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Travel Impacts of TSM Actions

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Behavioral Impacts of Flexible Working Hours

MARIAN OTT, HOWARD SLAVIN, AND DONALD WARD

This paper presents new results on the behavioral responses to flexitime, a system of flexible working hours. Flexitime is of particular interest as a transportation systems management strategy that has potentially significant impacts on work schedules, travel behavior, traffic congestion, and energy consumption. Although it has generally been established that flexitime has been beneficial to both employers and workers, very little evidence on individuals' activity and travel responses exists. Consequently, this study, based on a flexitime experiment at a large government research and development facility, was designed to permit a rigorous assessment of these behavioral impacts and their implications for transportation planning. Significant changes in work scheduling were observed with a majority of workers who shifted their average work arrival times by more than 15 min. Individuals also exhibited considerable daily variation in their work schedules. These findings suggest that workers derive significant benefits from the opportunity to vary work schedules. Preliminary econometric models indicate that work-scheduling responses to flexitime are strongly influenced by socioeconomic and life-cycle characteristics, savings in travel time, and activity patterns. Flexitime also had a large impact on the journey to work. Approximately 9 percent of the workers changed modes in response to flexitime; for those who shifted mode, there were small net changes in favor of ridesharing and public transport. A majority of workers experienced savings in travel time due to flexitime. These savings are estimated to have caused a 5.8 percent saving in fuel consumption for vehicles driven to work. These findings suggest that flexitime may be an important strategy for reducing energy consumption.

This paper presents new results on the behavioral responses to flexitime, a system of flexible working hours under which workers are permitted to select their daily schedules within certain predefined limits. Flexitime has been implemented by an increasing number of firms and institutions in Europe and the United States and is of particular interest as a transportation systems management stragegy that has potentially significant, but largely unknown, impacts on traffic congestion and energy consumption. By removing a constraint on the choice of work schedules, flexitime permits individuals to vary their activity patterns and travel behavior with benefits that result from more satisfactory activity and travel choices. The timing and mode of work trips are among the principal travel choices that may be modified in response to flexitime. Assessment of these impacts is essential to an understanding of the aggregate policy consequences of flexible working hours. Consequently, this study, which makes use of an extensive data base assembled in order to evaluate a flexitime experiment at a large government research and development facility, was designed to permit a rigorous assessment of these behavioral impacts and their implications for transportation planning.

PREVIOUS RESEARCH

Although it has generally been established that flexitime has typically been beneficial to both employers and workers (1,2), there is some controversy among urban transportation analysts about whether flexible-work-hour programs are consistent with the goals of reducing congestion, energy consumption, and air pollution through increased use of carpools and transit (2). Currently, very little and somewhat conflicting empirical evidence on individuals' activity and travel responses exists (3). A study of flexitime at a suburban employment site in Reading, England (1), found few changes in activities and travel behavior, although many workers chose earlier work schedules. Their travel behavior responses, however, may have been severely constrained by short journeys to work and the absence of attractive alternative travel options. Similarly, a study of variable working hours in Ottawa (4) found no basis for concluding that flexitime has any impacts on mode split but noted increased dispersion of work schedules. In contrast, a shift toward carpools was noted in a demonstration program in Toronto (5) and a shift toward carpools and public transit in an experiment in Sacramento (2). However, the Ottawa, Toronto, and Sacramento studies were confounded by gasoline shortages and changes in transit service (3), which is one reason why further research is needed to establish and explain the impacts on mode split of flexitime. Although it seems clear that, when given the choice, individuals will choose to shift their work schedules, virtually no analysis has been made of how their responses vary with sociodemographic characteristics, travel options, or activity patterns.

Another important question concerns the stability of decisions about work schedules (3). The hypothesis that individuals will exhibit considerable variability in their daily work schedules when freed from fixed hours of work is suggested by a prospective attitudinal study by Tannir and Hartgen (6) that found that favorable views toward flexitime were motivated largely by an individual's desire for increased flexibility in activity schedules. Because of its implications for transport planning, this hypothesis also needs to be examined empirically.

DESCRIPTION OF THE FLEXITIME EXPERIMENT

The basis for this study is a flexitime experiment conducted at the U.S. Department of Transportation's Transportation Systems Center (TSC) in Cambridge, Massachusetts. More than 600 persons are employed at this facility, which is located in a dense and congested area of the Boston region that enjoys high accessibility by all modes of urban transport.

The flexible program of work hours adopted has a midday core from 9:30 a.m. to 3:30 p.m., during which employees are required to be present except for their lunch period. Employees may arrive between 7:00 and 9:30 a.m., and may leave after they have worked 8 h. Employees are not permitted to work through lunch in order to leave 0.5 h earlier. The program allows employees to opt for a lunch longer than 0.5 h as long as they work 8 h between 7:00 a.m. and 6:00 p.m.

Study Approach

The major impacts on individuals anticipated in response to flexitime included changes in work schedules, travel behavior, nonwork activity patterns, and attitudes. These changes, which are studied in this paper, reveal improvements in individuals' satisfaction with their travel and activity choices and, thus, are important indicators of the benefits of flexitime realized by workers.

The data for the analysis in this paper come from two sources: (a) a survey administered to all employees and (b) arrival and departure time data for a sample of 300 TSC employees for approximately 100 days. An excellent response rate in excess of 75 percent was achieved--479 individuals returned the survey instrument. Since not all respondents answered every question, the sample size for some results based on the survey is smaller.

For this study, only arrival and departure times for those days the employee was at TSC for a full workday (i.e., not on leave or travel for any part of the workday) were used. Part-time employees were also excluded from the analysis. Only normal workdays were used for the analysis of work scheduling under flexitime so that the effects of flexitime would not be confused with other factors, such as attendance at outside meetings or the use of leave.

Impacts on Work Schedules

The average arrival and departure times of the staff are examined below along with measures of the variability of individual schedules. Significant benefits from the ability to vary work schedules can be inferred from the data.

The distribution of mean work arrival times is presented in Figure 1. The distribution approximates a normal curve and has a mean of 7:55 a.m. and a standard deviation of 32 min. The fact that the distribution is approximately symmetrical means that, although a majority of employees' average work schedules are close to an 8:00 a.m.-4:30 p.m. day, the remainder are fairly evenly distributed between early and late flexers. The shift in the mean of the distribution makes it clear that many TSC staff have chosen work schedules that are significantly different from those prior to flexitime. Approximately 56 percent arrive at or before 8:00 a.m. Another 14 percent arrive at or after 8:30 a.m. These findings suggest that there are large differences in staff preferences for the choice among alternative work schedules.

In contrast to many other programs of flexible working hours, the experiment at TSC permitted staff to vary their working hours from day to day without prior notice. Analysis of the data on arrival and departure times indicates that many individuals exhibited considerable variation in their daily work schedules rather than merely shifting to a different but relatively fixed work pattern. The table below indicates the percentage of individuals' arrival times that deviated from their average arrival times by more than 10 min.

Percentage of Arrival Times That Deviated from the Individual's Average Arrival Time by More Than 10 min	Percentage of TSC Staff
0-25	21
25-50	26
50-75	29
75-100	24

More than half of the workers deviated from their mean work arrival times by more than 10 min more than half of the time. This wide variability in individuals' arrival time behavior suggests that this aspect of the opportunity for flexible working hours also affords them significant benefits.

