for trip reduction and improved commuter services in view of possible impacts from planned campus development. The U-PASS program is a flexible package of transportation benefits offered through a pass that allows University of Washington students, faculty, and staff to choose from a variety of commuting options at a greatly reduced price. U-PASS is a $17.4 million 3-year demonstration program that began in October 1991. Parking system revenue funds cover 30 percent of the program. To achieve this funding level, parking fees were raised to the market rate of the University District. At a 75 percent participation rate, monthly U-PASS user fees of $9.00 for faculty and staff and $6.67 for students contribute 40 percent of the cost. The remaining 30 percent of the program is subsidized by the university through a variety of funding sources. After 1 year of operation, the U-PASS program has been viewed as a success and a model to other employers. Vehicle trips to campus are down 16 percent, parking lot use has decreased from 91 percent to 78 percent, transit ridership is up 35 percent, carpools have increased 21 percent and the number of vanpools grew from 8 to 20 in less than 9 months.

As the need to reduce congestion and air pollution increases, jurisdictions and developers alike face difficult choices. The following question is key: Can significant transportation demand management (TDM) strategies reduce the need to spend large, often scarce, sums of money to build more roads and parking structures? The U-PASS program, with its flexible package of benefits and unique funding approach, demonstrates that the answer is yes: significant TDM measures can have a major impact on traffic and parking.

Implemented September 30, 1991, the U-PASS program is possibly one of the most comprehensive transportation management programs (TMPs) of its kind in the United States. The program offers a flexible, broad package of high-occupancy vehicle (HOV) options through a U-PASS sticker on university identification cards. Available at a greatly discounted price, the U-PASS has been a huge success in decreasing single-occupancy vehicle (SOV) trips. Of the 50,000 people in the university community, more than 36,000 participate in the program. Trips to campus have decreased 16 percent during the morning peak period, and for the first time in memory, campus parking lots have not filled up. Monthly transit trips have increased by 35 percent, and the number of vanpools has increased to 20, up 150 percent.

By offering flexibility, something for everyone, and a unique funding strategy, U-PASS planners ensured an optimum participation rate. With a large base of participants, the cost per user for access to all of the benefits dropped significantly. For example, before the U-PASS program was implemented, a transit pass alone cost as much as $48.00 per month. With U-PASS, costs for all HOV benefits are $9.00 a month for staff and faculty and $6.67 a month for students. Higher participation rates, increased SOV parking rates, and university funding sources enabled the U-PASS program to improve existing transportation alternatives, including an addition of 60,000 hr annually of transit service.

Employers with 100 or more employees in the eight largest counties of Washington are preparing to comply with the new Commute Trip Reduction Law, which requires a significant reduction in the number of SOV commute trips. Programs such as the U-PASS will play a significant role in helping employers meet their goals.

The purpose of this paper is to describe the U-PASS program, document its success, and show how TDM strategies can be effective in changing commuting behavior. It documents the history of the U-PASS program, including how the university formed a partnership with the Municipality of Metropolitan Seattle (Metro) and Community Transit (CT) to help solve the transportation impacts associated with proposed campus development. In addition, the paper documents the first-year results of the program and summarizes the lessons learned and implications for other employers.

BACKGROUND

Campus Setting

The University of Washington is a comprehensive teaching and research institution with more than 33,000 students and 17,000 faculty and staff. The 640-acre campus includes a major medical center and health sciences complex and is located in the Seattle neighborhood known as the University District. This district is the largest employment and activity center in King County outside the Seattle Central Business District.

More than 225,000 vehicles enter the University District each day—20,000 during the peak hour alone. It is estimated that through traffic accounts for more than 40 percent of total vehicle trips entering and exiting the area. Metro and CT both provide transit service to the University District. With the exception of the Seattle Central Business District, the Uni-

M. E. Williams, University of Washington, Transportation Office, University Facilities Annex, FJ-08, Seattle, Wash. 98195. K. L. Petrait, Municipality of Metropolitan Seattle, Service Development Division, 821 Second Avenue, MS-128, Seattle, Wash. 98104.

versity District has the highest percentage of transit usage in King County.

City Requirements and Existing TMP

In 1983, the university and the City of Seattle entered into an agreement calling for the university to create a physical development master plan and TMP that would (a) maintain traffic to and from campus during the peak periods at 1983 levels, (b) not increase the number of vehicles parking in surrounding neighborhoods, and (c) limit the university parking supply to 12,300 spaces.

In response to these goals, the university developed a TMP that was sufficient to maintain traffic at the 1983 level and did not increase neighborhood parking impacts. Despite this success, participation in the program had decreased by 1989. Use of the parking system exceeded 94 percent; on many days student daily pay lots spilled over into surrounding neighborhoods. Both daily pay and permit carpools were declining, and ridematch applications had dropped sharply. The vanpool program, which peaked at 12 vans in 1985, declined to 8 vans by 1988. Transit pass sales had been flat for several years.

DEVELOPMENT OF U-PASS

Two factors led to strengthening the university's TMP.

First, in 1989, the university began a new general physical development plan for 1991 through 2001 (*1*). The plan called for the addition of 2.2 million gross ft^2 of new development. The transportation impacts of the plan included 4,300 new faculty and staff, which would result in an increase of 1,000 peak-hour and 10,000 daily vehicle trips and the loss of 1,700 surface parking spaces, resulting in the need to construct four new parking garages.

Second, independent of the expected growth in faculty and staff, patient vehicle trips to the University of Washington Medical Center were also projected to increase as a result of the trend toward more out-patient care.

These concerns, coupled with the university's commitment to maintain traffic at 1983 levels and lack of growth in existing transportation programs, pointed to the need to develop a new TMP. That new TMP was U-PASS.

U-PASS Program

U-PASS is a comprehensive TDM program consisting of nine features: increased transit service, shuttle service, carpools, vanpools, ridematch, bicycles, reimbursed ride home, commuter tickets, and merchant discounts. Individuals may use any combination of these features to satisfy their varying daily transportation needs. Because the participation rate is high and parking revenue covers a portion of the costs, the price of the pass to the user is extremely low.

History of the Program

A task force of Metro planners and university faculty, students, and staff was established in May 1989 to develop and implement an improved TMP at the University of Washington. The task force decided early on that there was a need to provide a range of transportation incentives as well as disincentives (e.g., increased parking rates) if a successful program was to be established. One idea was to treat transportation like a health benefit, where all would share the costs and the benefits. Access to this transportation benefit would be by way of a "universal pass" that would allow the use of many forms of alternative transportation. A review of other universities across the nation revealed that a transit pass in combination with a student identification card had been successfully implemented at a number of universities. The majority of these programs, however, were located at universities in low-density areas, and most did not include faculty and staff. Furthermore, these programs usually offered only a bus pass.

In June 1990, the task force presented its recommendations to both the University's Advisory Committee on Transportation (ACT) and Metro officials. (ACT is a committee of faculty, staff, and students appointed by the Executive Vice President of the university to give advice on transportation issues.) The recommendations called for a reduced rate universal pass, or U-PASS. This pass would be part of the university identification card and would entitle the holder to an array of transportation options.

U-PASS Campaign

Once the preliminary U-PASS program had been defined and endorsed by ACT and by Metro officials, a campaign was initiated to inform the campus community of the program's potential benefits and to gain feedback on its potential acceptance. The motto of the campaign was U-PASS: For You and the U. Campaign material stressed that the U-PASS program would benefit the user through lower prices, more commute options, and a better environment. At the same time, it would benefit the university by meeting commitments to the City of Seattle and the neighborhoods to mitigate its traffic and other environmental impacts.

Steps in the U-PASS campaign included the following:

- A brochure and other materials highlighting the U-PASS program and its benefits were distributed.
- A transportation fair was held the first week of autumn quarter 1990 to promote U-PASS.
- An advisory ballot/survey and a U-PASS brochure were mailed to all 34,000 students in November 1990 to solicit their input on the program. Students were asked if they favored the program and whether it should be mandatory or optional.
- A questionnaire and a brochure were sent to a sample of campus staff to gain their input.
- A letter was sent to all faculty and staff requesting comments on the proposed U-PASS program and parking cost increases.
- Campus groups such as the Associated Students of the University of Washington (ASUW), the Graduate and Professional Student Senate (GPSS), the Student Assembly, the Faculty Senate, and the Professional Staff Organization debated the merits of the program.

• A campuswide U-PASS forum was held in November 1990 to discuss the merits of the plan and to encourage students and staff to return their ballot surveys.

While the U-PASS campaign was under way, an ACT subcommittee was established to develop cost estimates and recommend a price structure for both the U-PASS and campus parking. This subcommittee assumed that the administration would maintain its current level of transportation subsidy and that parking rates would increase to cover existing costs, the cost of a new west campus garage, and a portion of the U-PASS expenses. The remainder of the U-PASS funds would come from sales of the pass.

U-PASS Campaign Results

Highlights and the results of the U-PASS campaign follow.

Student Ballot/Survey

Of the 8,304 students who returned their ballots, 7,151, or 88 percent, were in favor of the U-PASS program. Of those in support of U-PASS, 60 percent favored an optional program whereas 40 percent favored a mandatory program. More than 64 percent of those who chose an optional U-PASS were willing to pay up to $10.00 per month for the pass.

Staff Transportation Survey

More than 91 percent of the respondents agreed or strongly agreed that the university should implement the U-PASS program as it was presented.

Campus Organizations

GPSS adopted a resolution supporting a mandatory U-PASS program for students, and the ASUW Board of Control voted for an optional U-PASS program. After much debate, the Faculty Senate voted 60 to 4 in favor of the U-PASS program and of increased parking rates to help fund it.

Advisory Committee on Transportation

By January 1991, the ACT subcommittee had developed a proposed U-PASS budget and financing package. The total cost of the program was estimated to be $17,471,000 for October 1991 through June 1994 (see Table 1).

The largest single cost element of the U-PASS program is transit service. The majority of these costs come from the guarantee that the university would reimburse both Metro and CT the amount of revenue collected through pass sales and cash fares from the campus community before the U-PASS program. Through this commitment, both Metro and CT remained revenue neutral.

Both agencies have a budget of additional hours that can be implemented throughout their systems. These hours usually go to the areas with the greatest need or the areas that show the greatest commitment to encouraging transit ridership (e.g.,by providing transit subsidies, limiting parking supply, or increasing parking fees). The U-PASS program provided such a commitment, so additional hours were committed to the university. It was agreed that the marginal cost of additional transit service would be shared equally by the university and the transit agencies.

The level of university funding ($5,646,000) was based on past expenditures for the transit pass subsidy and other TMP elements. To generate the almost $5 million needed from the parking system, the ACT subcommittee recommended that parking rates be increased significantly (see Table 2). The parking costs were set to approach market rates in the University District. These market rates were determined through surveys of other parking providers in the area. The subcommittee based its rate recommendations on the results of this survey and specific revenue needs.

The subcommittee also recommended that the faculty and staff permit include a free U-PASS. This would encourage SOV drivers to make occasional use of alternative modes of

TABLE 1 Projected U-PASS Operating Expenditures and Funding

U-PASS Element	Total Cost	Percent
OPERATING EXPENSES		
Administration	$ 644,000	3.7
Monitoring & Evaluation	127,000	0.7
Information & Marketing	692,000	4.0
Health Sciences Express	1,504,000	8.6
Disabled Persons Shuttle	362,000	2.1
Night Ride	769,000	4.4
Transit Services[a]	12,766,000	73.0
Vanpools	376,000	2.2
Carpools	128,000	0.7
Commuter Tickets	6,000	0.0
Reimbursed Ride Home	34,000	0.2
Bicycle Operations	63,000	0.4
Total Expenses	$17,471,000	100.0
OPERATING FUNDING & REVENUE		
University Sources	$ 5,646,000	32.3
Parking System	4,962,000	28.4
User Fees	6,863,000	39.3
Total Funding/Revenue	$17,471,000	100.0

[a]This is the amount of money the University pays to Metro and Community Transit. It represents the 25 percent that is typically collected at the fare box. The remaining 75 percent ($38,000,000) of the costs are paid by the county taxpayers.

TABLE 2 Recommended Parking Rates Under U-PASS Program

Parking Type	Term	Existing Oct 1990	Oct 1991	Jul 1992
Faculty/staff permit	Monthly	$24.00	$36.00[a]	$40.00[a]
Montlake lot--student	Daily	0.75	1.25	1.50
Daily pay--visitor	Daily	4.00	4.00	4.50

[a]Includes free U-PASS

travel. Program materials made clear that the parking rate starting in October 1991 would be $36.00 and that the U-PASS was an extra benefit and not something that could be declined for a reduction in rates.

Once the university and parking system revenues had been determined, the U-PASS had to be priced to cover the remaining $6.9 million in expenses. Two different prices were developed: one for a mandatory student U-PASS and one for an optional U-PASS. Under both pricing schemes the faculty and staff U-PASS was priced higher because parking rates for faculty and staff were higher and because faculty and staff had the additional benefits of the reimbursed ride home and commuter tickets (see Table 3).

In February 1991, ACT accepted the subcommittee's recommendations concerning U-PASS expenses, proposed parking system rates, and U-PASS fees. ACT recommended to the administration that the parking fee increase be accepted and that a mandatory student U-PASS fee be proposed to the board of regents.

Board of Regents

In March 1991, the proposal for a mandatory U-PASS program for students was introduced to the University of Washington Board of Regents in preparation for its April meeting. After much discussion, the regents decided that the final proposal for action in April should include an optional U-PASS program. In making this recommendation, they took into account student opinion and the hope that the program could generate enough support among the students that it would not need to be mandatory.

On April 11, 1991, a public hearing was held on campus to hear testimony concerning the proposed parking rate increases and the U-PASS program. Several hundred people attended. The majority of the testimony from faculty and staff centered around the increase in parking rates. Most students testified in favor of an optional U-PASS program.

Given the results of the public hearing and additional information from staff concerning the feasibility of operating and funding an optional U-PASS program, the regents voted eight to one in favor of a 3-year demonstration U-PASS program. A goal of 75 percent student participation was assumed under the optional plan.

Metro Council and CT Board

On April 18, 1991, the Metro Council approved the U-PASS program with the provision to add 60,000 annual hr of new service during the 3-year life of the demonstration project. The CT Board followed suit a month later.

TABLE 3 Monthly U-PASS Cost: Mandatory Versus Optional

	Mandatory			Optional		
Population	1991	1992	1993	1991	1992	1993
Faculty/Staff	$ 8.00	$10.00	$11.00	$ 9.00	$ 9.00	$11.00
Students	4.00	5.00	5.50	6.67	6.67	8.00

The University, Metro, and CT spent the next 4 months negotiating separate contracts and developing an implementation plan for the U-PASS program.

On September 30, 1991, the U-PASS program officially began at the University of Washington. From the first day, it has proven to be a popular program and a tremendous success in decreasing vehicle trips to campus. Table 4 presents a summary of the program elements.

U-PASS EFFECTIVENESS

One of the most important aspects of developing any program is evaluation of the components to determine the program's effectiveness. The effectiveness of the U-PASS program was determined using three TDM measures of effectiveness: participation rate, reduction in vehicle trips, and changes in mode choice.

Data relating to these TDM measures were collected through the U-PASS evaluation and monitoring program, a joint effort by the university, Metro, and CT. Methods of collecting data included monthly monitoring of individual program elements, traffic surveys, a mail survey, and a telephone survey conducted during February and March 1992 by an independent research company (*2*).

Participation Rates

The goal of the program was to have a 75 percent participation rate for faculty, staff, and students. This goal was based on the desire to mitigate vehicle trips and on the need to generate student U-PASS revenue under the optional program. During the 1991–1992 academic year, U-PASS participation averaged 32,600, with a high of 37,000 during fall 1991. The campuswide average participation rate was 72 percent—74 percent for students and 68 percent for faculty and staff (see Figure 1). Among pass holders, almost 97 percent of the students and 57 percent of the faculty and staff purchased their U-PASSes directly. The remainder received theirs free with their $36 per month parking permit.

Reduction in Vehicle Trips

In October 1991, the university conducted its annual traffic counts as required by the agreement between the city and the university (*3*). The results were dramatic. With the U-PASS program in operation for only 3 weeks, trips to campus in the morning had decreased 15 percent and trips from campus in the afternoon had decreased almost 9 percent compared with the previous year (see Table 5).

