16. J.B. Olson. Evaluation of Flex-Time and Job Sharing in the State Personnel System. Department of Personnel, Denver, CO, 1978.
17. D.W. Jones, F.D. Harrison, and P.P. Jovanis. Work Rescheduling and Traffic Relief: The Potential of Flex-Time. Public Affairs Rept., Vol. 21, No. 1, Feb. 1980.
18. S.M. Bronte. Draft Report on Variable Work Hours. Commuter Pool, Seattle, WA, Nov. 1977.
19. Milwaukee Area Work Time Rescheduling Study Prospectus. Southeastern Wisconsin Regional Planning Commission, Waukesha, Dec. 1978.
20. Staggered Work Hours Study Phase 1 Final Report. Port Authority of New York and New Jersey, New York, Vols. 1-3, Aug. 1977.
21. F. Harrison, D. Jones, and P. Jovanis. Flex-Time and Commuting Behavior in San Francisco: Some Preliminary Findings, Summary Report. Institute of Transportation Studies, Univ. of California, Berkeley, Rept. UCB-ITS-RR-79-12, Aug. 1979.
22. P.P. Jovanis. Analysis and Prediction of Travel Responses to Flexible Work Hours: A Socioeconomic, Workplace, and Transportation System Perspective. Department of Civil Engineering, Univ. of California, Berkeley, Ph.D. dissertation, 1979.
23. Y.M.M. Bishop, S.E. Fienberg, and P.W. Holland. Discrete Multivariate Analysis: Theory and Practice. MIT Press, Cambridge, MA, 1975.

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

Assessment of Flextime Potential to Relieve Highway Facility Congestion

PAUL P. JOVANIS

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

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

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

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

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

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

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

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

FLEXTIME TRAVEL SURVEY

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

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

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

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

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

STUDY SITE--OAKLAND BAY BRIDGE

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

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

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

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

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

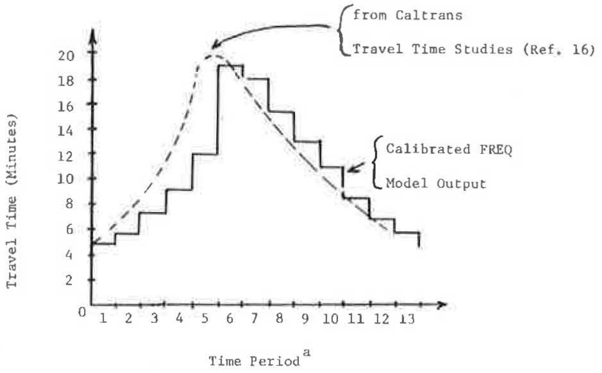
By applying the 15-min traffic demand to the described freeway facility, the peaking pattern of traffic and its associated queues and delays can be replicated. The model, when properly calibrated, has been shown to be an accurate predictor of freeway travel conditions. The basic simulation outputs of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

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

COMPARISON OF FLEXTIME TRAVEL SURVEY WITH OTHER BAY AREA TRAVEL SURVEYS

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

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



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

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

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

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

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

Financial District Scenario

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

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

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

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

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

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

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

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

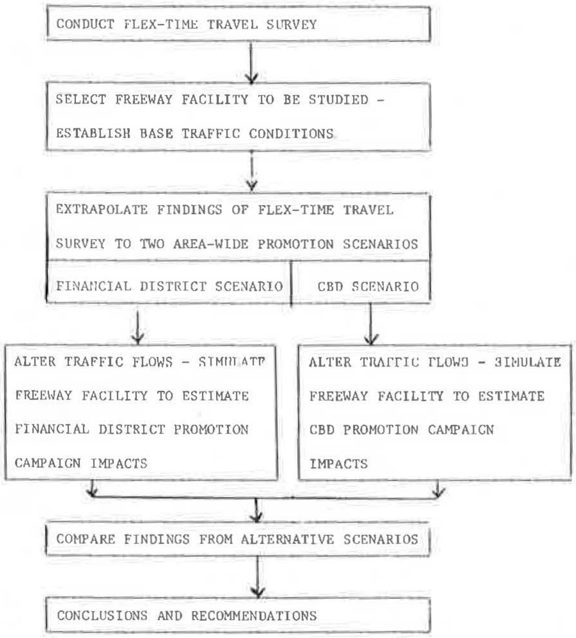
The next step is to account for mode changes expected to occur with flextime. Although detailed analyses of flextime mode changes, reported in my other paper in this Record and elsewhere (13), indicate general decreases in driving alone and increases in transit use, they could not completely isolate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

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

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

[a] BART and bus combined.

Figure 2. Revised design of experiment.