In the survey, staff were asked to indicate factors that influenced their work schedule decisions. Almost three-quarters of the respondents reported the scheduling of after-work activities as a factor in determining their work schedules. The desire to avoid congestion also affected work schedule and travel choices. More than two-thirds of the respondents indicated that it was a factor in their work schedule decision; about one-third of the survey respondents indicated it was the most important determinant. Other determinants of work hours, each mentioned by about one-quarter of the respondents, included before-work activities, work-related reasons, schedules of other household members, family meal schedules, sleep patterns, and carpool arrangements.

Obviously a wide variety of factors may be significant determinants of work scheduling decisions observed here through the choice of a work arrival time. In addition to the motives noted above, work schedule decisions are hypothesized to be a function of the socioeconomic characteristics of the individual, the travel options available, and nonwork activity patterns. Socioeconomic characteristics, particularly life-cycle, are thought to be important determinants of individual's work schedules under flexitime. Children's schedules may also influence parent's choices of arrival time at work and, particularly if the children are on a fixed schedule, result in their parents' arrival times being relatively consistent.

Travel options and mode choice are also thought to enter into the work scheduling decision. For example, carpoolers are apt to be relatively consistent in their work arrival times and the variability of arrival times of transit users are dependent to some degree on the reliability of the transit system.

Another determinant of an individual's arrival time at work is probably nonwork activities. These can include a desire to participate in a sports activity, to shop, or to enjoy entertainment and recreation both in and out of the home.

Arrival Time Modeling

Since many factors influence an individual's decision about work arrival time, multivariate analysis is necessary to determine the relative importance and significance of each. To test the hypotheses that socioeconomic characteristics, travel options, and patterns of nonwork activities are significant determinants of an individual's arrival time at work, a preliminary, exploratory model of individuals' mean arrival times was developed. A linear regression model was selected for this initial analysis, although the use of more-sophisticated econometric techniques is anticipated for further work on this data set.

The independent variables used in the model are described in Table 1. The socioeconomic and life-cycle characteristics include dummy variables for workers of different ages; the number of children in various age groupings; the number of full-time workers in the household; the ratio of the number of automobiles to the number of licensed drivers in the household; and the worker's grade (GS) level, which is a proxy for occupation and income.

The travel variables used in this preliminary analysis were dummy variables for mode choice and travel time. For the model we assume that decisions about mode choice typically precede decisions about work schedules although, of course, the characteristics of alternative work schedules enter decisions about mode choice. (Consequently, some individuals will change both mode and work schedules at the same time in response to flexitime.) One way that travel options enter the work-schedule model is in their effect on mode choice. Savings in travel time from alternative work schedules enter the model through dummy variables whose coefficients reflect the deviation from peak-period arrivals for individuals who cited the desire to avoid congestion as a primary motive in making decisions about work schedules. Two separate dummy variables are needed to reflect shifts to both earlier and later work schedules. Travel time to work is also included in the model in

order to test for the effects of location and journey duration.

To capture the effects of nonwork activity patterns, variables were constructed based on the reported primary importance to the individual of after-work activities and schedules of other household members in influencing their decisions about work scheduling. As above, two dummy variables were used to measure the effect of schedules of other household members as the major determinants of the individual's work schedule.

Figure 1. Distribution of employees' mean arrival times.

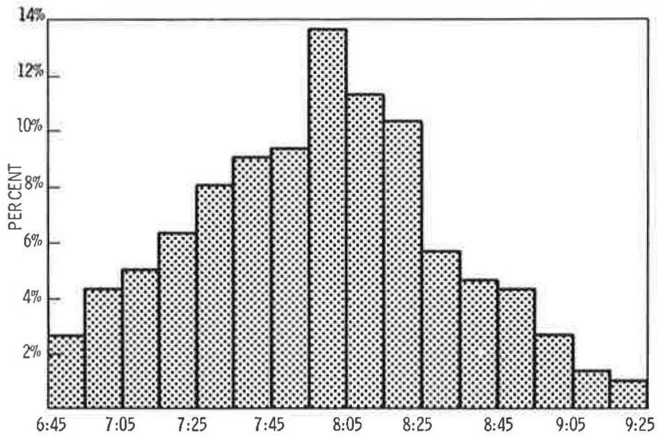

Table 1. Model variables.

Variable	Description
Travel	
TRANSIT	1 if transit user, 0 otherwise
CARPOOL	1 if carpooler, 0 otherwise
TTIME	Travel time in hours
BCONG	1 if avoiding congestion is most important factor determining work schedule and mean arrival time is before 8:15 a.m., 0 otherwise
ACONG	1 if avoiding congestion is most important factor and mean arrival time is after 8:15 a.m., 0 otherwise
Socioeconomic and life-cycle	
GS	GS salary level
A3039	1 if between 30 and 39 years old, 0 otherwise
A4049	1 if between 40 and 49 years old, 0 otherwise
A50	1 if 50 or older, 0 otherwise
CU5	Number of children under 5
C513	Number of children 5-13 years old
C1418	Number of children 14-18 years old
FWKR	Number of full-time workers in household
OTHH	Number of others in household not counted as children or full-time workers
AUTODR	Automobiles in household per licensed driver
Self-reported determinants of work scheduling	
AFT	1 if after-work activities were ranked as most important factor in determining work schedule, 0 otherwise
BSCHED	1 if schedules of other household members most important and mean arrival time is before 8:15 a.m., 0 otherwise
ASCHED	1 if schedules of other household members most important and mean arrival time is after 8:15 a.m., 0 otherwise

The results of estimation of two versions of the disaggregate work-arrival-time model are shown in Table 2. Model 1 does not include the dummy variables that represent the factors cited by individuals as the primary determinants of work schedules. These are included in model 2. The results from these models are quite encouraging in that almost all the coefficients have the correct sign, and many of the factors hypothesized to influence decisions about work schedules were statistically significantly different from zero. (For models such as these that have a large number of degrees of freedom, t-statistics that have absolute values in excess of 1.65 imply significance at the 90 percent confidence level.) The degree of explanation achieved was acceptable, especially for a disaggregate model.

The coefficients for both model 1 and model 2 are quite similar and convey important findings with respect to work schedule behavior under flexitime. Specifically, the models indicate that sociodemographic characteristics are important determinants of flexitime impacts, which suggests that these impacts may vary considerably from place to place as a function of the distribution of the characteristics of workers and their households.

Mean arrival times are later for individuals who have longer travel time, higher salaries, and use transit. Mean work arrival times are earlier for those who have higher numbers of children and other members of the household. The models also indicate that older individuals have earlier arrival times than others. Interestingly, workers who have children under five years old choose earlier schedules than those who have older children. This perhaps reflects the earlier schedules of young children and their parents' desire to spend time with them. Participation in a carpool and the number of automobiles per driver were not significant in either version of the model.

With fuller specification of model 2, the explanatory power of the model, as measured by R^2, was substantially increased. The coefficients of the congestion variables are significantly different from zero, and their magnitudes suggest that relatively large shifts are made in some individuals' mean arrival times to avoid congestion. Similarly, schedules of other household members, particularly for those who have late arrival times, are significant determinants of work scheduling.