To determine if U-PASS would continue to affect commute trips, a special April traffic count was taken in 1991 (pre-U-PASS) and again in April 1992 (post-U-PASS) (*4*). The results show that the U-PASS program has continued to decrease trips to campus at an even greater level than was reported in autumn (see Table 5).

Changes in Mode Choice

The most dramatic shifts in commute modes occurred for SOV commuters and bus riders. Before the U-PASS, the dominant

TABLE 4 U-PASS Program Elements

Program Element	Description
U-PASS Costs	The optional U-PASS fee was established in October 1991. - Faculty/Staff: $9.00 per month - Students: $6.67 per month
Parking Costs	The following parking costs were adopted to help fund the U-PASS program: Parking Type / Oct 91 / Jul 92 Permit* (month) $36.00 $40.00 *Includes free U-PASS Montlake Lot (day) 1.25 1.50 Daily Pay (day) 4.00 4.50
Transit Service	Metro and CT will add over 60,000 annual hours of new service, a 20 percent increase, between September 1991 and February 1994.
Circulation	Two-way transit service added to campus; Metro and CT routes serve as a campus shuttle.
Shuttle Service	In addition to the Health Sciences Express and Disabled Persons Shuttle, a new Night Ride shuttle operating Sunday through Thursday from 6:00 P.M. to 12:30 A.M. has been added. It provides service from campus to areas north, west and east of campus.
Carpool	Free carpool parking if the driver and passengers all have a U-PASS. Permit carpools still available for faculty and staff.
Vanpool	Free vanpool fares for U-PASS holders on Metro and CT vanpools.
Ridematch	Ridematch system improved and the pool for matches expanded.
Bicycles	Install additional bike racks and bike lockers and improve bicycle routes.
Reimbursed Ride Home	Faculty and staff are reimbursed for 90 percent of the taxi fare up to 50 miles per quarter if their usual transportation is unavailable when they must leave the University.
Commuter Tickets	Faculty and staff U-PASS holders can purchase up to 25 commuter tickets per quarter for $1.25 each. (This is nearly half the cost of the non-U-PASS rate.)
Merchant Discounts	U-PASS holders receive merchant discounts at participating businesses and restaurants.
Marketing/ Information	Activities include: - Added full-time information specialist - Joint marketing with Metro and CT - Complete new line of U-PASS brochures - New campus commuter centers/kiosks - U-PASS newsletter - Annual transportation fair/fall campaign
Monitoring/ Evaluation	Activities include: - Annual traffic and parking survey - Annual mode choice survey - Biennial telephone survey conducted jointly with Metro - Monthly monitoring of each U-PASS element

commute mode was driving alone (33 percent), followed by transit (21 percent). Since U-PASS began, the numbers have been reversed: 33 percent of the campus commuters travel by bus, and only 23 percent drive alone (see Figure 2).

Commute modes vary among campus population segments, as shown in Table 6. The number of students driving alone has dropped by almost half, from 25 percent to 14 percent of the student population. At the same time, the percentage of students commuting by transit has risen from 21 to 35. Although not as dramatic, faculty and staff drive-alone mode choice has decreased significantly and transit usage has increased 7 percent.

INDIVIDUAL PROGRAM ELEMENTS

In addition to measuring the effectiveness of the overall U-PASS program, the individual program elements were evaluated.

Use of U-PASS Features

Research has shown that commuters often do not use the same commute mode consistently. The U-PASS was designed to address these varying needs by offering flexibility. This approach has worked well. Nearly half (45 percent) of U-PASS

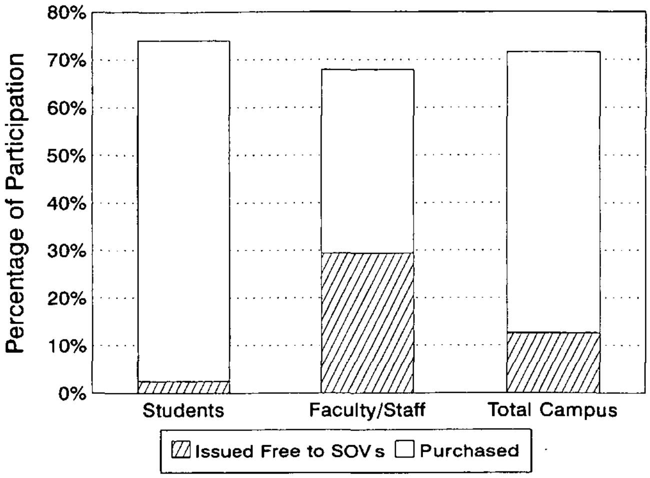


FIGURE 1 U-PASS participation (data from university transportation records).

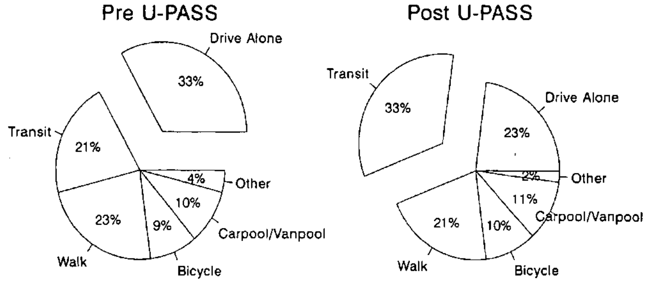


FIGURE 2 Changes in mode choice (data from 1989 and 1991 transportation survey).

holders regularly use their passes for two or more services, and 14 percent use it for at least three. The other half (48 percent) use it only for riding buses.

The bus feature of the U-PASS is by far the most used: 85 percent of all U-PASS holders have used their U-PASS to ride on Metro or CT buses (see Figure 3). The survey also confirmed that, although not as widely used, the other U-PASS features were important benefits in meeting the needs of specific markets.

Changes in SOV Permit Sales

Parking records indicate that SOV permit sales dropped 17 percent when the parking fee was increased from $24 to $36 per month in October 1991. When parking fees were increased to $40 in June 1992, SOV permit sales dropped another 7.5 percent. These significant changes are due to both the increase in SOV parking rates and the availability of improved services under the U-PASS.

TABLE 5 Campus Cordon Traffic Counts

	October		
Direction/Time	1990	1991	Percent Change
A.M. Trips to Campus (7-9 A.M.)	7,800	6,628	(15.0)
P.M. Trips from Campus (3-6 P.M.)	8,979	8,205	(8.6)
	April		
Direction/Time	1991	1992	Percent Change
A.M. Trips to Campus (7-9 A.M.)	7,592	6,365	(16.2)
P.M. Trips from Campus (3-6 P.M.)	9,053	8,176	(9.7)

When asked an open-ended question on the telephone survey about the reason they had changed their usual commute mode, most students and staff cited costs. It was unclear, however, if this referred to the increased price of parking or the low cost of the U-PASS.

Metro Transit Ridership

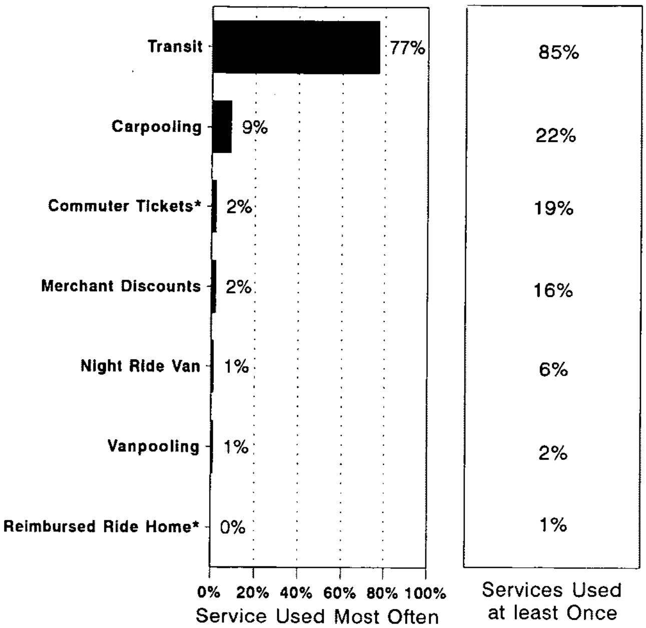
Overall, transit trips taken by the university community have increased by 35 percent since the inception of U-PASS. In October 1990, monthly transit trips taken by students, faculty, and staff were estimated at 492,000. One year later, in October 1991, transit trips were estimated at 663,000. The 36,000 pass holders average 4.3 trips each per week. Among those pass holders who commuted to the university during the 1990–1991 school year but were nonriders, 56 percent are now riding. Likewise, 46 percent of the pass holders who were infrequent users in 1991 (one to five rides a month) took at least two one-way trips during the week preceding the telephone survey (see Table 7).

During the week preceding the survey, 56 percent of U-PASS holders took at least one one-way ride on a Metro bus. More than one-third (36 percent) of the respondents took at least six rides.

Although the majority of trips were for commuting to or from the university, 15 percent of the trips were for noncommute purposes. Among those pass holders who lived close to campus, 39 percent of the trips were for noncommute purposes. This is significant: U-PASS holders are seeing the benefits of traveling by bus.

TABLE 6 Comparison of Campus Mode Split

	Student		Faculty/Staff	
Mode	Pre U-PASS	Post U-PASS	Pre U-PASS	Post U-PASS
Drive alone	25%	14%	49%	40%
Carpool/vanpool	9	8	14	15
Transit	21	35	21	28
Bicycle	10	11	6	6
Walk	31	28	6	7
Other	4	4	4	4
Total	100%	100%	100%	100%



* Percent of faculty/staff U-PASS holders only.

FIGURE 3 Service use among U-PASS holders (*2*).

Carpool and Vanpool Usage

During the 5 years preceding the U-PASS program, carpooling and vanpooling experienced little growth. During the first 9 months of the U-PASS program, the number of carpool permits rose by 21.2 percent, with a 17 percent increase in the number of participants (see Table 8). The vanpool program increased by 150 percent, from 8 to 20 vanpools with almost 200 participants. Sixty-three of the new vanpool riders (50 percent of all new riders) formerly drove alone. Before the U-PASS program began, the average vanpool fare in a university van was $45 per month. With the U-PASS, the fare has been reduced to U-PASS fees alone: $9.00 per month for faculty and staff and $6.67 for students. The growth in vanpools can be attributed directly to the greatly reduced cost of commuting by vanpool under the U-PASS program.

TABLE 7 Metro Bus Rides Taken by U-PASS Holders

Rides Taken the Week Prior to 1992 Survey	1991 Non-User	1991 Infrequent User[a]	1991 Frequent User[b]
None	44%	47%	18%
One	4	8	3
Two	10	9	9
Three to Five	12	9	12
Five to Ten	27	18	45
More than Ten	3	10	13
Mean	3.3	3.5	8.4

[a] 1 to 5 rides per month
[b] More than 5 rides per month or commuted by transit

TABLE 8 Carpools and Vanpools

Type	October 1991	October 1992	Percent Change
CARPOOLS			
Carpool permits	708	858	21.2
Carpool participants	1,653	1,932	16.9
VANPOOLS			
Number of vanpools	8	20	150.0
Vanpool ridership	71	197	177.5

Night Ride Program

For those who live close to campus, U-PASS provides the Night Ride shuttle to take them home after dark. (It does not operate during summer quarter.) During its first 9 months of operation, the Night Ride averaged 2,625 riders per month—an average of 145 riders per night, or 24 riders per hour.

The Night Ride service was an important component in the decision to buy a U-PASS for 31 percent of both the respondents who live within 1 mi of campus and the respondents who usually walk to campus. Although only 6 percent of the university population has used the Night Ride service, 35 percent of all respondents feel safer because of it. Of those who use it, 54 percent feel safer.

The university has a 3-year contract with an outside vendor to provide the Night Ride service at a rate of $39.00 per hour. In addition, university staff monitor both the contract and the service. The cost per rider was almost $11.00 for the first 9 months of operation. In the future, this high cost per rider will need to be weighed against the increased participation of the campus population who walk to campus.

Reimbursed Ride Home Program

Missing a bus or carpool or having an emergency at home are some of the major concerns of the HOV commuter. The reimbursed ride home program was designed to overcome that concern, by offering a limited number of taxi rides home. University commuters perceive this to be a valuable benefit, yet usage and program costs are minimal.

Reimbursed ride home benefits are for faculty and staff only and have been used less than 15 times per month. The average taxi ride home is 8 mi and costs about $12. Less than 1 percent of the faculty and staff with a U-PASS have ever used the reimbursed ride home, but 34 percent of the staff and 19 percent of the faculty consider it an important feature of the program.

Commuter Tickets

The commuter ticket feature for faculty and staff provides both flexibility and convenience to the non-SOV user. Information on precise usage is not available, but the sale of these tickets has doubled, from an average of 5,640 per month before the U-PASS program began to 10,730 after the program began.

INFORMATION AND MARKETING

To introduce the new program to the campus and to encourage high participation rates, an information and marketing program was established, a family of brochures developed, and nine campus commuter centers created. New students and employees receive program materials at orientation sessions or by mail. Program brochures, newsletters, and seasonal fliers are mailed and are also displayed at the commuter centers. Advertisements and articles in campus papers keep the program in the public eye on campus.

Effectiveness of U-PASS Marketing

The U-PASS telephone survey indicates that 74 percent of the campus population has seen or read the U-PASS User's Guide. Other U-PASS information that has reached at least half the population includes student newspaper advertisements (66 percent) and articles (63 percent) and the merchant discount brochure (53 percent).

Awareness of U-PASS Benefits

When telephone survey respondents were asked which U-PASS benefits they were aware of, by far the most common response was the bus pass, followed by merchant discounts, Night Ride, and carpooling (see Figure 4).

Students are more aware of many of the other services offered by the U-PASS than are faculty and staff. This is especially true of merchant discounts, Night Ride, and carpooling. The faculty and staff are, of course, more aware of the reimbursed ride home and commuter tickets, services that apply only to them.

Respondents who do not have a U-PASS are less aware of services than are U-PASS holders, but 50 percent were able to mention two or more services.

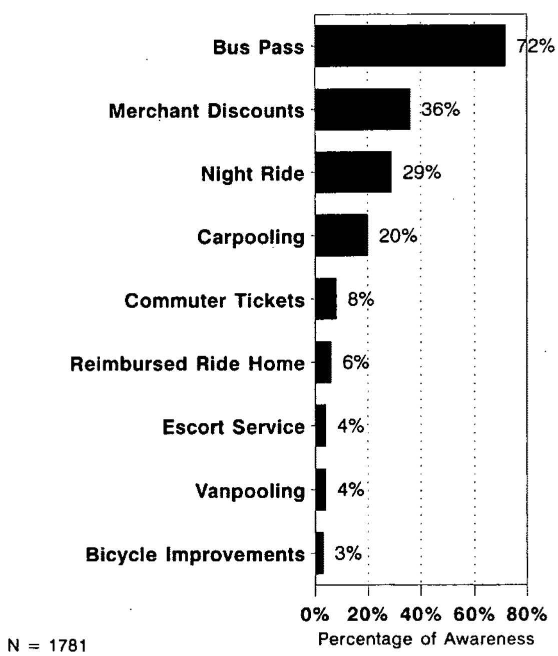


FIGURE 4 U-PASS awareness (2).

MONITORING AND EVALUATION

To track the effectiveness of the U-PASS program, a monitoring and evaluation system was established. It includes an annual traffic count, an annual transportation survey by mail, a biennial telephone survey conducted jointly with Metro, and the monthly monitoring of each U-PASS element.

Annual Traffic Count

The university's annual October traffic count provides the best indication of the effectiveness of U-PASS to reduce vehicle trips to campus. The 5-day count is taken at the campus boundaries by means of electronic traffic counters. The count does not, however, include drivers destined for the university who park in the commercial and retail areas and neighborhoods surrounding the campus.The number of vehicles that are parked off-campus is tracked through a count of vehicles parked in the neighborhoods and through questions on the annual transportation survey.

Since the start of the U-PASS program, there has been no evidence that the number of vehicles parking in the surrounding neighborhoods has increased.

Transportation Survey

Transportation surveys track changes in campus mode split, times of arrival and departures, and on- and off-campus parking locations. The surveys are on a simple scan-type form and are distributed to random samples of faculty, staff, and students.

The methodology was consistent for the November surveys taken in 1988, 1989, and 1991. To determine the pre-U-PASS mode split, the 1989 survey was used, and the post-U-PASS condition was based on the 1991 survey.