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

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

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

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

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

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

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

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

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

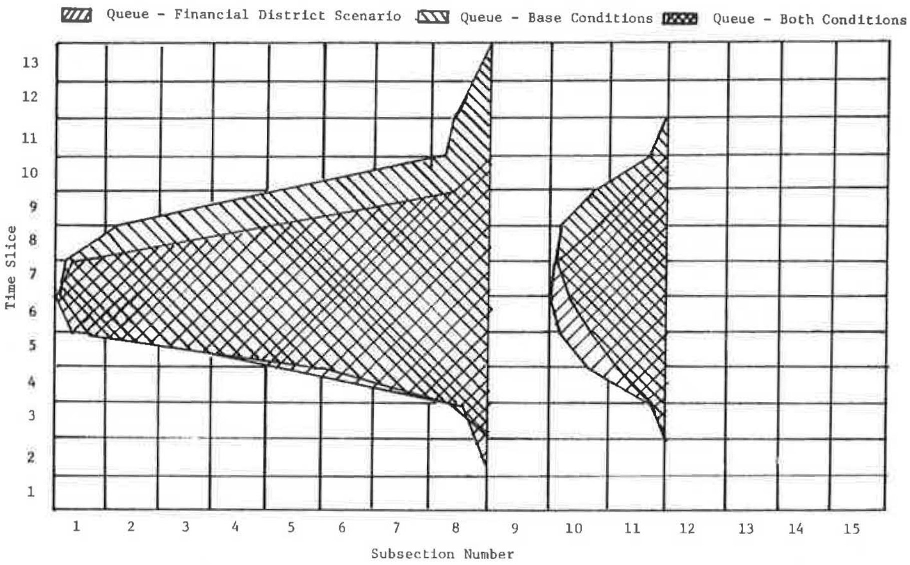
These aggregate benefits are very promising;

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

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

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

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



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

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

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

The distribution of travel-time savings for

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

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

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

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

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

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

Alternative Flextime Scenario--Promotional Campaign Throughout the CBD

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

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

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

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

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

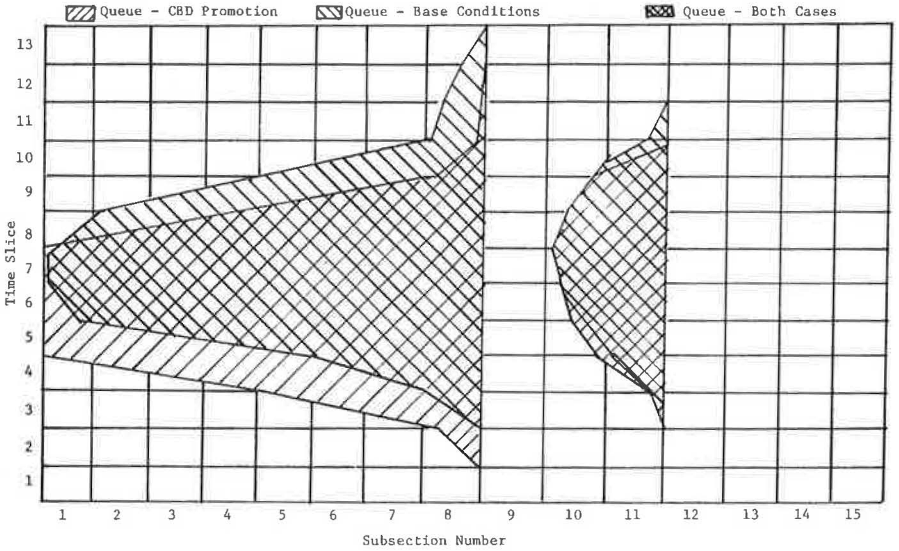


Figure 7. Travel time differences for CBD flextime program.

Time Slice After Flex-time

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

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

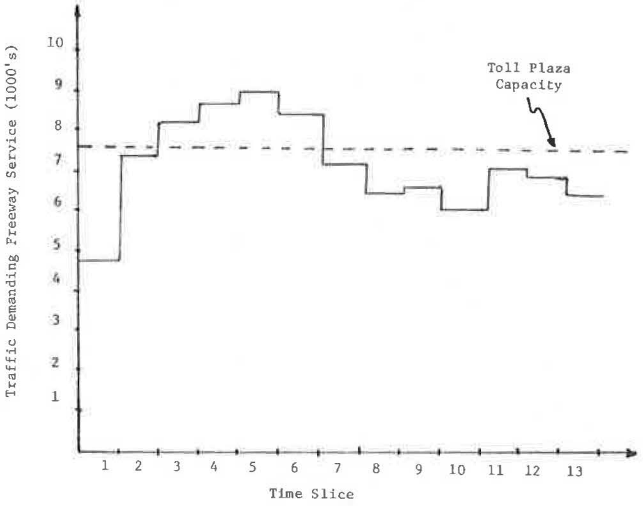
The major finding of this simulation of this areawide plan is the substantial negative consequences that ensue. Congestion was actually worse with the hypothetical program than before. Although some of the work-arrival time changes inherent in the scenario are unlikely, the analysis does suggest one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