Models were also developed with the same specifications in an attempt to account for the variability of individual work schedules. These models, which have the standard deviation of individual work arrival times as the dependent variable, are presented in Table 3.

The explanatory power of these models is not as great as that of the model for mean arrival time. However, the signs of the significant coefficients are in the direction expected. The models indicate that carpooling decreases variability in arrival times. Variability in work schedules decreases with age; in fact, the magnitudes of the coefficients suggest that persons 50 years old or older are much more consistent in work schedules than are other employees. The coefficient of the number of children under five years old is negative, significant, and relatively large, which is possibly a reflection of the constraints young children impose on schedule variability. The model indicates

Table 2. Models of individual's mean arrival time.

Variable	Model 1 Coefficient	Model 1 t-Statistic	Model 2 Coefficient	Model 2 t-Statistic
Constant	7.615	41.385	7.884	47.632
TRANSIT	0.112	1.133	0.123	1.402
CARPOOL	-0.045	-0.607	0.043	0.662
TTIME	0.164	1.232	0.131	1.150
GS	0.047	3.793	0.027	2.476
A3039	0.075	0.716	0.059	0.652
A4049	-0.141	-1.303	-0.122	-1.305
A50	-0.457	-3.888	-0.351	-3.447
CU5	-0.244	-3.434	-0.168	-2.769
C513	-0.081	-1.931	-0.057	-1.605
C1418	-0.059	-1.579	-0.062	-1.929
FWKR	-0.035	-0.739	-0.152	-1.290
OTHH	-0.049	-1.218	-0.045	-1.314
AUTODR	0.025	0.266	0.008	0.104
BCONG			-0.376	-5.659
ACONG			0.655	5.777
AFT			-0.072	-0.919
BSCHED			-0.127	-1.061
ASCHED			0.451	3.479
R^2	0.1809		0.4236	

Table 3. Models of the standard deviation of an individual's mean arrival time.

Variable	Model 1 Coefficient	Model 1 t-Statistic	Model 2 Coefficient	Model 2 t-Statistic
Constant	0.462	4.424	0.5392	4.984
TRANSIT	-0.013	-0.233	0.017	0.299
CARPOOL	-0.054	-1.250	-0.019	-0.438
TTIME	0.0127	0.166	-0.009	-0.128
GS	0.0235	3.291	0.019	2.625
A3039	-0.038	-0.627	-0.039	-0.658
A4049	-0.092	-1.489	-0.085	-1.382
A50	-0.209	-3.101	-0.191	-2.874
CU5	-0.148	-3.633	-0.135	-3.398
C513	0.019	0.808	0.260	1.118
C1418	-0.036	-1.705	-0.036	-1.702
FWKR	-0.022	-0.793	-0.029	-1.114
OTHH	0.009	0.373	0.006	0.246
AUTODR	0.017	0.321	0.008	0.163
BCONG			-0.077	-1.769
ACONG			0.287	3.811
AFT			-0.016	-0.304
BSCHED			-0.083	-1.064
ASCHED			-0.038	-0.448
R^2	0.124 97		0.1991	

that other factors that reduce the variability of work arrival include the number of full-time workers and the number of older children. Earlier arrival times are planned either to avoid congestion or because of the schedules of other household members.

The variables significant in increasing variability in work schedules are GS level and later arrival times to avoid congestion. The number of children 5-13 years of age also contributes to variability in work arrival time. This may be due to parents' accommodating the busy extracurricular schedules of many preteens.

Before we examine the impacts on travel and activity choice suggested in the above discussion of individuals' decisions about work schedules, we first consider some of their aggregate consequences on work schedule patterns at TSC. These aggregate data are relevant to forming a management perspective on flexitime and also offer some additional insights into individual decision making.

Figure 2 illustrates the mean arrival time at TSC for each day in the sample. Note that, for most days, the average arrival time of employees at TSC is a little earlier than 8:00 a.m. The daily average arrival time is relatively consistent; almost all the average arrival times fall within a 15-min interval.

The graph of average daily arrival times suggests that there is a trend to later arrival in the fall and earlier arrival in the spring. This trend is correlated with and may be due, at least in part, to seasonal variation in the hours of daylight.

In addition to the seasonal trend, there also appears to be a day-of-the-week trend in work schedules. As illustrated in Figure 3, the average daily arrival times for Mondays are later than for Fridays. This difference, statistically significant at the 98 percent confidence level, suggests that work schedules are modified in order to extend the duration of the weekend.

IMPACTS ON TRAVEL TO WORK

Results from the survey show that flexitime has had a very significant impact on employee travel to work; it is estimated that 9 percent of TSC workers shifted modes to work due to flexitime. The percentage of respondents who drove dropped from 42.4 to 39.5 percent, and carpool participation increased from 35.4 to 37.4 percent. Transit patronage also increased slightly, from 21.5 to 22.5 percent. Those who switched modes due to flexitime had a significantly higher average GS level than those who did not and they were predominantly female.

Survey evidence also suggests that flexitime may have had an impact on automobile ownership. About 6 percent of the respondents indicated that flexitime had influenced the number of motor vehicles operated by their household. For most of these households, flexitime enabled them to decrease the number of vehicles operated.

As indicated in Table 4, many TSC employees reported savings in travel time due to flexitime. More than 60 percent of the automobile drivers and carpoolers who had not changed modes reported savings in travel time due to flexitime. All of those who switched to driving alone and carpooling reported savings in travel time; this suggests that savings in travel time were a major influence on these mode shifts.

A very small percentage of TSC staff who drive to work alone or carpool reported an increase in travel time to work. Of course, travel time increases due to flexitime are freely chosen and thus presumably offset by other benefits to each traveler. Some transit users (30 percent) also reported savings in travel time. Interestingly, more than 40 percent of those who switched to transit as a result of flexitime reported an increase in travel time.

The shift to temporally dispersed work schedules also implies further significant impacts on travel from flexitime. Since many TSC employees are traveling to work outside the peak commuting times, they have reduced their contribution to peak-period congestion on the highway and transit networks. In addition, those who are now driving during periods of less congestion are using less energy because they travel at more fuel-efficient speeds and with less stop-and-go driving.

For the range of urban driving speeds [up to 60 km/h (35 mph)], an increase in speed generally improves fuel efficiency. A rough calculation of energy savings was made by using the travel time savings reported in the survey and by using data developed at the Oak Ridge National Laboratory (7) on energy efficiency by speed, which takes account of the vehicle fleet mix and the range of urban driving conditions. For those who reported

Figure 2. Average arrival time of staff for sample days.

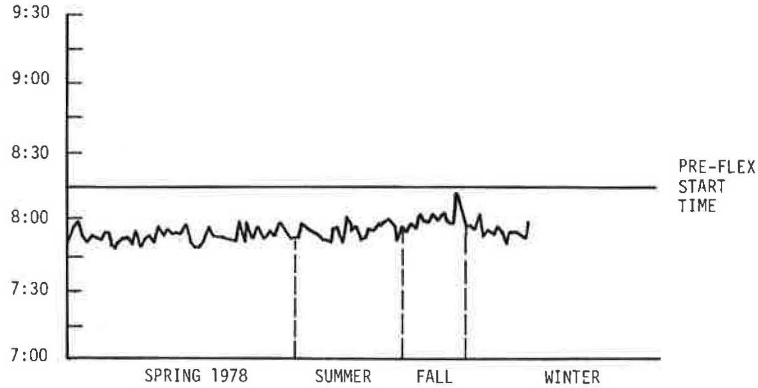

Figure 3. Average daily arrival time by day of the week.