Telephone Survey

To determine the U-PASS program's effect on commute modes, frequency of U-PASS use, level of awareness of program elements, and program satisfaction, the university and Metro contracted with a private research company to conduct a telephone survey of faculty, staff, and students. Between February 13 and March 18, 1991, the research company interviewed 604 students, 572 faculty, and 605 staff members.

LESSONS LEARNED

Many lessons have been learned through the development and implementation of the U-PASS program.

First, a balanced TDM program should include both benefits and disincentives. University parking rates would never have been increased to their current level had attractive, low-cost, alternative commute options not been provided.

Second, commuting options should be flexible. People cannot always commute by the same mode every day. To accommodate commuters' varying needs, the U-PASS provides access to options on a continual basis. In addition, faculty and staff who commute at least 3 days a week by non-SOV modes may drive alone the other days with commuter tickets. In addition, all SOV permit holders are issued a complimentary U-PASS to encourage them to use it whenever possible.

Third, parking fees may be used as a disincentive as well as a significant funding source for a TDM program. Free or low-cost parking is the biggest obstacle to a successful TDM program. Not only does free or low-cost parking encourage SOV use, it precludes the use of parking revenue to fund TDM options. In the case of U-PASS, parking revenue funds almost 30 percent of the total program costs.

Fourth, a comprehensive education campaign during the program development stage helps the program gain acceptance. The year-long effort to inform the campus community about the need for the U-PASS program played a major role in its acceptance and ultimate high participation rate. In the university environment, it was critical that the key campus committees and decision makers recognized the need for the program. Once the program received their support, it was much easier to bring along the general campus population.

Fifth, be prepared to meet the demand for services if it is greater than anticipated. From the first day of the U-PASS program, bus ridership was much higher than anticipated. Because the university, Metro, and CT had plans in place, they were able to add service in a matter of days. This quick response meant that new transit riders did not become discouraged and return to their automobiles.

RECOMMENDATIONS FOR FURTHER RESEARCH

With just 1 year of U-PASS operation complete, many questions remain about the ability of the program to continue to mitigate the number of vehicle trips over time and the effectiveness of specific program elements. In addition, how important was the increase in parking rates vis-a-vis the reduced cost of non-SOV commuting?

Recommendations for further research include the following:

1. Analyze the effect of providing a comprehensive package of commute alternatives accessed by a single card versus the traditional method of offering a collection of separate TDM program elements.
2. Determine which U-PASS program element is most effective for each segment of the faculty, staff, and student markets.
3. Determine the cost-effectiveness of each program element and the U-PASS program as a whole.
4. Assess which evaluation technique—traffic counts, mail survey, telephone survey—is best for measuring the program's effectiveness.

As the program matures and additional information is collected, many of these research topics will be addressed.

CONCLUSION

The U-PASS program has proven to be a model TDM program that works. Its comprehensive package of low-cost commuter options, coupled with the disincentive of an increased parking rate, has resulted in a balanced TDM program with high participation. Not only did the increased parking rates serve as disincentive to driving alone, they also provided funding for 30 percent of the program. Other major employers and institutions should be able to use the structure of the U-PASS program, and the lessons learned about parking rates, to develop and implement their own TDM programs.

ACKNOWLEDGEMENTS

The authors wish to thank the many people who helped make the U-PASS program a reality. They would also like to acknowledge the contributions of Michelle Majors and Sean O'Hogen of Metro and Janette Ollivier and Meighan Pritchard of the University of Washington in the development and production of this paper.

REFERENCES

1. *University of Washington General Physical Development Plan.* Campus Planning Office, University of Washington, Seattle, June 1991.
2. *The U-PASS Telephone Survey.* Gilmore Research Group, Seattle, Washington, June 1992.
3. *1991 Annual Traffic and Parking Study.* Transportation Office, University of Washington, Seattle, Jan. 1992.
4. *1992 Spring Traffic and Parking Study.* Transportation Office, University of Washington, Seattle, July 1992.

Publication of this paper sponsored by Task Force on Transportation Demand Management.

Gender Differences in Commuter Travel in Tucson: Implications for Travel Demand Management Programs

SANDRA ROSENBLOOM AND ELIZABETH BURNS

This paper reports on part of a study funded by the U.S. Department of Labor to evaluate whether individual transportation demand management (TDM) measures differentially affect salaried men and women in various household situations. Working women with children are the least able to make drastic changes in their daily activities but may be the most affected by employer sanctions and financial penalties. The study found that in Tucson, Arizona, women are (a) substantially more dependent on the private car driven alone than are comparable men, (b) far less likely to have switched to alternative modes, and (c) more likely to have chosen different alternative modes when they did switch. Moreover, there were differences between the sexes in travel time and distance to work, none of which could be explained by income or occupation. When workers were asked how effective various TDM strategies would be in increasing their use of alternative modes, women were more likely to see all potential strategies in a favorable light. Moreover, women were more responsive to strategies that addressed their domestic responsibilities (for example, their need to transport children or respond to family emergencies). Ultimately, while being more favorably disposed to TDM measures, women were less likely to give up driving alone because travel modes that are slower and less flexible than the private car may severely affect their working and family lives. These findings show the need to identify the equity consequences of specific TDM requirements, to target appropriate individual measures to working women, and to develop ways to offset the negative impacts on working mothers.

This paper describes the preliminary results of an ongoing U.S. Department of Labor study designed to critically analyze the impact of mandatory transportation demand management (TDM) measures or programs in two major metropolitan areas in Arizona: Tucson and Phoenix. Individual TDM measures, or packaged programs of measures, are designed to reduce traffic congestion, energy consumption, and environmental pollution by changing employee home-to-work travel behavior.

The overall study was structured to evaluate the extent to which TDM measures—from mandatory shifts in work hours to free transit passes—differentially affect salaried men and women in different household situations. A growing body of international research strongly suggests that working women with children may be disproportionately affected by policies that impose additional constraints on their already restricted choices. Working mothers have different travel patterns than their spouses, and single mothers have different patterns than both married parents because they retain child care and domestic responsibilities when they enter the paid labor force.

The analyses are based on mandatory employee surveys undertaken sequentially in 1990 and 1991; the data bases are large (over 50,000 respondents in each region in each year). This paper focuses on the Tucson findings that women are (a) substantially more dependent on the private car driven alone than are comparable men, (b) far less likely to have switched to alternative modes between 1990 and 1991 than comparable men, and (c) more likely to have chosen different alternative modes when electing not to drive alone. The findings for Phoenix are roughly comparable, although income data were not available in the Phoenix region. Full details of the study, the data bases used, the study methodology, and the comparative Tucson-Phoenix analyses appear in work by Rosenbloom and Burns (*1*).

These findings have important policy implications. Working women may have chosen to use the car for their work trip because it is the best—and perhaps only—way to balance their complicated obligations. TDM measures that force women workers with domestic responsibilities to choose slower, less responsive transportation alternatives may severely affect their working and family lives. TDM measures that require them to shift to alternative work schedules not of their own choosing may be equally harmful.

The following section of this paper explains travel demand management programs and describes a growing body of literature that suggests why women may be disproportionately affected by such programs. The next section explains the data on which the study here is based; the section following that describes the research findings from Tucson.

BACKGROUND AND POLICY ISSUES

Travel Demand Management Programs

Transportation demand management (TDM) programs attempt to directly or indirectly persuade, induce, or force workers to change transportation habits and patterns that cause traffic congestion, contribute to environmental pollution, or increase

S. Rosenbloom, Drachman Institute of Land and Regional Development Studies, University of Arizona, 819 E. First Street, Tucson, Ariz. 85721. E. Burns, Geography Department, Arizona State University, Tempe, Ariz. 85287-0104.

consumption of nonrenewable natural resources (*2–4*). These dysfunctional actions include driving alone, traveling during peak periods, and failing to use available alternatives to the private car.

Public TDM programs focus directly on large employers and only indirectly on individual employees; employers are encouraged or required to introduce measures that change their employees' behavior in appropriate ways. Employer TDM programs may include incentives for employee behavioral changes; for example, employers may provide bike lockers and showers to induce cycling and walking to work, or special carpooling parking near the door to encourage ridesharing.

Conversely, employer programs may include disincentives; for example, firms may charge substantial fees for formerly free parking, provide only carpool parking, or even ban employee parking. Firms may also introduce mandatory schedule changes, such as shortened workweeks or earlier or later start times.

Although most government efforts have not been compulsory, there is increasing likelihood that public agencies will soon be forced to implement mandatory TDM programs—and require employers to achieve measurable reductions the number of employees who drive alone. Many regions will have to adopt such programs in response to provisions of the Intermodal Surface Transportation Efficiency Act of 1991 and the Clean Air Act Amendments of 1990 (CAAA). Section 182 of the latter requires states with "severe" or "extreme" ozone nonattainment areas to require all employers of 100 or more workers located in nonattainment areas to reduce work-related automobile-usage among their employees.

The CAAA provisions specifically require all affected employers to develop programs that increase their employee work trip passenger occupancy by 25 percent above the area average—which creates, of course, an ever-increasing standard of attainment. Failure to meet these standards may cause a region to lose significant federal highway and transit funds.

How and Why TDM Programs Affect Women

Historically, salaried women have had different transportation patterns than men: employed women worked closer to home, traveled shorter time and distance to work, and more often used mass transit than men (*5,6*). However, most of these disparities were thought to be the result of economic differences, simply reflecting the fact that so many more women had low incomes. See work by Rosenbloom (*7*) for a review of the literature on traditional beliefs on women's travel patterns. Until recently, few analysts believed that (a) women with comparable incomes but different household situations—single mothers versus married mothers, for instance—might have different travel patterns than one another, (b) employed men and women with comparable incomes might have different travel patterns, or (c) such differences reflected crucial noneconomic considerations.

New Perspectives on the Travel Behavior of Women

Research during the last two decades shows that, in contrast with traditional thought, working women have different patterns than men in comparable households with comparable incomes and that single mothers are different from their married counterparts. These trends have been found in countries as diverse as Sweden, England, France, and the United States and as recently as 1990.

The literature shows that married mothers have different travel patterns than comparable male parents and single working parents have different patterns than their married counterparts. Women appear to make transportation and other decisions in order to successfully juggle a number of employment, child care, and household responsibilities (*6,8*). These needs may limit their ability to use alternative modes or radically change their work schedules (*9*).

For example, Hanson and Hanson found that Swedish married women were more likely to make more shopping and domestic trips than their spouses—and fewer social and recreational trips (*10*). A 1990 study in four Chicago suburbs found that employed women made twice as many trips as comparable men for errands, groceries, shopping, and chauffeuring children (*11*).

Comparative work by Rosenbloom in The Netherlands, France, and the United States found that women's travel patterns varied significantly with the age of their youngest child and were significantly affected by their children's needs in all three countries (*12*). Raux, in a 1983 study in Lyon, France, found that working women were the parent in two-worker households who arranged their work and travel schedules to fit child care needs (*12*). Perez-Cerezo also found that the age and presence of children more influenced the travel patterns of women than men in all types of households (*13*).

Rosenbloom also found that more than 80 percent of all married women made trips solely for children, compared with half of all men; however, the trips made by men were made infrequently and served only a back-up function (*14*). When Rosenbloom asked employed married and single parents to describe their children's most frequent travel mode, both married parents overwhelmingly agreed that the mother was the most frequent chauffeur for children of all ages. Only 5 percent of all American women and 2 percent of all American men reported that the father has greater responsibility for children's transportation (and then only for children under six) (*15*).

The limited research on differences between married and single parents shows comparable differences between traditional economic assumptions and reality. Kostyniuk et al. found that, except for the poorest women who did not drive, single parents in Rochester, New York made more trips and traveled further for all purposes than comparable married workers; they attribute these patterns to the need to balance employment and domestic responsibilities without the help of a resident partner (*16*). Johnston-Anumonowo found that although single women with children in Worcester, Massachusetts, were less likely to own cars, they were more likely to make their work trips in cars; she also found that single mothers had longer work trips than comparable married women (*17*).

Rutherford and Wekerle studied single and married workers in a Toronto suburb and concluded that single mothers spent more time traveling to work and that they were less likely to work in the suburb in which they lived than comparable married women (*18*). Rosenbloom found that single mothers in Houston and Dallas had different travel patterns than comparable married women, generally traveling further and using a car more often than either married worker at all income levels except below $5,000 a year (*19*).

Clearly the use of the car by even low-income women and the complicated travel patterns of working women reflect transportation needs generated by their primary responsibilities for children and for the conduct of household business (shopping, picking up drycleaning, etc.) To fulfill these obligations, working women alter their travel patterns—they make more linked trips to and from work (*20*), choose travel modes that allow them to respond to children in emergency situations (such as a child becoming ill at school or child care), and routinely chauffeur even their teenage children.

TDM Concerns for Working Women

It is clear that the travel choices of working women and men are dependent on a variety of nonwork, and often nonfinancial, variables—the most important of which may be time. In short, there are only 24 hr in a day in which to carry out multiple activities. Moreover, time becomes money for working women who are paying for child care or elder care, especially those paying premium prices for early or late hours of care. It is important to question, therefore, how TDM measures might negatively or positively affect women in the labor force, particularly those who juggle domestic responsibilities.

Giuliano and Golob (*21*), in a 1989 study of a major TDM program in Honolulu that focused on changing work hours, cautioned,

> . . . research provide[s] valuable information on the degree to which an individual's work schedule is embedded with the household activity schedule. When the work schedule changes, it affects all members of the household, and requires adjustments in all activities. Social activities, child care, children's activities, and household chores may be reorganized and rescheduled. The Honolulu experience also illustrated the dependence of workers on the schedule of other institutions and services. Thus spreading out the normal workday is dependent upon extending hours of child care services, banks, medical offices, etc. as well as extending work-trip oriented transit services.

Employees often report that their unwillingness to stop driving alone is due entirely or in significant part to their need for their car immediately before and after work, their child care needs, and their concern that they might be faced with a family emergency during the middle of the work day (*22–26*).

Although mass transit subsidies have been suggested as a way to offset any inequities imposed by mandatory TDM measures, low-income working women who drive have already accepted the expense of driving because their other economic needs (the hourly cost of child care) or noneconomic needs (the actual availability of a child care provider matched to their work schedule) are more pressing.

Given the average time differentials between the car and all other modes, mass transit subsidies are hardly likely to offset additional costs imposed on these women by mandatory changes in their work trip. For example, the average American work trip was 10.4 mi in 1990—such a trip would take barely 20 min by car in most suburban areas but more than 45 min by mass transit (*27*). Thus, a worker switching to mass transit could lose almost 1.5 hr per day (during which child care costs and the like could be mounting).

THE STUDY DATA SETS: ARIZONA TDM PROGRAMS

Both Tucson and Phoenix (with more than 70 percent of the State's population) have had mandatory TDM programs for more than 3 years. The Tucson program concentrates on increasing commuting participation in alternative modes: 15 percent in the first year, 20 percent in the second year, and 25 percent in the third year. The Tucson standards are far less onerous than they initially sound; mandatory changes in behavior need take place only 1 day a week to be counted.

Both regional TDM programs target only large employers (those with 100 or more employees at one site). The program in Phoenix, with a 1990 population of 2.1 million, includes just under 400,000 employees in 470 firms at 806 work sites. The program in Tucson, with a 1990 population of 670,000, includes 87,000 employees in 120 firms at 150 work sites.

The annual surveys that large employers in each region must administer to these employees constitute the data base for the research described here. In each region, the study team used the regional data bases for 1990 and 1991 to study general patterns and trends; in addition, the study team used the individual data bases from Arizona State University and the University of Arizona. As noted, this paper includes only the 1990 and 1991 Tucson regional findings.

These data bases are quite large, and all the differences reported on here are statistically significant unless otherwise indicated. The 1990 Tucson regional data set includes 50,866 respondents, and the 1991 data base includes 52,244 respondents. The Tucson data bases are not samples—they constitute 100 percent of all usable survey responses and represent more than 60 percent of the covered labor force.

TUCSON ANALYSES

Aggregate Travel Characteristics

Most Tucson respondents worked fairly close to their homes; more than 60 percent of respondents worked less than 20 min away from home in both 1990 and 1991, and less than 6 percent worked more than 40 min from home. Whereas travel times dropped nationally, mean travel time increased slightly in Tucson—from 20.7 to 20.9 min. The work trip distance patterns of Tucson were also slightly different from American trends on the whole. In 1990 the average American work trip was 10.6 mi, up from 9.2 in 1977; in Tucson the average work trip stayed the same at 10.4 mi.