SUMMARY

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

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

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



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

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

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

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

Operating Environment	Expected Impact
Few travel corridors, traffic heavily concentrated	
Intense congestion of extended duration	Congestion improvement or degradation possible; recommend detailed site-specific studies to assess reserve capacity
Intense congestion of brief duration	Strong likelihood of travel-time savings, either small or large
Little congestion	Small traffic impacts, primary benefits to flextime travelers; may shift incidence of congestion to earlier time periods
Many travel corridors, traffic spatially dispersed	
Intense congestion of extended duration	Improvement or degradation possible; risk of increased congestion on some facilities near major generators; recommend site-specific analysis
Intense congestion of brief duration	May have small traffic benefit near large generators
Little congestion	Small traffic impacts; small chance of shifting the incidence of congestion to earlier time periods

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

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

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

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

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

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

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

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

ACKNOWLEDGMENT

This study was conducted as part of a research project with Caltrans while I was a graduate assistant at the University of California at Berkeley. I gratefully acknowledge the support of Caltrans during the conduct of this research. I am especially indebted to Dolf May of ITS, principal investigator of the research project, who gave freely and graciously of his time in reviewing the research procedures and findings. Special thanks are due also to Greig Harvey and Elizabeth Deakin of ITS, who participated in many useful discussions regarding research methodology.

REFERENCES

1. Transportation Systems Management, Supplementary Information on Development and Implementation of TSM Plans. UMTA, Dec. 1975.
2. Staggered Work Hours Study Phase 1 Final Report. Port Authority of New York and New Jersey, New York, Vols. 1-3, Aug. 1977.
3. L.B. Cohen. Work Staggering for Traffic Relief, An Analysis of Manhattan's Central Business District. Praeger, New York, 1968.
4. D. Phillips. An Evaluation of the Effects of the Staggered Work Hours Project in Lower Manhattan. Lower Manhattan Association, New York, Feb. 1971.
5. A.M. Greenberg and D.M. Wright. Staggered Work Hours Final Evaluation, Queens Park Demonstration. Ministry of Transport and Communications, Downsview, Ontario, Canada, RR 198, May 1975.
6. R. Safavian and K.G. McLean. Variable Work Hours: Who Benefits? Traffic Engineering, Vol. 45, No. 3, March 1975, pp. 17-25.
7. A.J. Neveu and K.W.P. Koeppel. Who Switches to Alternative Work Hours and Why. New York State Department of Transportation, Albany, Prelim. Res. Rept. 162, 1979.
8. M. Ott, H. Slavin, and D. Ward. The Behavioral Impacts of Flexible Working Hours. Transportation Systems Center, U.S. Department of Transportation, Aug. 1979.
9. F. Harrison, D. Jones, and P. Jovanis. Flex-Time and Commuting Behavior in San Francisco: Some Preliminary Findings Summary Report. Institute of Transportation Studies, Univ. of California, Berkeley, Res. Rept. UCB-ITS-RR-79-12, 1979.
10. A.A. Tannir and D.T. Hartgen. Traffic Impacts of Work-Schedule Changes in Medium-Sized Urban Areas. TRB, Transportation Research Record 677, 1978, pp. 58-61.
11. D.W. Jones, T. Nakamoto, and M.P. Cilliers. Flexible Work Hours: Implications for Travel Behavior and Transport Investment Policy. Institute of Transportation Studies, Univ. of California, Berkeley, Dec. 1977.
12. A.A. Tannir and D.T. Hartgen. Who Favors Work-Schedule Changes and Why. TRB, Transportation Research Record 677, 1978, pp. 53-58.
13. P.P. Jovanis. Analysis and Prediction of Travel Responses to Flexible Work Hours: A Socioeconomic, Workplace, and Transportation System Perspective. Department of Civil Engineering, Univ. of California, Berkeley, Ph.D. dissertation, 1979.
14. W.A. Stock, J.J. Wang, and A.D. May. Priority Lane Operations on the San Francisco-Oakland Bay Bridge. Institute of Transportation and Traffic Engineering, Univ. of California, Berkeley, Special Rept. 87, April 1971.
15. Traffic Series A--Bay Bridge. Metropolitan Transportation Commission, Berkeley, CA, 1978.
16. Route 580 Existing Traffic Operation 1977/78 Route 238 to San Francisco-Oakland Bay Bridge. Metropolitan Transportation Commission; California Department of Transportation, Dec. 1978.
17. Workplace Survey. Metropolitan Transportation Commission, Berkeley, CA, Oct. 1979.
18. G. Harvey. Geographic Distribution of Work-Related Travel Impacts in the Bay Area. Institute of Transportation Studies, Univ. of California, Berkeley, April 1979.

Publication of this paper sponsored by Committee on Urban System Operations.