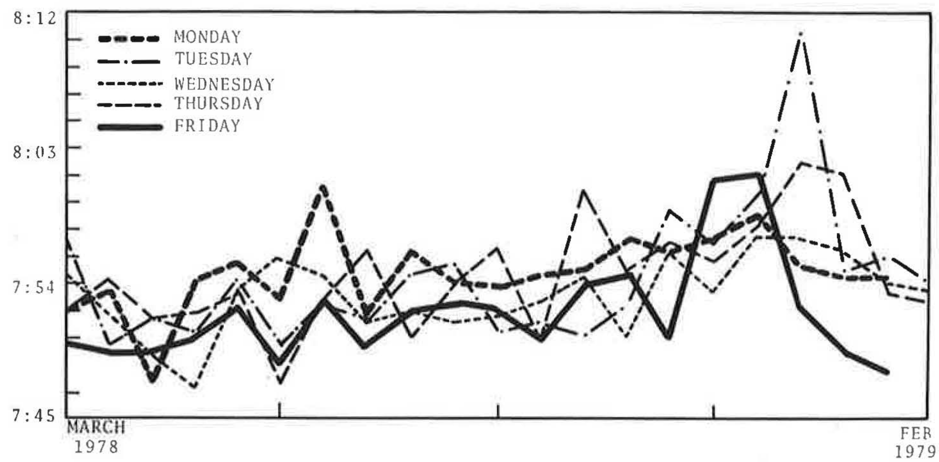

Table 4. Savings in travel time by mode.

Effect of Flexitime on Average Travel to Work	Drive Alone (%)	Carpool (%)	Transit (%)
For those who did not change modes			
Increase it	2	2	3
No effect	34	28	65
Decrease it[a]	63	68	30
Do not know	1	2	2
For those who changed modes due to flexitime			
Increase it			44
No effect			
Decrease it[b]	100	100	56
Do not know			

[a]For those who decreased their travel time, the average decrease was 13.7 min for those who drive alone, 10.74 min for those who carpool, and 11.37 min for those who use transit.
[b]For those who decreased their travel time, the average decrease was 18.23 min for those who drive alone, 13.0 min for those who carpool, and 11.4 min for those who use transit.

improvements in travel time, fuel efficiency improved by 11.7 percent [from 6.3 km/L (14.9 miles/gal) to 7.0 km/L (16.6 miles/gal)], and fuel consumption was reduced by 9 percent [from 3.8 L/trip to 3.4 L/trip (1 gal/trip-0.9 gal/trip)]. This implies a 7.6 percent overall improvement in fuel efficiency for vehicles driven to TSC and an overall 5.8 percent savings in fuel.

SCHEDULING AND ACTIVITY CHANGES

The survey results indicate that, consistent with prior expectations, employees have taken advantage of flexitime to make their personal schedules more convenient and to increase their participation in nonwork activities. More than 75 percent of the employees reported that flexitime enabled them to spend more time with their families and to increase participation in nonwork activities. Only 29 percent reported that flexitime had little or no effect on increasing the amount of time they were able to spend with their families.

Apparently flexitime's impacts on decisions about activity patterns have also resulted in significant decreases in the use of sick leave and short-term annual leave. Thirty-six percent and 50 percent of employees reported reductions in these leave categories, respectively. In addition to the benefits to staff from the ability to substitute varied work schedules for leave, benefits also accrue to the government from the reduced use of sick leave.

Attitudes Toward Flexitime

Flexitime is extremely popular with employees. Approximately 95 percent of the respondents like flexitime and would like to see it continued; this feeling is shared by supervisors and nonsupervisors.

Flexitime has also improved employee job satisfaction. Sixty-five percent of the employees who responded report that flexitime has increased their job satisfaction; only 1 percent reported that their job satisfaction had decreased due to flexitime. Reasons given for the improvement in their job satisfaction due to flexitime included that it is convenient, it is more professional, it allows them more responsibility and independence,

the work environment is more relaxed, and it is evidence of management's concern for employees. More than 20 percent of the respondents indicated that they would like additional flexibility in work schedules.

Organizational Impacts

Perhaps the biggest benefit of flexitime to TSC is its positive effect on morale; more than 85 percent of the respondents felt that morale had improved as a result of flexitime. In addition, results from the survey suggest that flexitime has improved productivity. This assessment revealed no significant work-related problems due to flexitime. Only 15 percent of the respondents indicated on the survey that they had experienced any work-related difficulties due to flexitime. The most-often-cited problems were difficulty in scheduling meetings (cited by 5 percent of the respondents) and difficulty in interacting with co-workers (6 percent).

Flexitime is as popular with supervisors as it is with their staff. Supervisors share the assessment that flexitime has improved morale and that it has increased productivity. However, larger percentages of supervisors than of staff reported work-related difficulties due to flexitime. Many had difficulty in interacting with co-workers (25 percent) and scheduling meetings (20 percent). Flexitime has virtually eliminated the problem of tardiness. This has reduced the burden on supervisors to discipline tardy employees and is inferred to have increased the number of hours worked by previously tardy employees. Furthermore, flexitime has reduced the number of work hours missed due to inclement weather because travel delays are made up at the end of the day.

An unanticipated impact of flexitime is reflected in the fact that more than one-fourth of the professional staff indicated that they voluntarily increased the average numbers of hours they work in response to flexitime; the average increase was reported to be about 30 min. Reasons stated for the increase included the desire to finish a task and a reluctance to leave while project co-workers remain. Only 3 percent of the respondents felt that flexitime led to a reduction in the number of hours they worked. Among the reasons given were bus schedules and clock watching.

The costs of flexitime have been minor. It was expected that overhead would increase by a small amount due to the need to keep the building open for a longer period of time each day. However, due to revised operating procedures, any costs that accrued from flexitime were offset, and the cost of facilities operation during the flexitime experiment remained about constant.

FUTURE WORK

This analysis has indicated that flexitime has potentially large and socially beneficial impacts on individuals' activity and travel choices. Further research, therefore, seems warranted to investigate the applicability of flexitime to a wide variety of different (nongovernmental) work settings; to explore the potential of flexitime programs to achieve energy conservation in the large, severely congested urban areas; and to corroborate the empirical findings on behavioral impacts obtained in this study. Improvements in modeling individual responses to flexitime are also warranted because of the models' usefulness in understanding and predicting behavior in other settings. In particular, model forms that reflect the underlying choice structure more appropriately should be investigated; variables that describe the travel options available to workers should be incorporated; and daily arrival times ought to be modeled with seasonal and day-of-the-week effects included.