Also in contrast to national trends, the use of the private car declined in Tucson between 1990 and 1991 by almost 7 percentage points. All of the alternative modes gained a share of the decline, but carpooling took the largest share of the drop in single-occupancy vehicles.

Although the TDM programs in Tucson had some success in increasing the use of alternatives to the private car driven alone, most workers still chose to drive alone in the face of TDM incentives and even sanctions. After the 1990–1991 shift away from the single-occupant car, more than 88 percent of all workers still arrived at work in a car as a passenger or driver, down from 90 percent in 1990.

Women's Travel Patterns

Basic differences between women and men in mode choice and time and distance to work are discussed in this section.

Women workers in Tucson tended to be even younger than the young aggregate labor force, more likely to be employed in low-paying occupations (secretarial instead of managerial jobs, for example), more likely to be in households with fairly low incomes, and less likely to be in households with fairly high incomes. Women were also slightly less likely to work a five-or-more-day workweek than comparable men.

In spite of the fact that women were either more likely to have lower incomes or to be in lower occupational jobs, they were (a) substantially more dependent on the private car than men, (b) far less likely to switch to alternative modes between 1990 and 1991 than men, and (c) when electing not to drive alone, more likely to choose different alternative modes than men.

Women were more likely to drive alone in both 1990 and 1991 by statistically significant margins. The most impressive fact is that, because of differential changes in mode choice from 1990 to 1991, the gap between men and women has intensified sharply. As these data showed, aggregate private car use dropped in Tucson; however, it has dropped the most for men. In 1991 the number of men driving alone to work declined by more than 9 percentage points, whereas women's driving declined by less than 4 percentage points. Thus the differences between the sexes in the use of the private car increased—comparatively speaking, women were even more dependent on driving alone to work in 1991 than men.

The data show that biking is largely a male mode; its use barely increased among women workers while showing meaningful gains among male workers. In Tucson in 1991 the bike accounted for 4 percent of male workers' commute mode while accounting for barely 1 percent of the work trips of female workers. The bus was used more often, on the other hand, by women in 1991 than men, although the gap is not as great.

There are both challenges to, and support for, traditional assumptions when examining time and distance to work by men and women. Women have shorter median work trips in miles than men—as would be expected given historical trends and their income and occupational characteristics. However, given that women had shorter commutes in miles, and were more likely to use a car for their work trips, their travel times were expected to be substantially less than men's. However, mean travel times were longer for women than men—in contrast to both traditional assumptions and the data already presented.

Synthesizing mode choice, time, and distance responses, the authors found more nontraditional than traditional patterns—with the largest discrepancy being the choice of the car by more women. Moreover, there is a problem in making consistent the time and mileage responses—if women overall work much closer to home than men, why does it take them almost as long to get to work, especially considering that they are more likely to be using the car—a faster mode?

One clear possibility is the following: women have retained child care and household duties, and their work trips are linked with trips to drop children at school, take other adults to work, or to carry out domestic responsibilities. If so, it is likely that they are reporting the total time from home to work, including these trip links, thus lengthening the time taken to drive the distance between their home and job.

Travel Patterns by Income

It is, of course, possible that traditional economic variables do explain some of the significant mode and time and distance differences between men and women; that is, in spite of the average income disparities, longer trips and higher automobile use by women could be the result of a small number of higher income or higher occupational status women among female respondents. This section examines that possibility.

Mode Choice by Sex and Income

Analyzing mode choice in Tucson by household income as well as sex shows the same patterns seen in the aggregate data: (a) at all income levels—including the lowest—women were much more likely to drive to work than comparable men; (b) at all income levels, women were less likely to have given up driving alone so that unexpected differences between the sexes intensified between 1990 and 1991, and (c) when changing from driving alone, men and women chose different travel alternatives, which varied with income. In short, the patterns seen in the aggregate travel data by sex are also seen across income groupings.

First, in both 1990 and 1991 the likelihood of driving alone increased for both men and women as income increased, but, at all income levels except the highest (above $80,000), women were more likely to drive alone to work. In general, in all except the lowest income category, the gap between the percentage of men and women driving alone increased as household income levels increased.

Second, as in the data aggregated by sex alone, fewer women stopped driving alone to work at all income levels between 1990 and 1991. As a result, the gap between men and women in the use of the private car widened from 1990 to 1991; again, although private car use dropped for both men and women, it dropped far faster for men at all income levels than for women. For example, at incomes below $10,000, the gap between men and women was 5.8 percent in 1990 and 8.5 percent in 1991—with women always more likely to drive alone.

Figure 1 shows car use by sex and income in 1991. In every income category, women are more likely to drive alone than men, sometimes by substantial, and always by statistically significant, margins. At incomes between $10,000 and $20,000, the gap between men and women in 1991 was just under 7 percent; between incomes of $30,000 to $40,000, the gap was almost 10 percent.

Third, men and women generally chose different alternatives to the private car, and the choices varied with household

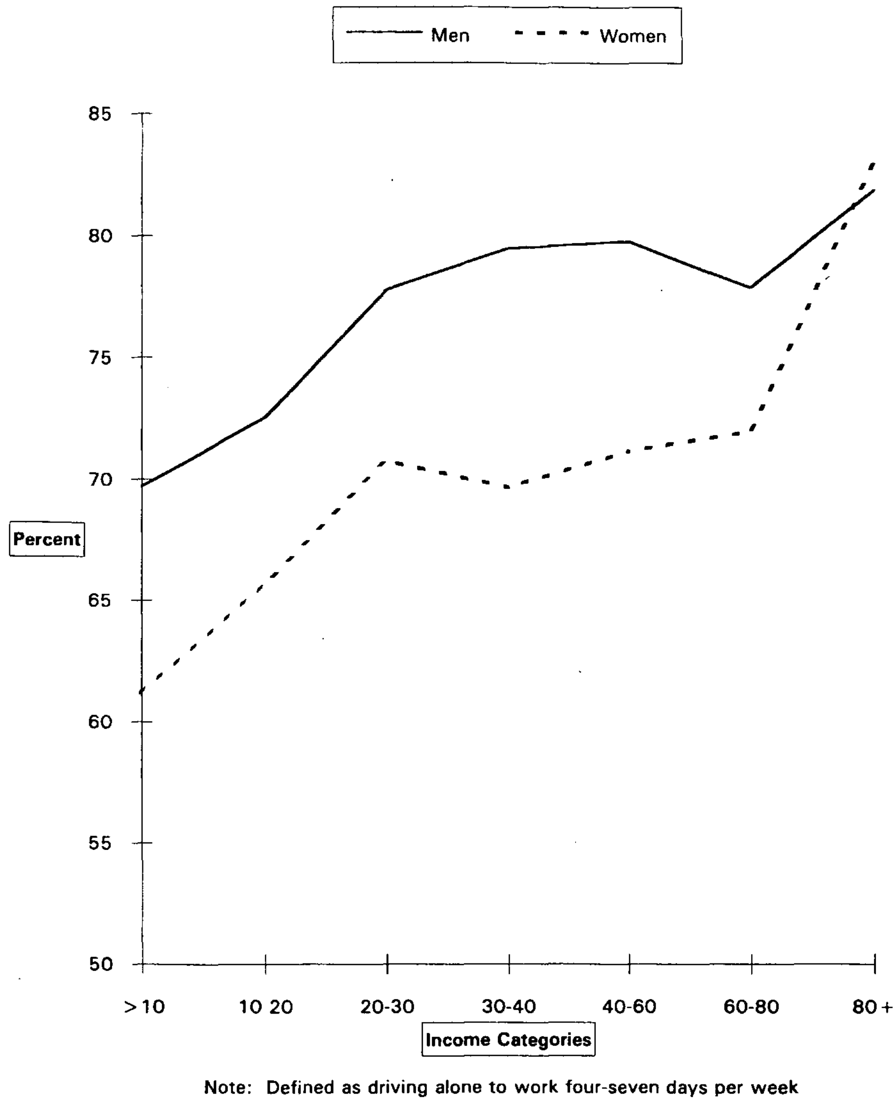


FIGURE 1 Car use by income and sex.

income. At income levels below $20,000 and above $60,000, more women than men carpooled in both years. Between 1990 and 1991, although the use of carpooling generally increased for both men and women, it went down for those with high and low incomes. The alternative of choice for low-income workers of both sexes was the bus, the use of which increased substantially for those with incomes below $10,000.

However, as Figure 2 shows, sometimes substantial differences occurred between the sexes in the use of these alternatives in 1991. Women who earned between $20,000 and $80,000 were less likely to carpool than comparable men. At low incomes (below $10,000) and those more than $30,000, women were more likely to use transit as their alternative mode than men. Note, however, that no more than 9 percent of any income group used the bus; less than 5 percent of all women workers in Tucson used the bus, although one-third of all women had incomes below $20,000.

When mode data were categorized by occupation, the analysis indicated that (a) women are more likely to drive alone to work in most occupational categories, regardless of the income potential of the occupation, (b) that women in all occupational categories were less likely to give up driving alone between 1990 and 1991 so that the gap between men and women in each occupational group intensified, and (c) that there were differences in the alternative modes chosen by men and women, which did vary with occupation.

In summary, in contrast with traditional models of travel behavior, neither income nor occupational variables provide an explanation of the most important differences in the mode choice of men and women. However, the analyses do show that income is associated with some differences in travel behavior; the differences between the sexes in the choice of alternatives to driving alone seemed to be affected by income (that is, the differences between the sexes are different at different income levels).

Travel Time and Distance to Work by Sex and Income

This section questions whether the aggregate differences between the sexes in time and distance are explained by the

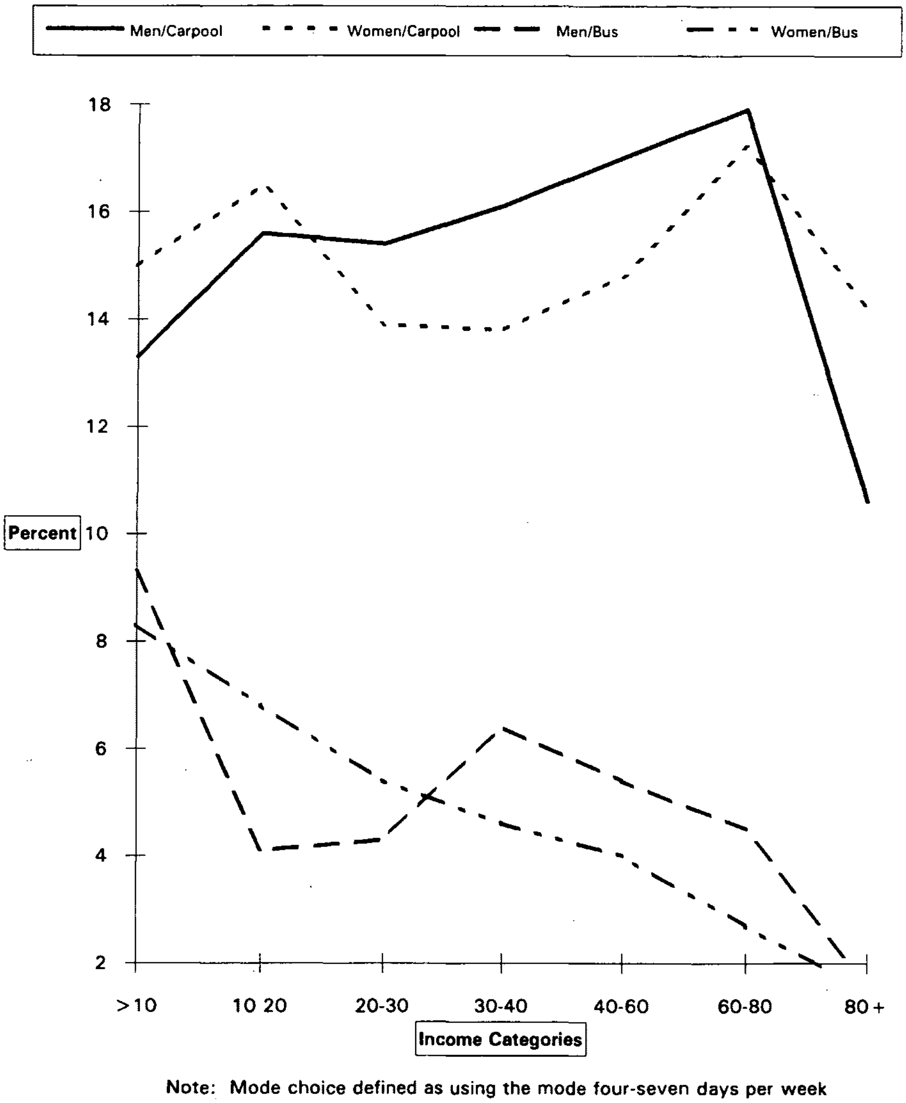


FIGURE 2 Mode to work by income and sex.

traditional variable of income. Overall, trip length to work increases for both men and women as income increases—as traditional theories would hold. However, there are differences, sometimes substantial, between men and women within most income categories, and the differences vary with income in ways that traditional thinking would not predict.

At income levels below $20,000, women had a significantly longer average commute in both 1990 and 1991 than comparable men. On the other hand, as Figure 3 shows, the average commute for women at incomes above $20,000 was less than comparable men until high income levels were reached.

The disaggregated data show that at incomes under $30,000, there were more men than women who worked close to home (less than 5 mi). Conversely, men at all income levels were more likely to work far from home; for example, more than 9 percent of men but less than 2 percent of women with incomes between $30,000 and $40,000 worked more than 26 mi from home.

Alternatively, women have longer mean travel times to work than comparable men for all household income groups below $30,000; for example, at incomes between $10,000 and $20,000, the mean commute for women was more than 20 min compared with 18 min for men. Although these differences are not large, they are significant and important because they move in a different direction than expected, given average travel distances. Figure 4 shows that all women have different commute times than comparable men.

Income data do not provide much explanation for the disparity between women's travel distances and their travel times; women have shorter commutes but take more time to make them, despite that they are more often using the fastest mode available. Overall, these findings support the contention that the other responsibilities of salaried women create diverse needs that are incorporated into their travel patternsneeds that are not incorporated into the patterns of comparable men.

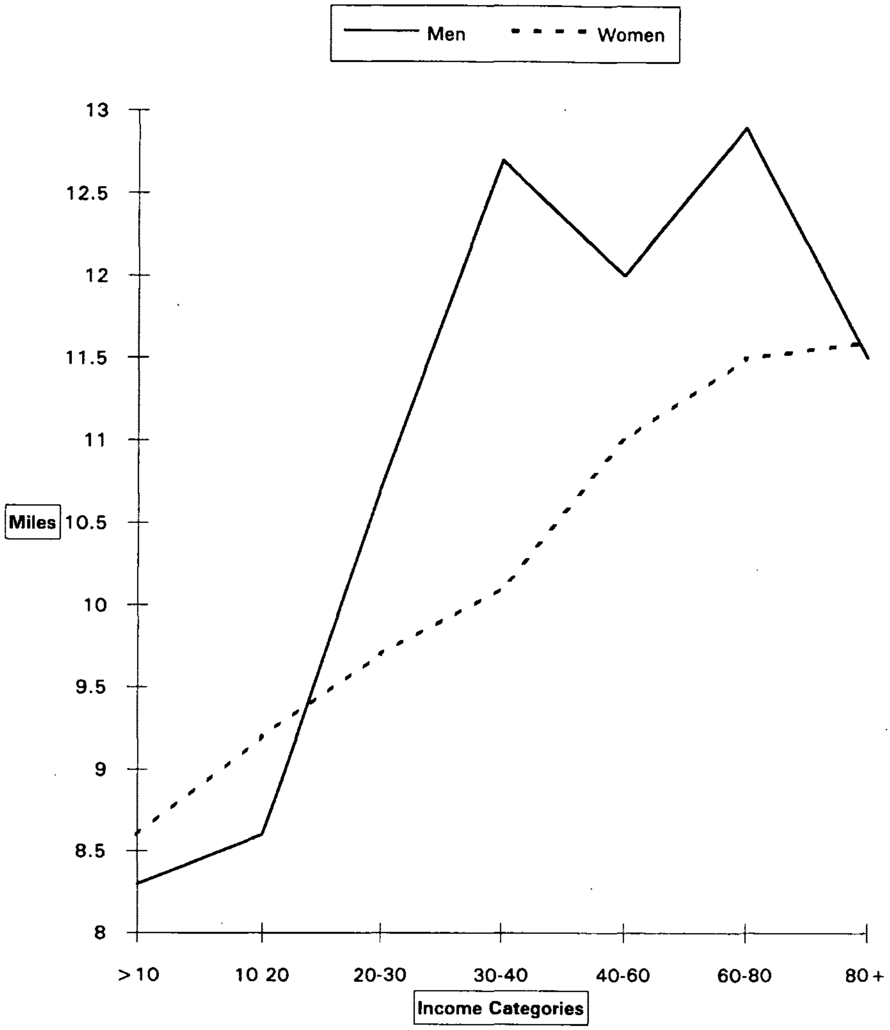


FIGURE 3 Average distance to work by income and sex.