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Who Switches to Alternative Work Hours and Why

ALFRED J. NEVEU AND K.-W. PETER KOEPPEL

A survey of employees at the main office of the New York State Department of Transportation was undertaken in late May 1979 to determine their response to a program of alternative work hours implemented in December 1978. The survey contained questions that dealt with changes in work schedules, perceived impacts, characteristics of work trips, and demographic information. A sample of 105 employees was obtained, and the sample provided a good representation of the total work force of the main office. Examination of the responses yielded the following results: More than half of the employees surveyed changed their work schedule; the majority switched to earlier starting times. Respondents who have long commute times were more apt to shift; however, even nonswitchers also saved travel times. Thus, this program reduced highway congestion somewhat. Contrary to expectations, ridesharing increased after implementation. The primary reason for this was the department's Carpool Coordinator Demonstration Project. Attitudes toward travel impacts generally do not influence the desire to alter work schedules. On the contrary, alteration of one's work times leads to favorable attitudes toward travel-related impacts of alternative work schedules.

The concept of alternative work hours has been under discussion for many years; proposals range from staggered work hours to compressed workweeks. Tannir (1) provides a comprehensive review of the work in this area. Alternative work schedules have been implemented by various government agencies and business enterprises in the United States and overseas, particularly in Germany (2). Proponents of the strategies claim increased employee morale, productivity, and job satisfaction as the primary benefits of such programs.

In view of the current energy situation in the United States, renewed interest has been focused on alternative work schedules by government planners and members of the business community as a way of promoting energy conservation in work travel by reducing highway congestion. Accompanying this resurgence of interest comes the need to better understand the impacts of such strategies, both positive and negative, and the demographic, travel, and attitudinal characteristics of the employees who elect to alter their work schedules. The main thrust of this report is to provide some information on the latter two issues.

Table 1. Representativeness of sample.

Item	Sample (%) (n = 105)	Main Office (%) (n = 1735)
Grade and salary		
1-9, $6 500-$9 800	27.6	30.6
10-19, $10 400-$17 300	35.2	37.7
20-29, $18 200-$29 300	36.2	26.6
30+, $30 800 +	1.0	5.1
Bargaining unit		
Administrative	28.6	28.8
Operational	1.9	1.8
Institutional	0.0	0.1
Professional, scientific, and technical	61.9	55.8
Management, confidential	7.6	13.5

In 1977, the Planning Research Unit of the New York State Department of Transportation (NYSDOT) conducted a study of employee favorability toward alternative work schedules (3) to determine what factors influence attitudes and willingness to participate. Surveys were conducted in the main office in Albany, New York. Results showed that the primary motivation behind favorability was the desire for flexibility in family life; alternative work hours were most favored by employees younger than 45 who were from three- or four-person families and professionals. Attitudes were generally favorable and highest for leisure and family activities.

In December 1978, NYSDOT implemented a program of alternative work hours for employees in its main office. Under this arrangement, employees may elect to alter the former work schedule (8:00 a.m.-4:10 p.m.) to one of five alternative schedules, which includes the former one. The employees work those schedules for one calendar quarter, at which time they have the option of selecting a different schedule or remaining with their previous selection.

In late May 1979, the Planning Research Unit of NYSDOT undertook a simple random survey of employees of the main office to determine their response to the implemented program of alternative work hours. The survey contained questions on work-schedule changes, perceived impacts, characteristics of the work trip, and demographic information. A sample of 105 responses was obtained; the respondents provided a good representative sample of the total work force at the main office on the characteristics of state grade level and bargaining unit (Table 1). A companion paper (4) analyzes a special portion of these data collected in the trade-off format. A more detailed discussion of the survey methodology may be found elsewhere (5).

The analysis focused on three areas:

1. What were the work-schedule changes adopted by the employees? How many workers altered their schedules?
2. What were the effects of the alteration of work hours on the trip to work, including travel times and mode changes? and
3. What were the characteristics of the individuals who opted to change their work schedules?

WORK-SCHEDULE CHANGES

Table 2 shows a percentage breakdown of the changes in work schedules for each of two quarters. It can be seen that 44 percent of the sample opted to alter their work schedules in the first quarter after implementation; this number increased to 51 percent in the second quarter. This second-quarter number includes new work-schedule changes from the 8:00

Table 2. Changes in work schedules.

	Percentage of Respondents Working				
Time Period	7:00 a.m.– 3:10 p.m.	7:30 a.m.– 3:40 p.m.	8:00 a.m.– 4:10 p.m.	8:30 a.m.– 4:40 p.m.	9:00 a.m.– 5:10 p.m.
Before December 1978	0	0	100	0	0
December–March 1979	6	26	56	9	3
April–June 1979	17	28	49	6	0

Table 3. Characteristics of those who shifted work schedules.

Characteristic	Percentage Who Changed Work Times	Characteristic	Percentage Who Changed Work Times
Sex		Carpool	
Male	61	Yes	49
Female	35	No	58
Age		Mode to work	
19-34	64	Car	54
35-54	53	Bus	34
55+	42	Other	88
Cars per household		Travel time (min)	
0	0	0-15	61
1	20	16-30	68
2+	35	30+	45
Household size		Travel distance (miles)	
1-2	53	0-15	51
3-4	53	16-30	56
5+	63	30+	65
State grade		Bargaining unit	
1-9	40	Administration	41
10-19	57	Professional, scientific, and technical	62
20+	63	Management, confidential	50
Traffic congestion			
Low	49		
High	62		

a.m.-4:10 p.m. time period as well as those employees who altered their work schedules for a second time. The total percentage of employees who shifted their work schedules at any time is 54 percent.

A vast majority of those respondents who altered their work schedules selected earlier starting times (77 percent), especially in the second quarter. One possible explanation for this behavior would be the desire for earlier work hours during the summer months (a resurvey in the winter months would confirm or dismiss this assumption).

TRAVEL TO WORK

The table below shows automobile and public transit (bus) use for the work trip both before the implementation of the alternative-work-schedule program and currently.

Mode	Percentage Using Mode: Before December 1978 (n = 105)	May 1979 (n = 105)
Car	83	85
Public transit	7	6
Other	10	9

The automobile is by far the predominant mode of travel for the work trip in both time periods. The location of the main office is well served by several arterials and expressways, has plenty of free parking for employees, and is poorly served by the local bus system. Thus, this high automobile use comes as no surprise.

One of the most often cited negative impacts of

Figure 1. AID tree.

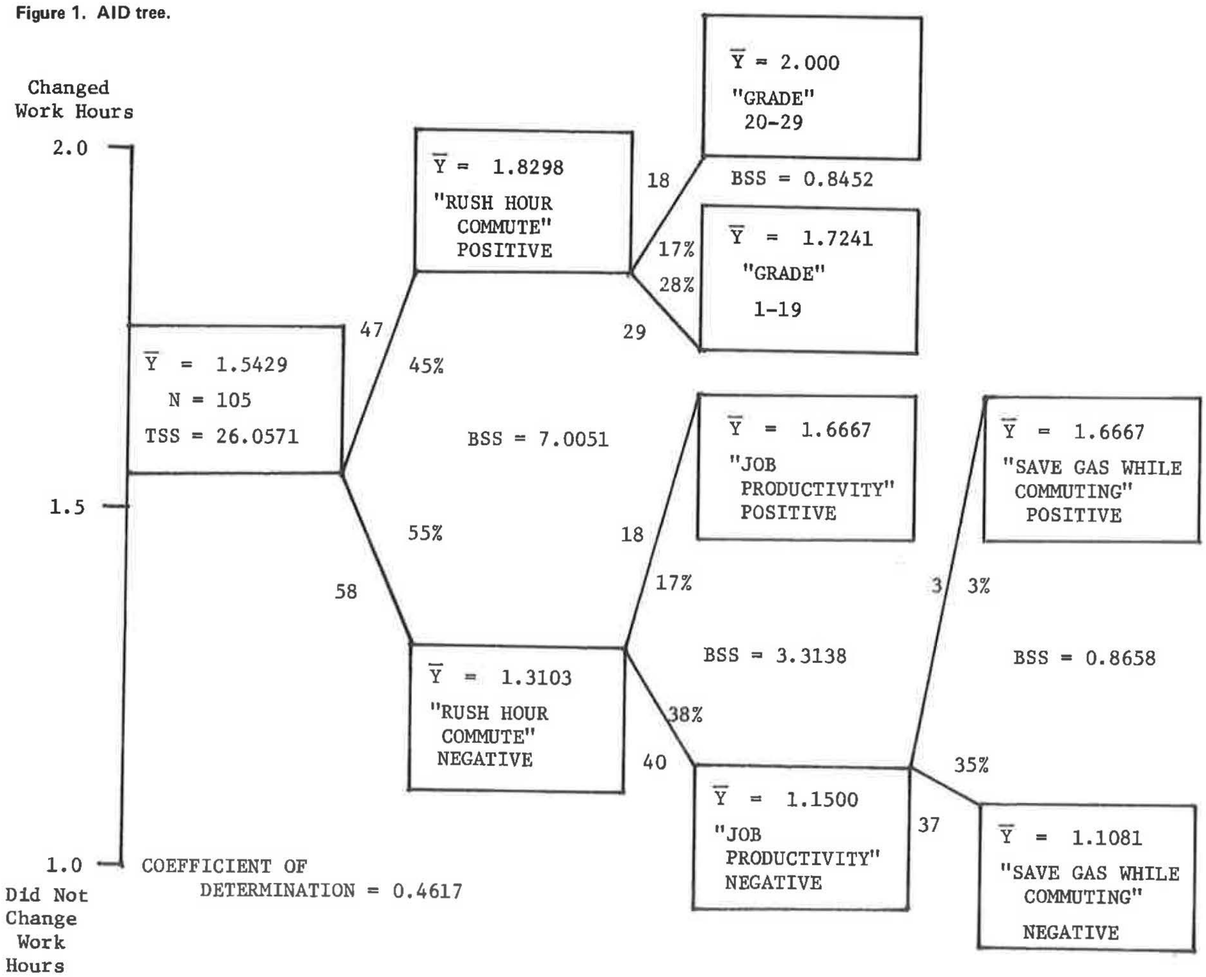
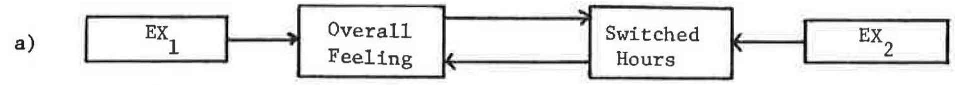
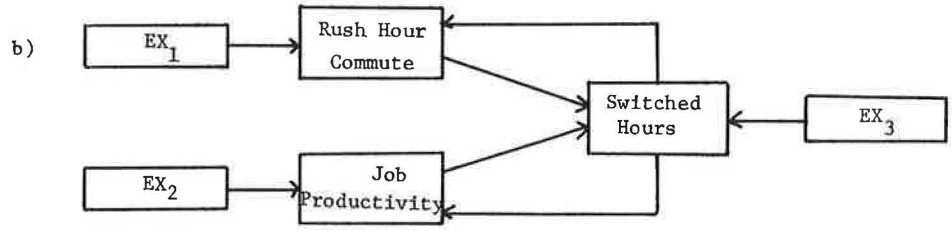


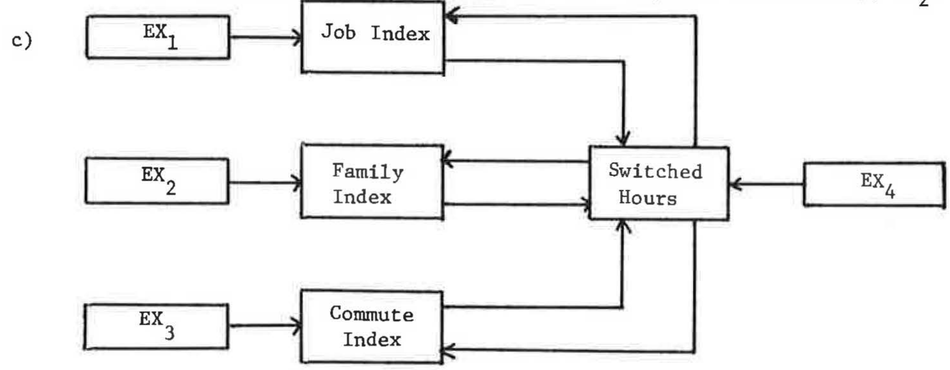
Figure 2. Paradigm of two-stage least-square tests.



1. Overall Feeling = f(Switched Hours, EX_1)
2. Switched Hours = g(Overall Feeling, EX_2)



1. Rush Hour Commute = f(Switched Hours, EX_1)
2. Job Productivity = g(Switched Hours, EX_2)
3. Switched Hours = h(Rush Hour Commute, Job Productivity, EX_2)



1. Job Index = f(Switched Hours, EX_1)
2. Family Index = g(Switched Hours, EX_2)
3. Commute Index = h(Switched Hours, EX_3)
4. Switched Hours = j (Job Index, Family Index, Commute Index, EX_4)

where

Job Index = average attitude score for Opportunity for Second Job + Job Satisfaction + Job Productivity + Communication with Employees and Public + Fatigue;
Family Index = average attitude score for Leisure Time + Family Time + Use of Vacation Time + Use of Sick Leave + Use of Personal Leave + Ability to Do Shopping and Errands + Child-Care Arrangements; and
Commute Index = average attitude score for Rush-Hour Commute + Save Gasoline While Commuting + Ability to Form Carpools.

alternative work schedules is the decreased ability to form and maintain carpools. In an effort to determine the impact of the new work-schedule arrangements, the respondents were queried as to their ridesharing behavior both prior to implementation and currently. Those results are summarized in the table below.

	Percentage Who Rideshare	
Response	Before December 1978 (n = 105)	May 1979 (n = 105)
Yes	27.6	30.5
Sometimes	6.7	10.5
No	58.1	52.4
Car not used	7.6	6.6

From that table, it can be seen that, contrary to expectations, ridesharing behavior actually increased (from 34.3 percent to 41.0 percent) after the program of alternative work hours was established. However, during this same time period (January-June 1979), the department's Carpool Coordinator Demonstration Program (6) was also in operation and, of course, energy prices rose rapidly and gasoline shortfalls appeared. It is reasonable to assume that a large portion of the increase in carpooling is attributable to these other events. Whatever the reason, it is therefore possible to alleviate, or even reverse, the trend away from carpooling after the implementation of an alternative-work-schedule program, thus removing one

of the prime detriments to the increased use of such programs.

The table below shows the average travel times (one way) before and after implementation for respondents who changed their work schedule and those who remained on the old schedule.