DIFFERENCES BETWEEN THE SEXES IN RESPONSE TO ALTERNATIVE TRAVEL MODES

Workers were also asked in the annual surveys to evaluate the potential effectiveness of ways in which alternatives to the car could be made more appealing. Tucson respondents were asked to identifying the single policy or incentive that would most encourage their use of specific alternative modes.

The data suggest that (a) women are slightly more likely than comparable men to indicate interest in policies that facilitate the use of alternative modes and (b) they tend to be interested in the same policies as men—but then in addition are far more interested in other policies for encouraging the use of specific alternative. That is, men and women generally respond to many of the same measures; most of the top-rated policies in all the specific modal analyses are top-rated for both men and women. However, in addition, women are far more likely to respond to options that affect their children or their flexibility in carrying out domestic obligations.

Table 1 shows response to selected options encouraging transit use. Although all respondents were most interested in bus service improvements (closer home and work stops, no need to transfer, express or frequent bus service), men were slightly more responsive to these improvements than women. Women, however, were more responsive to arrangements for child care and guaranteed rides home. Almost 6 percent of women say that being able to arrange transportation for their children is the single most important factor that would encourage their mass transit use, almost treble the percentage of comparable men. Women were also more likely to be interested in a guaranteed ride home.

Women were also more concerned with safety and security, which is not shown in the table. More than 5 percent of female respondents said that the single most important factor in their potential bus usage would be safer buses and stops (compared with less than 1 percent of comparable men).

Table 1 also shows responses to selected options encouraging carpool use; for both men and women, living near other employees and having compatible work schedules are important. However, women are less likely to highly rank these policies than men. Conversely, women are much more likely to care about arranging children's transportation than men; more than 6 percent of women in the region but only half that percentage of men said that this was the single most important incentive to carpooling. A fairly major response was to another policy that implies flexibility: almost 9 percent

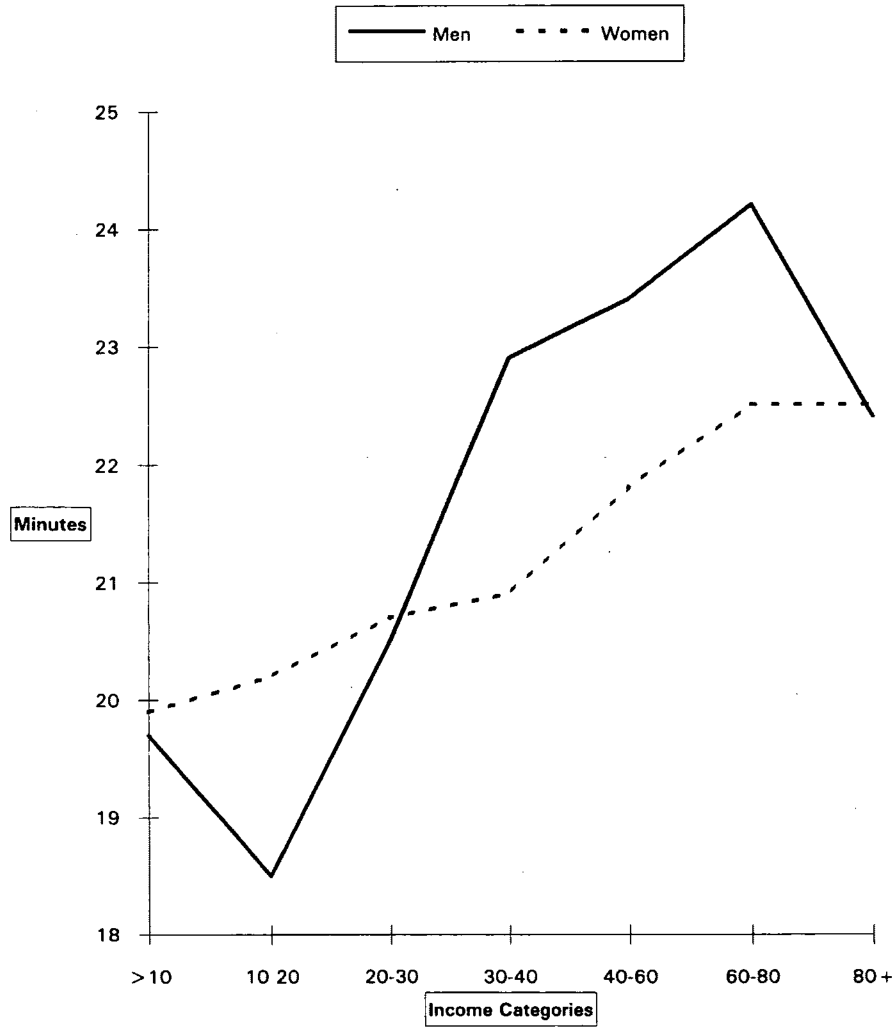


FIGURE 4 Average time to work by income and sex.

TABLE 1 Single Option Encouraging Use of Bus and Carpool by Sex

Bus: Measure	Men	Women	Carpool: Measure	Men	Women
Close Stops	18.8%	16.9%	Compatible Work Schedules W/Others	22.7%	20.4%
No Transfers	7.5	8.5	Live Close To Others	18.0	16.7
Express Bus Service	6.4	6.6	Can Carpool Often But Not Daily	6.1	8.7
Frequent Bus Service	6.6	5.6	Guaranteed Ride Home	8.4	9.7
Guaranteed Ride Home	4.5	5.4	Arrange Children's Transportation	2.4	6.3
Arrange Children's Transportation	1.9	5.7	Free or Covered Parking	3.5	2.7
Others or None	54.3	51.3	Others or None	38.9	35.5

of women but only 6 percent of men said that being able to carpool regularly but not daily would encourage them to pool.

In short, although men and women tend to respond to similar incentives and encouragement policies for all the alternative modes, there are sometimes substantial differences in the relative importance of those policies. For all the modes analyzed, women were more concerned with, above all, being able to respond to their domestic responsibilities and children's needs. They were also more concerned than men with safety and security.

SUMMARY AND CONCLUSIONS

Salaried women have different travel patterns than comparable men; everything about their actual travel patterns and their stated preferences shows that they are fulfilling multiple roles and meeting multiple obligations. Women's travel decisions are made as part of a network of financial and nonfinancial concerns, concerns that include the transportation and other needs of their children. It is clear that traditional theories do not explain women's travel decisions; women's transportation behavior is best understood as a part of a complex set of employment and domestic responsibilities.

Therefore, various TDM measures will have different cost and noncost implications for working women. If employers make certain measures mandatory—for example, banning parking or changing work schedules—working women may be disproportionately affected. Conversely, incentive measures, such as offering showers for bikers or free transit passes, may not provide as much encouragement to women because these incentives do not address the additional time and indirect monetary costs created by using alternative modes. For example, a $52/month transit subsidy may not cover the extra 22 to 44 hr/month of child care expenses created by the additional time required to take a bus.

Working women have slightly more positive attitudes toward alternative modes and are more likely to consider them when provided with ways to address the double and triple burdens that they carry—and that they currently meet in many cases by driving alone to work. TDM measures could only become both effective and equitable if they also included realistic and meaningful options that allow salaried women to get their children safely to and from school, to respond to family emergencies at home, or to shop on the way home from work.

The study reported on here is on-going; in its final phase, the researchers are focusing on the impact of the age and number of children and marital status on the travel and activity patterns of salaried men and women. They are doing so using data from the University of Arizona and the Arizona State University (more than 10,000 respondents), which added special questions to their mandatory annual TDM surveys. This effort will suggest the women most likely to be negatively affected by mandatory TDM measures and how those negative impacts might be offset.

REFERENCES

1. S. Rosenbloom and E. Burns. *Understanding the Impact of Transportation Demand Management Programs on Working Women.* Final Report to Women's Bureau, U.S. Department of Labor, Washington, D.C., 1993.
2. C. K. Orski. Transportation Management Associations: Battling Suburban Traffic Congestion. *Urban Land,* Dec. 1986, pp. 2–5.
3. C. P. Flynn and L. J. Gazer. Ten Cities' Strategies for Transportation Management. In *Transportation Research Record 1212,* TRB, National Research Council, Washington, D.C., 1989, pp. 11–23.
4. E. Ferguson. Transportation Demand Management: Planning, Development, and Implementation. *Journal of the American Planning Association,* Vol. 56, No. 4, 1990, pp. 442–456.
5. S. Rosenbloom. Women at Various Cycles in Their Life. In *Full Cycles: Women and Their World* (J. Monk, ed.), (in preparation).
6. M. Wachs. Men, Women, and Wheels: The Historical Basis of Sex Differences in Travel Patterns. In *Transportation Research Record 1135,* TRB, National Research Council, Washington, D.C., 1987, pp. 10–16.
7. S. Rosenbloom. The Growth of Non-Traditional Families: A Challenge to Traditional Planning Approaches. In *Transport and Mobility in an Era of Transition* (G. Jansen, ed.), Elsevier, Amsterdam, Holland, 1985, pp. 79–95.
8. S. Hanson and I. Johnston. Gender Differences in Work Trip Lengths: Implications and Explanations. *Urban Geography,* Vol. 6, No. 3, 1985, pp. 193–219.
9. S. Rosenbloom. The Impact of Growing Children on Their Parents' Travel Behavior: A Comparative Analysis. In *Transportation Research Record 1135,* TRB, National Research Council, Washington, D.C., 1987, pp. 17–25.
10. S. Hanson and P. Hanson. The Impact of Women's Employment on Household Travel Patterns: A Swedish Example. In *Women's Travel Issues* (S. Rosenbloom, ed.), U.S. Government Printing Office, Washington, D.C., 1980.
11. P. Prevedouros and J. L. Schofer. Trip Characteristics and Travel Patterns of Suburban Residents, In *Transportation Research Record 1328,* TRB, National Research Council, Washington, D.C., 1991.
12. S. Rosenbloom and C. Raux. Employment, Childcare and Travel Behavior: France, The Netherlands, and the United States. In *Behavioral Research for Transport Policy,* VNU Science Press, Utrecht, The Netherlands, 1985, pp. 365–381.
13. J. Perez-Cerezo. *Women Commuting to Suburban Employment Sites: An Activity-Based Approach to the Implications of TSM Plans.* Institute of Transportation Studies, University of California, 1986.
14. S. Rosenbloom. *The Transportation Patterns and Needs of Salaried Mothers; A Comparative Assessment.* The Rockefeller Foundation, Austin, Tex., Feb. 1988, 97 pp.
15. S. Rosenbloom. *The Transportation Problems of Single Mothers in France and the United States.* U.S. National Science Foundation and Centre National du Recherche Scientifique, Austin, Texas, June 1987, 61 pp.
16. L. P. Kostyniuk, R. Kitamura, and K. Goulias. Mobility of Single Parents; What Do the Travel Records Show? *Journal of Specialized Transportation Planning and Practice,* Vol. 3, No. 3, 1989, pp. 203–218.
17. I. Johnston-Anumonwo. Journey to Work: A Comparison of Characteristics of Single and Married Parents, *Journal of Specialized Transportation Planning and Practice,* Vol. 3, No. 3, 1989, pp. 219–246.
18. B. M. Rutherford and G. R. Wekerle. Single Parents in the Suburbs; Journey to Work and Access to Transportation, *Journal of Specialized Transportation Planning and Practice,* Vol. 3, No. 3, 1989, pp. 277–294.
19. S. Rosenbloom. The Transportation Needs of Single Salaried Mothers; A Critical Analysis, *Journal of Specialized Transportation Planning and Practice,* Vol. 3, No. 3, 1989, pp. 295–310.
20. P. Gordon et al. Gender Differences in Metropolitan Travel Behavior, *Regional Studies,* Vol. 23, No. 6, 1989, pp. 499–510.
21. G. Giuliano and T. F. Golob. Staggered Work Hours for Traffic Management: A Case Study. In *Transportation Research Record 1280,* TRB, National Research Council, Washington, D.C., 1990, p. 31.
22. S. J. Frederick and K. L. Kenyon. The Difficulty with the Easy Ride Project: Obstacles to Voluntary Ridesharing in the Suburbs. In *Transportation Research Record 1321,* TRB, National Research Council, Washington, D.C., 1991.
23. P. Roybal. HOV/TSM Evaluation Study Final Report. Presented at 70th Annual Meeting of the Transportation Research Board, Washington, D.C., 1991.
24. A. M. Freas and S. M. Anderson. Effects of Variable Work Hour Programs on Ridesharing and Organizational Effectiveness: A Case Study, Ventura County. In *Transportation Research Record 1321,* TRB, National Research Council, Washington, D.C., 1991.
25. D. Davidson. Impact of Suburban Employee Trip Chaining on Transportation Demand Management. In *Transportation Research Record 1321,* TRB, National Research Council, Washington, D.C., 1991.
26. C. McKeever, J. W. Quon, and R. Valdez. Market-Based Strategies for Increasing the Use of Alternative Commute Modes. Presented at 70th Annual Meeting of the Transportation Research Board, Washington, D.C., 1991.
27. S. Rosenbloom. Why Working Families Need a Car. In *The City and the Car: The Automobile, the Built Environment, and Daily Urban Life,* (M. Wachs and M. Crawford, eds.), University of Michigan Press, Ann Arbor, 1992, pp. 39–56.

Publication of this paper sponsored by Task Force on Transportation Demand Management.

Spatial Dimensions of Commuting and Transportation Demand Management: An Analysis of Eastern Pima County, Arizona

ALI MODARRES

With the increasing number of regions adopting or revising travel reduction ordinances (TROs), the performance evaluations of these TROs should be standardized. The author of this paper argues that the effects of TROs should be considered at different geographic scales and that attention should be given to the socioeconomic characteristics of commuters. The methodologies used highlight the importance of socioeconomic and urban employment structures and the spatial variations of transportation infrastructures and services in determining the transportation behavior of employees. This paper suggests that the success of a transportation demand management program is as much a function of the type of activities it adopts as the type of neighborhoods from which the employees commute. The overall spatial distribution of socioeconomic characteristics, as determined by factor analysis and the commuter matrix, closely predict the predominance of transportation modes and their changes in Eastern Pima County, Arizona.

In early 1988, the jurisdictions of Pima County, City of Tucson, City of South Tucson, Town of Oro Valley, and Town of Marana passed a travel reduction ordinance (TRO) in an attempt to improve the regional air quality in Eastern Pima County, Arizona. As in other parts of the nation, the Pima County TRO emphasizes programs that improve air quality and decrease traffic congestion through transportation demand management (TDM). With an overall goal of increasing the efficiency of the existing urban transportation infrastructure, TDM programs may be operated in two ways. The first way is implementation of strategies that manage and accommodate traffic, such as removal of street parking and flextime, which shifts peak-hour traffic. The second way is adoption of measures that reduce travel demand mainly by reducing solo driving and increasing the use of alternative modes (e.g., carpools, vanpools, bicycles, and walking). Measures in this category include parking management techniques such as increased parking costs and preferential parking for alternative mode users, marketing alternative modes through incentives, and telecommuting. Bhatt and Higgins (*1*) provide a complete discussion of available transportation control measures.

The recent growth of TDM programs in the United States, especially in areas such as Southern California, has created an environment in which program and policy evaluation has become problematic because there is no standardized performance evaluation for TDMs, especially for cost-benefit analyses. This problem is aggravated further by the different requirements and language of each TRO. Even in Arizona, Pima and Maricopa Counties have some differences, making cross-comparisons difficult.