Response	Average Travel Time to Work (min) Before December 1978	May 1979	Average Savings (min)
Changed work hours	34.7	28.1	6.6
Did not change	28.4	27.3	1.1
Avg	31.8	27.7	4.1

Overall, the average savings per respondent was more than 4 min each way or more than 8 min/day. This is almost a 13 percent saving in travel time for the entire sample. Those respondents who changed their work schedules saved 19 percent of their previous travel time by changing their schedules. Moreover, the respondents who did not change their work schedules saved 4 percent, which implies reduced congestion for nonswitchers. Thus, savings in travel time for the work trip accrue to all employees in an alternative-work-schedule environment. The largest savings, however, go to those employees who alter their work schedules since, on the average, they had a longer work trip than employees who did not change their work schedule. This result confirms theoretical work published earlier (7).

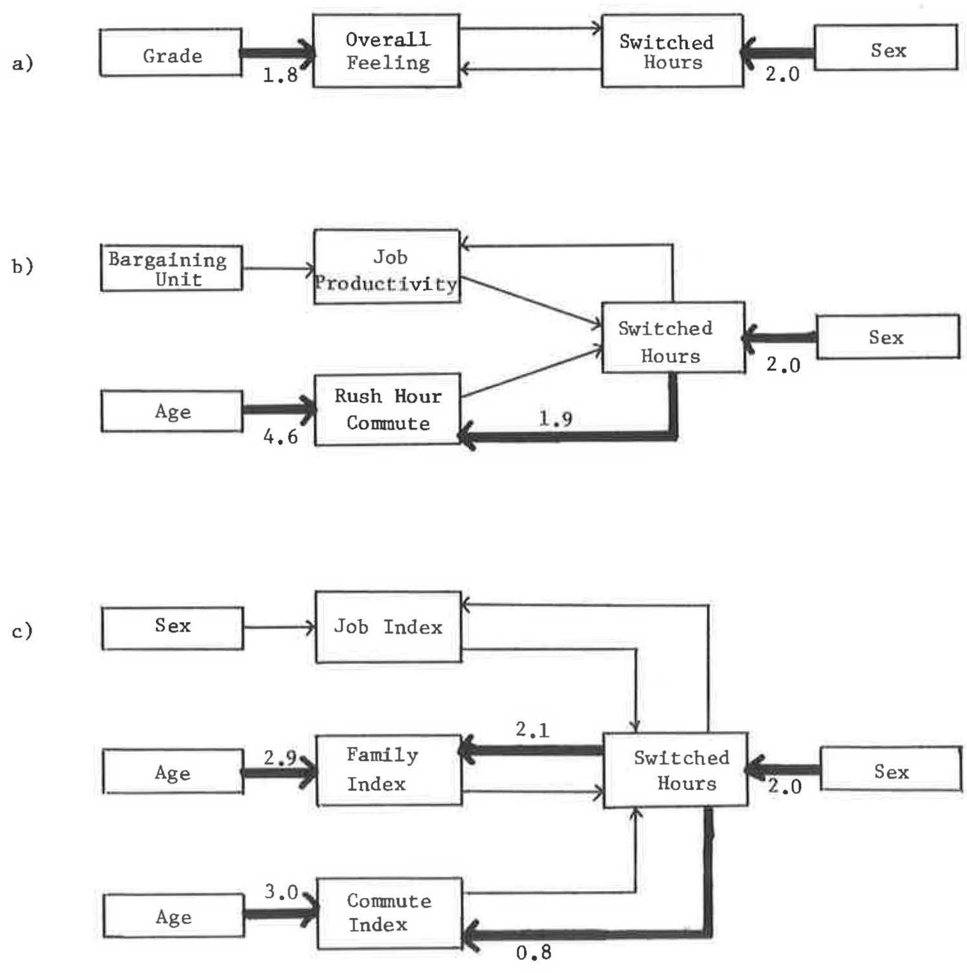
CHARACTERISTICS OF SHIFTERS

The analysis in this phase of the research was performed in two parts. First, by using only demographic information collected in the survey, descriptions of the types of employees who altered their work schedules were developed. Second, the demographic information was combined with attitudinal information on the perceived impacts of the alternative-work-hours program in order to judge the effect of attitudes toward travel impacts on the propensity to alter work schedules.

In the second phase of this analysis, a statistical tool called Automatic Interaction Detector (AID) was used. The objective of AID is to explain the variance of the dependent variable, in this case, whether the respondent altered his or her work schedule. The algorithm divides the sample on a series of binary splits by using the independent variables. The independent variables are selected in decreasing order of their power to explain the variance on the dependent variables. AID has been used in several studies at NYSDOT (1,8,9) and a more detailed discussion of this procedure may be found elsewhere (10).

Table 3 shows results from the first phase of the analysis, by using the demographic data to describe the respondents who changed their work schedules. Several conclusions are readily evident when considering this table. First, men had a greater propensity to change their work schedules than did women; younger employees, those from larger households, those who thought traffic congestion on the work trip before implementation was bad, and

Figure 3. Results of two-stage least squares.



those at higher state grade levels (higher income levels) were also more apt to switch hours. Employees who did not change their work schedules may be characterized by the following: women, older employees, from smaller households, make shorter work trips, and lower state grade levels.

These results are similar to those predicted by Tannir (1) by using the trade-off method. He analyzed the favorability of several programs of alternative work hours at NYSDOT and estimated their acceptability to the employees. The results from this research confirm his estimates.

To determine the influence of the respondent's attitudes toward the impacts of this program, several AID runs were conducted by using the demographics and perceived impacts as the dependent variables. Figure 1 presents the run that explains the greatest variation of the dependent variable (changes in work hours).

The AID tree demonstrates the importance of the perceived impacts of the alternative-work-hours program. Those employees who perceived negative impacts in "having to commute during rush hour," "job productivity," and "saving gasoline while commuting" were less likely to change their work schedules. Those who had a favorable attitude toward "rush-hour commuting" and were in the high state-grade-level positions were the most likely group to change their work schedules. This AID tree explains 46 percent of the variation in the sample.

The first split in rush-hour commuting is similar to what was seen by Tannir (1). In his work, when the independent variable was "overall attitude toward variable working hours," the first split was identical.

However, it is unclear whether the perception of the positive effect on commuting during rush hour caused the switching behavior or whether the switching behavior caused the positive perceptions. In order to test the interrelationship between attitude and behavior, three hypothesized relationships of attitudes and behavior were tested by using two-stage least squares. This technique has been applied in previous tests of attitude and behavior linkages (11-13) and has been found to be a useful tool.

The three paradigms are illustrated in Figure 2 along with the equations (and the definition of the variables) derived from each hypothesis. The results are shown in Figure 3.

For the first paradigm, there was no significant relationship between overall feeling toward the program and changing work hours. In the second paradigm, there is only a one-way relationship between the impact of rush-hour commuting and whether the respondent altered his or her work schedule. This relationship implies that the favorable attitude toward rush-hour commuting was formed after the change in the respondent's work schedule, and some positive aspects of the commute to work under alternative work schedules was experienced.