The Pima County TRO was adopted in 1988 with the goals of reducing the number of vehicle miles traveled (VMT) of major employers (those with 100 employees or more at a work site), increasing their alternative mode usage (AMU), or both. Each work site under the TRO was to conduct a survey in 1989 and, using that as a baseline, achieve 15, 20, and 25 percent reductions in their VMT (or demonstrate a 15, 20, and 25 percent AMU) during the next 3 years.

Pima County's TRO began like many other TROs throughout the country, with the aim of addressing the commuting behavior of employees at large work sites, and hence targeting a major portion of the working population. However, a number of jurisdictions (e.g., the South Coast Air Quality Management District) are considering including smaller work sites (25 employees or more) in their TRO program. Before such an attempt is made, the potential administrative problems and the methodology that will be used to measure the performance of different TDM programs at these work sites must be considered. Since agencies responsible for the implementation of TROs evaluate TDM programs mainly for individual work sites or at a cumulative regional level, the spatial variations in the effectiveness of TDM programs are rarely addressed. The recent requirements of the 1990 Clean Air Act Amendments, reflected in the Environmental Protection Agency's Employee Commute Options Guidance (*2*) highlight this shortcoming and attempt to mitigate it. Requiring regions to adopt average vehicle occupancy (AVO) zones is a step toward creating subregional performance requirements that are more responsive to the urban and social structure of the region. The problem, however, remains that in determining the AVO zones, politics of development and economic growth and the prospect of administrative demands for implementation are apt to play a much stronger role than transportation and air quality considerations.

Unfortunately, TDM research has not provided much in the way of profound methodologies for spatial analysis or an understanding of the relationship between transportation behavior modification and the urban structure. The general urban theory is most likely the best explanation available for commuting patterns and their changes in most American cities. Even though the importance of geography is incorporated in some of the recent literature (*1*,*3*,*4*), these researchers focus only on specific sections of cities (e.g., suburban work centers)

Department of Geography and Urban Analysis, California State University, Los Angeles, 5151 State University Drive, Los Angeles, Calif. 90032.

and rarely attempt to explain the urban system as a whole. Among geographers, there has been a more direct attempt to explain the social theory behind transportation behavior, and the urban structure has been examined more closely (*5–9*). The concern among these authors appears to be focused on two aspects of urban transportation that are highly relevant to TDM programs. First, they examine the dynamic nature of urban places, especially the restructuring of work places and home. Second, they examine socioeconomic, ethnic, and gender differences and how these variables affect transportation behavior patterns.

The author will attempt to integrate some of these theories in order to understand the commuting characteristics of Eastern Pima County, Arizona.

SOURCE OF DATA

Since 1989, the Pima Association of Governments' Travel Reduction Program (PAGTRP) has been collecting data on the commuting behavior of Eastern Pima County's work force at work sites with 100 or more employees. The TRO Task

TABLE 1 Work Force Under Pima County TRO

	1989	1990
Number of Companies	153	134
Number of Work Sites	148	120
Number of Employees	77,230	77,118
Surveys Returned	52,892	57,559
Response Rate	68.5%	74.6%

TABLE 2 Changes in Weekly Mode Split by Employee Trips

Mode	1989 (%)	1990 (%)	Change (%)
Drive alone[a]	77.2	76.5	−0.9
Carpool and vanpool	13.5	14.2	5.2
Transit	3.9	4.7	20.5
Walk	2.9	2.0	−31.0
Bicycle	2.5	2.6	4.0
Total trips	249,848	267,903	

NOTE: Respondents who indicated commuting more than 7 days per week were excluded from this calculation.
[a]Includes motorcycle trips.

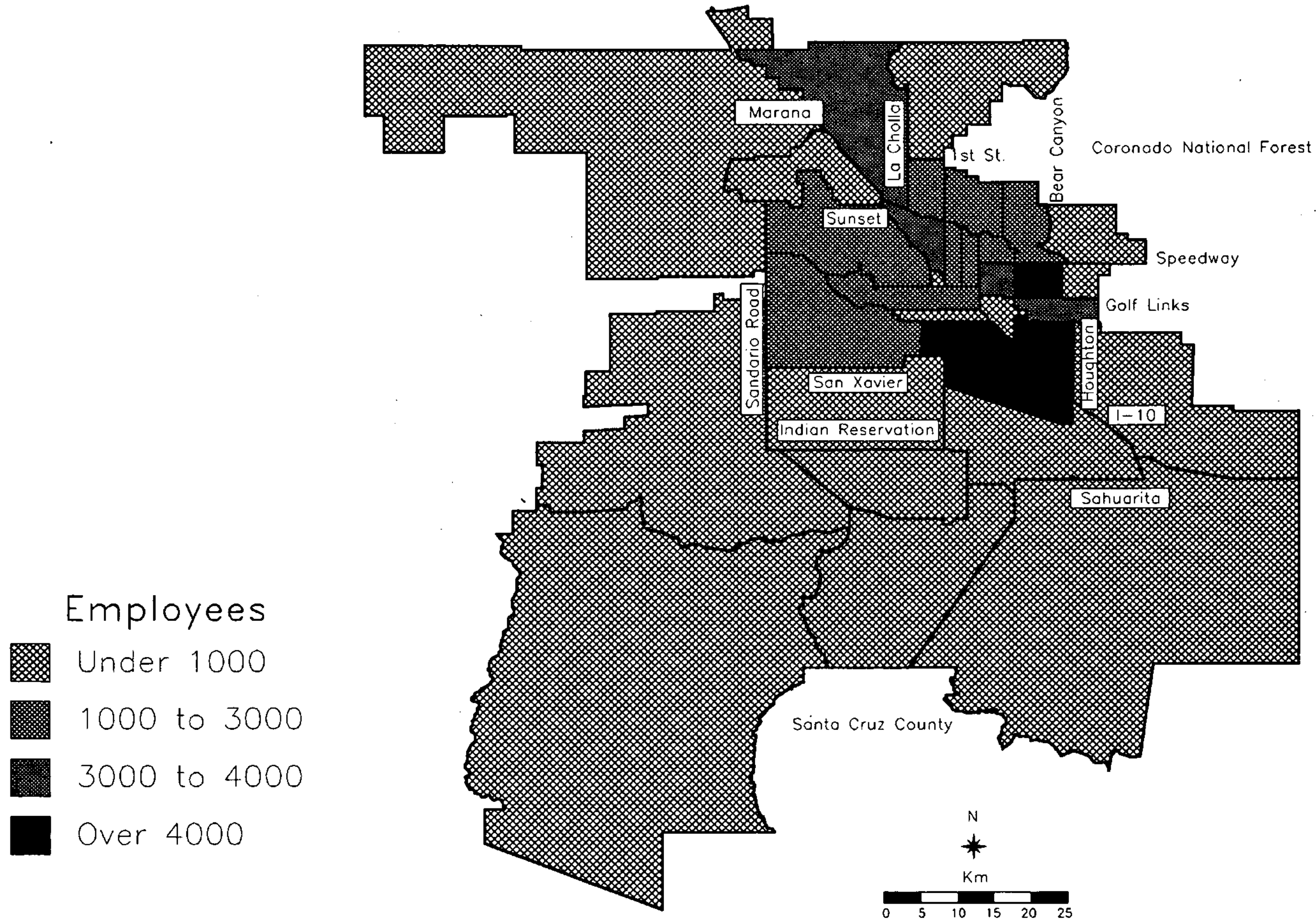


FIGURE 1 Employee residential distribution, 1989 (source: PAGTRP).

Force Committee mandated that these work sites were to achieve a minimum response rate of 50 percent on their annual survey, the only instrument used to measure each work site's compliance with the ordinance. Because nonrespondents are automatically counted as solo drivers, most work sites have attempted to achieve the highest response rate possible. These efforts yielded a regional response rate of 68.5 percent in 1989, which increased to 74.6 percent in 1990. This translates to 52,892 surveys in 1989 and 57,559 in 1990 (see Table 1).

Because employees at major work sites constitute about one-third of the total labor force in eastern Pima County, the travel reduction program (TRP) data base is extremely valuable for transportation research. In this paper, the 1989 data, considered the baseline data, are compared with the results from 1990 to illustrate the significant spatial variations in the level of success and failure of TDM programs. The selection of the 1989 data base is to ensure that the spatial characteristics of commuters are evaluated using data collected before the implementation of any TDM activities resulting from the TRO.

It should be noted that the TRP data base is made available to the public with one modification. Any variable that could identify a specific work site is removed from the data base to ensure complete anonymity.

To assist in this research, PAGTRP provided the author with information on the spatial distribution of work sites (i.e., number of sites per ZIP code). These data supplemented the employee transportation information for a general evaluation of the relationship between residential and employment concentrations in Eastern Pima County.

DATA ANALYSIS

General Characteristics

With respect to commute distance, time, and speed, employees at major work sites in Eastern Pima County appear to be similar to those at U.S. suburban employment centers (SECs). In 1989, the base year, the average one-way commute was 17.2 km (10.7 mi), well within the national range of 15.4 to 19.1 km (9.55 to 11.9 mi) for SECs, and the average travel time was 21.4 min, which is slightly less than the national range of 21.6 to 25.9 min (*3*). The average commuting speed was 47.1 km/hr (29.25 mph), which is again within the national range of 46.7 to 51.5 km/hr (29 to 32 mph) for SECs. In 1990, the average one-way commute distance, time, and speed were 17.2 km (10.7 mi), 21 min, and 47.6 km/hr (29.6 mph), respectively. Therefore, regionally, these commuting characteristics have not changed significantly since 1989.

Table 2 presents the 1989 and 1990 mode split for the employees. These percentages reflect the number of trips by each mode and do not incorporate ridership.

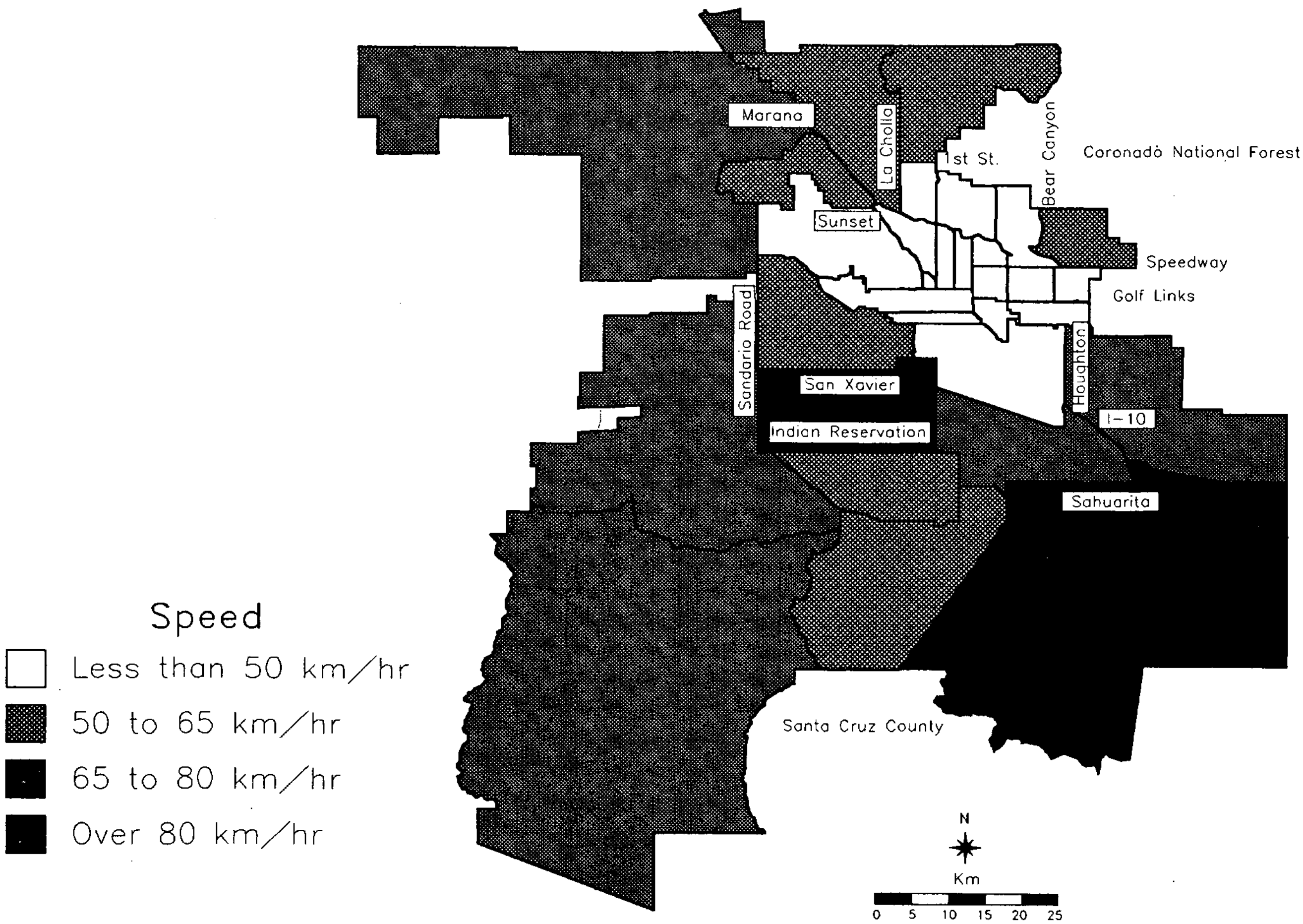


FIGURE 2 Average commute speed, 1989 (source: PAGTRP).

The 1989 mode split is similar to other regions of the country, with driving alone and carpooling being the primary means of getting to work. The low percentage of riding public transit, walking, and bicycling indicates that Tucson is generally a low-density community with characteristics not unlike other southwestern cities. The low density is partially caused by a land annexation policy that has occurred at a much faster rate than population growth. Between 1980 and 1985, Tucson annexed 69.4 km^2 (26.8 mi^2), a growth of 25 percent, while its population grew by only about 7 percent (*10*).

From 1989 to 1990, employee trips appear to shift from driving alone to alternative modes of transportation, with carpooling and transit accounting for most of these trips. Interestingly, not unlike other regions, walking appears to have declined regionally after the implementation of TDM programs. See work by Wachs and Giuliano (*11*) for the case of Southern California.

Despite the seemingly small changes in the mode split, the regional level of AMU increased from 17.59 in 1989 to 20.2 in 1990, reflecting a nearly 15 percent improvement. However, in the case of VMT, which reflects the changes in mode split more closely, the regional reduction was at a modest level of 2.9 percent, from an average of 76.1 weekly one-way km (47.3 mi) in 1989 to 73.85 km (45.9 mi) in 1990.

Although the overall regional changes in Eastern Pima County appear to provide an overview of the TROs effectiveness in the area, a spatially smaller scale of analysis is necessary to determine the relationship between the urban and social structure of the major work sites' employees and their commuting characteristics.

Spatial Examination of Commuters

To allow determination of a work site's compliance with the TRO, respondents have to provide answers about mode choices and number of days per week in each mode. Because a person may use several modes to get to work, the spatial association with each mode requires a set of parameters to define a person specifically as a solo driver, carpooler, bus rider, walker, or bicyclist. To remove personal biases from such a definition and to incorporate the varying nature of mode use from one city to another, the best method is to use the frequency distribution. The mode value for the number of days in each transportation alternative is considered the defining index for that category. For an individual to be associated with a single form of transportation, he or she must use that form as many days or more than the mode value.

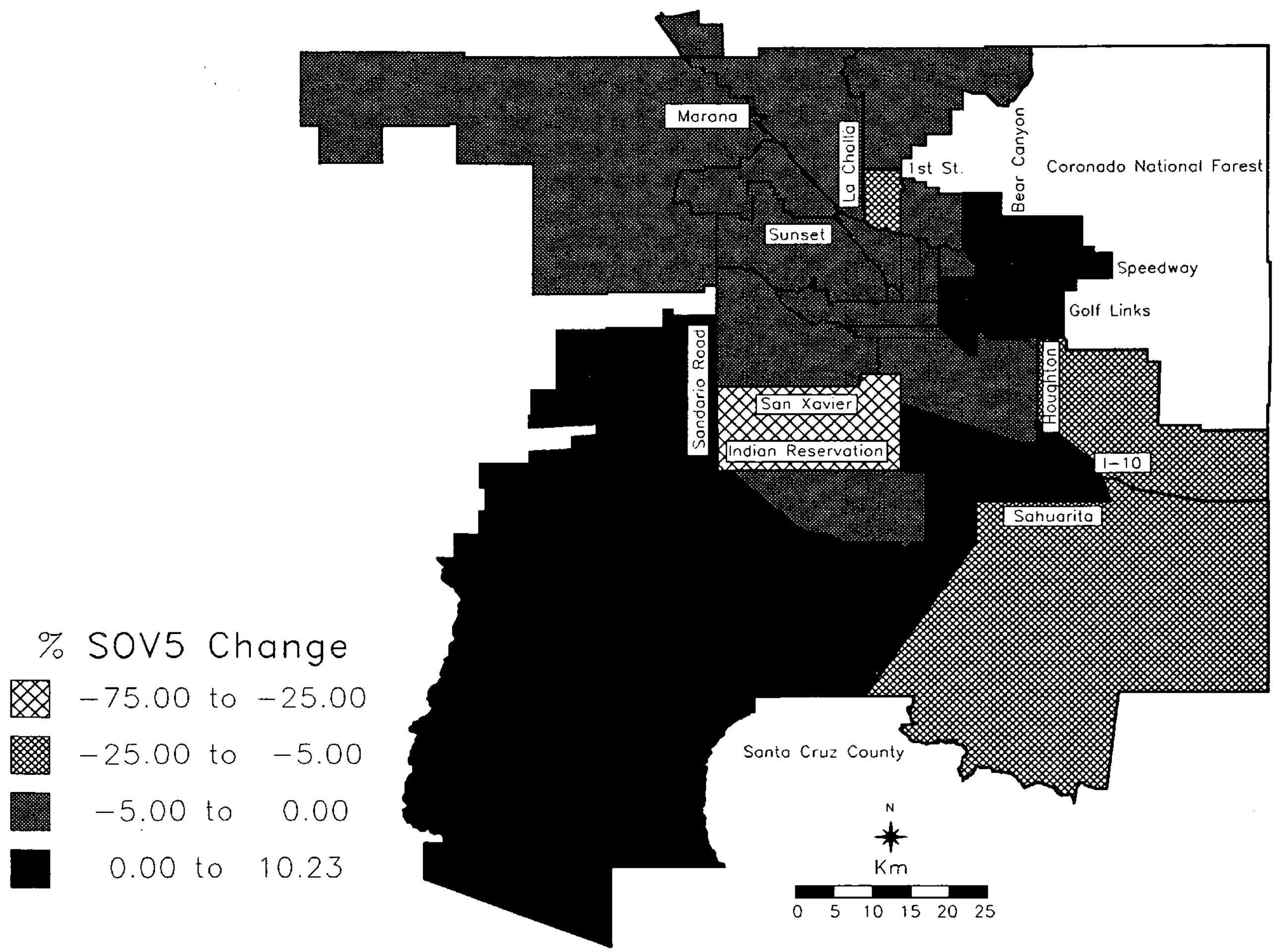


FIGURE 3 Percent change in 5 days per week SOV (source: PAGTRP).

A frequency distribution of the 1989 and 1990 data indicated that 5 days is the mode value for all transportation alternatives. A subset of the 1989 and 1990 data was created by aggregating the home ZIP code of commuters to provide a spatial data base for an analysis of the commuting characteristics of employees at major work sites and their changes over time. The final data base contained ZIP codes for 47,874 employees in Eastern Pima County for 1989 and 51,188 employees for 1990. This is nearly 91 percent of the entire data base for 1989 and 90 percent for 1990.

Figure 1 shows that the highest level of residential concentration of employees occurred in the southern and northwestern portions of the metropolitan area. This pattern remained unchanged in 1990. Considering that the majority of work sites are located in the south-central portion of the region, it is clear why average commuting speed is similar to that found in SECs throughout the nation. There is clearly a separation between major residential concentration of employees and work sites, which leads to major commute-related congestion problems within the core of the region (see Figure 2). It is interesting that the northwestern portion, the least favorable area for ridesharing, has an overall faster commute, compared even with the Foothills area. This is primarily because the northwest is one of the few places with access to I-10, making it easier to reach a variety of jobs downtown and in other areas of the city. Interestingly, the greatest number of single-occupant vehicle (SOV) trips originate in the northwest, which is caused not only by easier access to the freeway, but also by inadequate public transit service. From 1989 to 1990, TDM activities resulted in a 5 percent reduction in the number of employees who drive alone 5 days a week in this area (see Figure 3). Actually, with the exception of the northeastern area, which has witnessed a high level of growth in recent years, Eastern Pima County has experienced some level of SOV trip reduction throughout the region. The causes of these changes will be discussed later.

Carpooling appears to be lowest in the core, increasing with distance toward the periphery. This low rate is to be expected because ridesharing is considered inconvenient and less beneficial for short commuting distances. The highest spatial concentration of carpoolers occurs in the south. This pattern is significant because this area is also associated with a higher representation of low-income population (more than 20 percent of the residents have incomes below $15,000).

By 1990, the carpooling rate for 5 days per week had increased further in the periphery areas (with the exception of the northeast), whereas locations closer to the center of the urban area witnessed a small level of decline (see Figure 4).

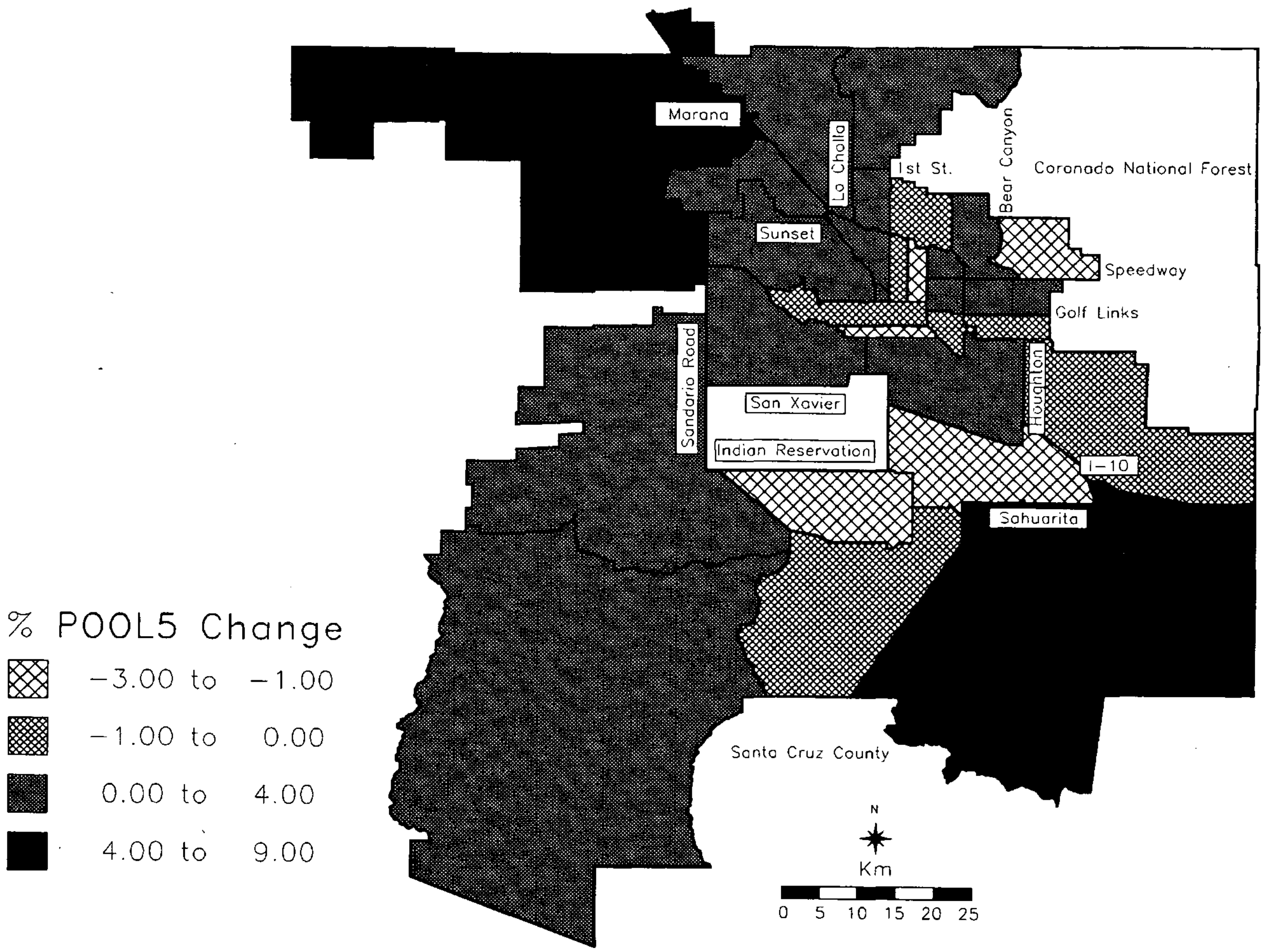


FIGURE 4 Percent change in 5 days per week carpool (source: PAGTRP).

TABLE 3 Commute Distance, Time, and Speed by Mode

Mode	Average Distance (km)	Average Time (min)	Average Speed (km/hr)
Drive alone	16.9	20.4	49.7
Bus	17.4	34.7	30.1
Carpool	22.5	24.9	54.2

NOTE: Based on 1989 data.

ZIP codes with 1 percent or more decline are those with the highest level of growth. The neighborhood east of Bear Canyon and north of Speedway is a good example of such an area. This is mainly a middle to upper middle class region with inadequate access to public transportation services.

The use of public transit as a mode of traveling to work is generally low in Tucson. This low rate is due to two factors: (a) the bus service is spatially limited, and (b) in areas where buses are available, mainly the core of the city, commuting distances are short. Therefore, without offering substantial incentives, it would be difficult to encourage employees to take buses to work. Tucson could not really market public transit from the standpoint of commute time because carpooling appears to be the best option among all the ridesharing modes (Table 3).

Although the variables discussed demonstrate some of the unique characteristics of employees' commuting patterns and highlight possible problem areas, the resulting spatial structure is not fully explained. In order to provide such an insight, the urban and social structure of Eastern Pima County has to be examined. In this paper, two methodologies will be used to illustrate the different possible approaches to this problem.

The first technique is factor analysis, which is used by many researchers in urban geography and related fields. For the purpose of this paper, the available socioeconomic and trans-

TABLE 4 Factor Matrix

	Factor I	Factor II	Factor III	Factor IV	Factor V	Factor VI	Factor VII	Factor VIII
Variables	Low Income Commuting	Job/ Housing	Socio-economic Status	Drive-Alone	Carpool	Industrial Area	Older Neighborhood	Public Transit
Commute Speed		-0.36		0.56	0.36	0.3		
Number of Work Sites		0.77						
Number of Male		0.95						
Number of Female		0.97						
Percent 5+ days SOV				0.8				
Percent 5+ days Carpool					0.66			
Percent 5+ days Bus								0.84
Percent 5+ days Walk	0.68							
Percent 5+ days bike	0.72			-0.3				
Percent Young[1]	0.83							
Percent Middle Age[2]	-0.83							
Percent Old[3]							0.76	
Percent Low Income[4]	0.77					0.38		
Percent Middle Income[5]	-0.38		-0.79					
Percent High Income[6]	-0.3		0.84					
Percent Clerk							0.74	
Percent Managerial			0.74			-0.3		
Percent Manufacturing						0.86		
Percent Professional					0.87			
Percent Service				-0.76				
Percent Skilled			-0.47	0.55	-0.48			
Percent Technical			0.47					0.55
Eigenvalue	3.8	3.5	2.5	2	1.6	1.6	1.2	1
Percent of Variation	17.3	16	11.4	9.1	7.4	7.2	5.5	4.6

1 Percent of employees 18 to 25 years old
2 Percent of employees 26 to 65 years old
3 Percent of employees 66 years or older
4 Percent of employees with less than $15,000 yearly income
5 Percent of employees with $15,000 to $40,000 yearly income
6 Percent of employees with over $40,000 yearly Income

portation variables were combined to perform this analysis. The selected variables were aggregated values of each ZIP Code for commuting speed, number of major work sites, percent male, percent female, percent employees in each commuting mode, percent employees in each income category, and percent employees in each job category (see Table 4 for a list of these variables).

The results of the factor analysis are presented in Table 4. Each factor is labeled according to the pattern of variables it loads. For brevity, a full discussion of the results will not be presented here; however, because the purpose of this analysis is to seek an explanation for the spatial distribution of commuting patterns, the significance of Factors I and III will be briefly discussed.

The resulting scores from Factor I are illustrated in Figure 5. This map identifies those ZIP codes with the highest rates of bicycle and walking (i.e., areas with high positive scores). The majority of these ZIP codes occur in areas where young and low-income employees reside. This includes both the central part of the urban area and the San Xavier Indian Reservation.

Scores from Factor III illustrate the socioeconomic structure of the area, as defined by the employee characteristics (see Figure 6). The data identify the Tucson Foothills as the area with the highest socioeconomic score value. This is the area north of River Road and east of First Avenue. Comparing this map with Figure 3 reveals an interesting spatial covariation. Areas with the highest socioeconomic scores are least amenable to reduction in the number of SOV commuters. This problem appears more aggravated in areas where a fast rate of growth is experienced. This finding supports previous work by researchers (*9,12*) emphasizing the importance of income level in determining how people get to work or how far they travel.

In order to investigate the role of socioeconomic status, a second methodology is adopted from Rutherford and Wekerle (*8*). While discussing women's employment characteristics, these researchers suggest that urban commuting patterns may be understood through a two-by-two matrix, which categorizes commuters into four groups on the basis of their income and distance traveled to work. This matrix is presented in Table 5.

Using the 1989 data, the median values for percent low income (i.e., percent employees with yearly incomes of $15,000 or less), percent high income (i.e., percent employees with yearly incomes above $40,000), and distance to work were calculated and used to create the matrix in Table 5. Each ZIP code is then defined in terms of the four possibilities. Fig-

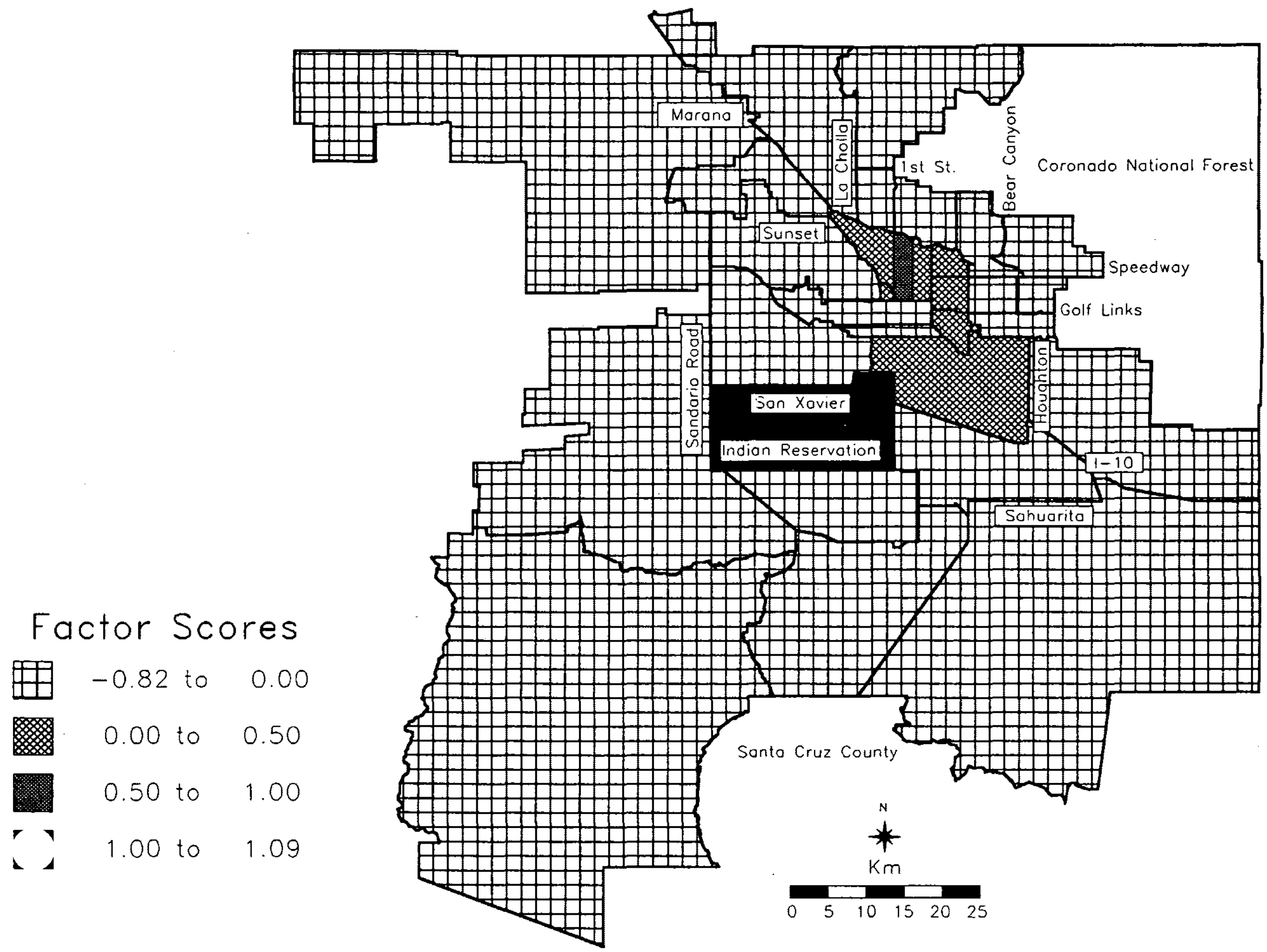


FIGURE 5 Low-income commuting patterns (source: PAGTRP).

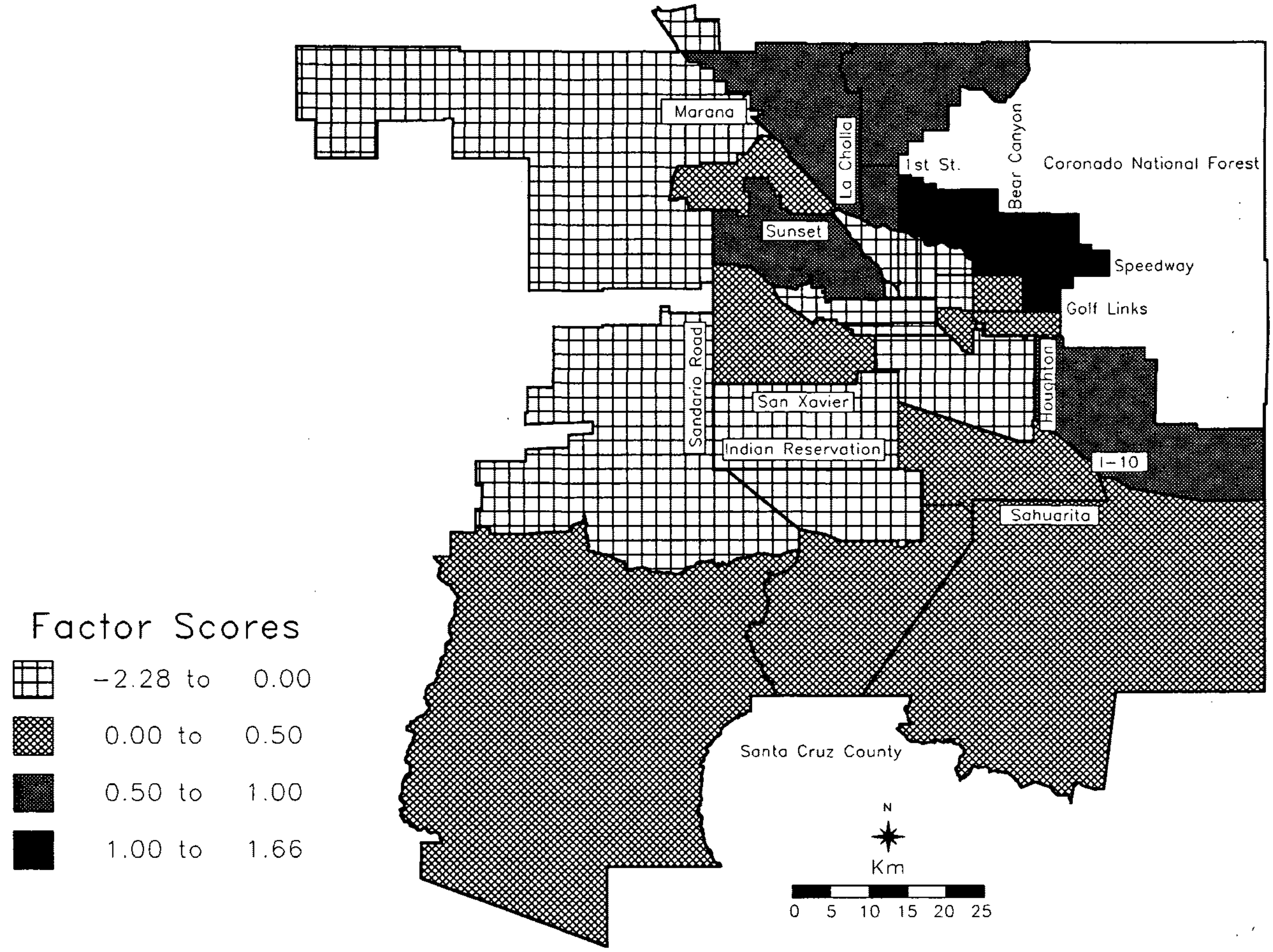


FIGURE 6 Socioeconomic status (source: PAGTRP).

ure 7 shows the spatial distribution of these commuting zones. As can be observed, the "worst zone" occurs west of I-10 from Marana to south of the San Xavier Indian Reservation. The growth of medium-low- to low-income neighborhoods west of Tucson Mountain and along Ajo Highway to Three Points could be responsible for this. Despite an increased residential concentration in this area, Ajo Highway to the south and I-10 to the north appear to be the only major access routes to the area (two other roads are Gates Pass and Picture Rock). This problem leaves local residents who have long-distance commutes to work with only one option: the automobile. Fortunately, as indicated by the 1990 data, the rate of carpooling has increased in this area (see Figure 4). In the absence of adequate public transportation, carpooling appears to be the only solution possible.

As expected, the "captive zone" occurs within the core of Tucson. This area contains low-income individuals who commute short distances to work, and it also accounts for most of the bus riders, walkers, and bicyclists. The pattern of the "captive zone" is much like Factor I of the previous analysis. The "captive zone" should demonstrate the highest level of TDM success rate, because if the low income and high transportation options of this zone are mixed with appropriate incentives, a higher participation rate in ridesharing and a lower drive-alone rate would result. Indeed, the usage of public transit increased significantly from 1989 to 1990.

The "ideal zone," which contains the high-income population with a short commuting distance, is concentrated in two parts of the metropolitan area. One is the Foothills neighborhood north of River Road from Bear Canyon to First Avenue, and the other is the area west of I-10 between 22nd Street and Ina Road. The "ideal zone" describes parts of the city where carpooling promotion could be successful and where the short commute distances allow for the serious consideration of some nonmotorized commuting modes. The high income, however, will be detrimental to the success of any alternative mode of transportation. Data from 1990 suggest that despite their ideal situation, employees in these areas still rely on driving alone to work as a major form of transportation (see Figure 3). However, carpooling has increased in the areas west of Interstate 10 and the areas west of Bear Canyon (see Figure 4).

TABLE 5 Commuter Matrix

	Low Distance	High Distance
Low Income	Captive	Worst
High Income	Ideal	Enterprising

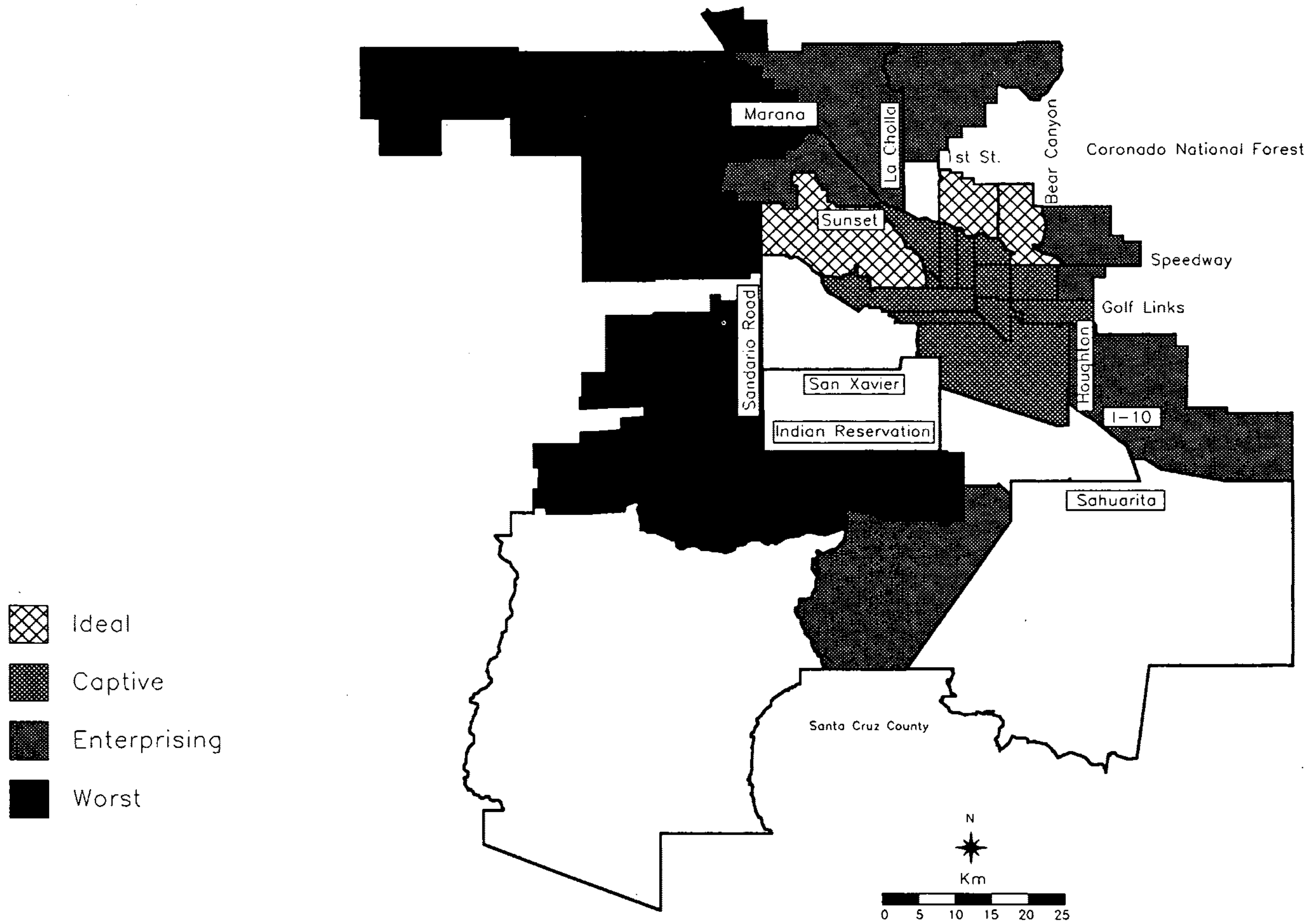


FIGURE 7 Eastern Pima County transportation zones (source: PAGTRP).

"Enterprising zones" are typically on the periphery of the metropolitan area. They occur in regions where the high cost of housing, combined with an unfavorable residential/bedroom community characteristic, creates an environment in which the number of VMT is high and alternative modes of transportation are rarely used. A combination of high income and inadequate transportation services leaves only one option available, and that is the automobile. This situation, however, can be remedied by carpooling and vanpooling. In Tucson, the preferred commuting mode within the "enterprising zone" is driving alone. This zone covers the following areas: (a) east of Bear Canyon and Harrison Road, north of Golf Links Road; (b) west of Houghton Road, south of Irvington Road, and north of I-10; and (c) the northwestern portion, mainly north of Hardy Road and east of I-10.

The 1990 data suggest that the third neighborhood has witnessed an increased level of carpooling, and the drive-alone rate has dropped in the second neighborhood. Due to their unique characteristics, "enterprising zones" should be the primary target of TDM programs with an emphasis on carpooling and vanpooling.

Because of general accuracy with which transportation zones can predict possible commuting patterns and their changes over time, this methodology may prove useful for specific targeting in any TDM program. However, care has to be taken in determining the zones and their exact configuration.

CONCLUDING REMARKS

The spatial characteristics of commuting (both of commuters and their means of transportation) are as dependent on individual behavior and characteristics as they are on the urban spatial structure and its transportation environment. This paper provided a case study of Eastern Pima County, Arizona, in which individual commuters and their collective behavior were analyzed. It was demonstrated that the home-to-work commute is not independent of the spatial distribution of commuter characteristics. Furthermore, as one attempts to understand and analyze commuting patterns, it becomes clear that the spatial vantage point not only provides a clearer picture of this complex phenomenon, but also enhances the programming and detailed population targeting for different marketing strategies.

Eastern Pima County, like other regions of the country, is attempting to implement a TRO to alleviate congestion and improve air quality. The effectiveness of these programs is generally viewed from a regional perspective, whereas program implementation is at the work-site level. The author's findings suggest that a spatial evaluation makes it possible to examine the success and failure of TROs in smaller spatial units than an entire metropolitan area. If this analysis is conducted annually, program implementation could be better planned, and eventually, it will be possible to recommend modifications to existing TROs.

The policy implications of applying spatial analysis to commuting do not end here; it can provide additional programming options for major mitigation processes. For example, in the case of congestion management, where an entire traffic network system is concerned, a full understanding of the spatial aspects of commuting characteristics will allow for either (a) varied TRO requirements by zones, instead of one standard for the entire city or (b) different TDM activities tailored to each zone for the maximum possible return in the form of lower VMT and higher AMU. In this case, solutions for specific areas, such as major cross-sections with severe congestion problems, could be more readily addressed.

These few points illustrate the importance of applying spatial approaches to the study of commuting characteristics of specific urban areas.

REFERENCES

1. K. Bhatt and T. Higgins. *An Assessment of Travel Demand Approaches at Suburban Activity Centers.* DTRS-57-88-C-00113, Topic 88-UM1. U.S. Department of Transportation, Cambridge, Mass., 1989.
2. *Employee Commute Options Guidance.* Environmental Protection Agency, Washington D.C., Dec. 1992.
3. R. Cervero. *America's Suburban Employment Centers: A Study of the Land Use-Transportation Link.* DOT-T-88-14. Urban Mass Transportation Administration, U.S. Department of Transportation, 1988.
4. K. G. Hooper. *NCHRP Report 323: Travel Characteristics at Large-Scale Suburban Activity Centers.* TRB, National Research Council, Washington, D.C., Oct. 1989.
5. O. Blumenn and A. Kellerman. Gender Differences in Commuting Distance, Residence, and Employment Location: Metropolitan Haifa 1972 and 1983. *Professional Geographer,* Vol. 42, No. 1, 1983, pp. 54–71.
6. R. A. Erickson. The Evolution of the Suburban Space Economy. *Urban Geography,* Vol. 4, No. 2, 1983, pp. 95–121.
7. S. Hanson and P. Hanson. Gender and Urban Activity Patterns in Uppsala, Sweden. *Geographical Review,* Vol. 70, No. 3, 1980, pp. 291–299.
8. B. M. Rutherford and G. R. Wekerle. Captive Rider, Captive Labor: Spatial Constraints and Women's Employment. *Urban Geography,* Vol. 9, No. 2, 1988, pp. 116–137.
9. P. Villeneuve and D. Rose. Gender and the Separation of Employment from Home in Metropolitan Montreal, 1971–1981. *Urban Geography,* Vol. 9, No. 2, 1988, pp. 155–179.
10. R. Melnick and D. Roepke. *Urban Growth in Arizona: A Policy Analysis.* Morrison Institute for Public Policy, Tempe, Ariz., 1988.
11. M. Wachs and G. Giuliano. Regulation XV—Beginning to Show Results. *ITS Review,* Vol. 15, No. 1, 1991, pp. 4–6.
12. S. McLafferty and V. Preston. Gender, Race, and Commuting among Service Sector Workers. *Professional Geographer,* Vol. 43, No. 1, 1991, pp. 54–71.

Publication of this paper sponsored by Task Force on Transportation Demand Management.