In the third paradigm, again the attitudes had no influence on changing work schedules, but the change in work schedules influenced, albeit weakly, the feelings toward family activities and commuting. This result adds support to that obtained from the second paradigm. The above analysis can be summarized as follows: Travel habits and attitudes do not influence the propensity to alter work schedules, but the alteration of those schedules produces favorable attitudes toward the travel impacts and family-related alternative-work-schedule programs.

SUMMARY AND CONCLUSIONS

A survey undertaken after the implementation of a program of alternative work hours queried the employees on their work-hour shift, work travel habits and changes, perceived impacts of the program, and demographic data. The analysis examined the magnitude of the changes in work schedules, the changes in work travel patterns, the characteristics of the respondents who shifted their schedules, and the influence of travel habits and attitudes on the potential to change work hours. From these analyses, the following conclusions are evident:

1. More than one-half of the employees surveyed changed their work schedules; the majority switched to earlier starting hours.
2. Respondents who have long commute times were more apt to shift and saved 20 percent of their travel time; however, since even nonswitchers also saved travel time, this program reduced highway congestion somewhat.
3. Contrary to expectations, ridesharing increased after implementation, the primary reason being NYSDOT's Carpool Coordinator Demonstration Project. Thus, one of the major negative impacts of alternative work schedules--reduced carpooling--can be alleviated with the addition of ridesharing incentives.
4. Employees who shifted work schedules can be characterized as male, younger, from larger households, thinking that traffic congestion before implementation was bad, and in the higher state grade levels (higher income levels).
5. Attitudes toward travel impacts generally do not influence the desire to alter work schedules; on the contrary, alteration of one's work times leads to favorable attitudes toward travel-related impacts of alternative work schedules.

Overall, it is evident that NYSDOT's program of alternative work hours has a favorable impact on the employees and their commuting to work. More research is needed in order to further quantify the impacts of such programs. In this time of concern with energy conservation and the search for effective and efficient policy actions, the implications of programs of alternative work hours must be given due consideration as a feasible option.

ACKNOWLEDGMENT

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Microsimulation of Organized Car Sharing: Description of the Models and Their Calibration

PETER BONSALL

This report is one of a series that report the methodology and findings of an investigation of the likely impact of organized car-sharing schemes. This volume summarizes the structure of a microsimulation model of organized car sharing. It includes a description of the model itself, the preparation of the necessary data base, and the calibration of the choice models by using data from a special survey. Microsimulation is a technique of computerized modeling within which the decision-making process is replicated for each individual in the system. Monte Carlo sampling of probability distributions is used to generate all the individual decision makers, each of whom is uniquely identified within the model. The model consists of three stages: In the first stage it considers each eligible trip maker and predicts whether or not he or she will apply to join an organized car-sharing scheme; in the second stage all these applications are processed to produce match lists of potential traveling companions; in the final stage the model considers the decision by each applicant of whether to form a car-sharing arrangement with anyone on his or her match lists. The model was successfully calibrated and its predictions accord well with empirical evidence of the performance of car-sharing schemes.

This report is one of a series (1-3) that emanates from a study of organized car sharing. Readers interested primarily in the likely effects of car-sharing schemes will find the relevant results of the modeling exercise elsewhere (3); those who have an interest in the surveys on which calibration of the models is based should see another report (2).

The objective of the study was to provide guidance for policymakers who are contemplating the implementation of car-sharing schemes, by estimating the relationships that exist between the performance of schemes, the policy environment in which they operate, and the nature of the schemes themselves, and so predict the likely impact of schemes that operate under a variety of conditions.

Although field trials must obviously constitute the final test of the performance of car-sharing schemes, it was decided to base the current investigation on calibrated models. The models allowed us to experiment with a wider range of options than would have been possible in field trials and enabled us to gauge the likely scale of impact on public transport (a desirable preliminary since this impact could be very important).

Several studies have suggested that organized work-journey car sharing has the potential to have a large effect on the transport system (4,5). Given this potential impact, the problem is how to estimate the likely impact. Valuable work in the United States (6,7) has treated car sharing as a separate mode and has estimated demand by simple extension of existing modeling techniques. However, these techniques cannot produce accurate estimates since they do not consider the compatibility of carpool members (compatibility of location, journey time, and personality). Other work has concentrated on attitudes toward car sharing (8-12). It has provided useful insights into the likely behavior and compatibility of individuals but it is, in itself, not readily adapted for predictive purposes because it is concerned with individuals rather than populations and cannot consider the likelihood that the compatibility constraints will be met.

This project was intended to bridge the gap between theoretical modeling and attitudinal investigation by developing a model that, although based on the attitudes and consequential decisions of individuals, could take into account the availability, characteristics, and compatibility of potential partners and could thus predict not only the demand for car-sharing arrangements but also whether they were likely to be established. The form of model best suited to this task is considered to be microsimulation.

MICROSIMULATION

Microsimulation is a technique of computerized modeling within which the decision-making process is replicated for each individual decision maker within the modeled system. These decision makers effectively become actors who are each uniquely identified. The decision-making processes are driven by Monte Carlo-type sampling, according to probabilities that are determined previously, depending on the many different attributes of the actors, their environment, and the proposed scheme.

The simulation suite itself has three stages, each of which represents a distinct process in the establishment of an organized car-sharing scheme. The first stage is concerned with the scope and intensity of the scheme being simulated and the decisions by members of the public to be associated with it. The second stage deals with the mechanics of attempting to match up potential partners, and the third stage deals with the reactions of the participants in the scheme to their proposed partners.

The model has been designed so that a variety of car-sharing schemes can be tested in a variety of policy environments. The complete list of control parameters and coefficients includes (a) descriptions of the actors in the system (inhabitants of the area); (b) parameters to define the scope and operational details of the scheme to be tested (for example, Which workers or residents are to be exposed to publicity for the scheme? How intense will be the publicity and how many people will be included on each match list?); and (c) coefficients that govern the decision to apply to join a car-sharing scheme and the decision to match with a given person (each decision is calibrated by special survey). Other parameters allow the user to test changes in the operating environment, such as changes in gasoline prices, changes in public transport fares, or the provision of reserved parking for carpoolers.

The model predictions are fed into an analysis package that provides for a range of descriptions and performance indicators that include some graphical display. The list of indicators includes profiles of the applicants and participants, operational characteristics of the scheme, and effects on selected components of the transport system such as vehicle distance traveled, car occupancies, and abstraction of public transport patronage.

Synthesis of the Population Base

A fundamental input to a microsimulation model is a unique description of each of the actors in the system of interest. These individual descriptions cannot be replaced by collective probability matrices because microsimulation involves strict accounting procedures: As each individual passes through the system, records must be kept on his or her progress. This is particularly important in the present case because it is a fundamental feature of car sharing that there be absolute equality between supply and demand (each lift is given once and once only).

Ideally, of course, the population of actors would be taken from a 100 percent household census, but since this is not feasible a synthetic population has to be generated. (In some microsimulation models a sample population would suffice, but in the case of car sharing it is not possible to properly represent the spatial relationships of potential partners unless the total population is included.) This synthetic population must be more sophisticated than that which would be produced by a simple factoring-up procedure because simple factoring would have produced a population of sets of identical people whose mutual interactions would therefore have been quite different from those of the true population. The method of synthesis used in the current project is described below; however, it should be stressed that the population synthesis is not a part of the microsimulation technique, but merely a device that prepares data for it.

Structure of the Synthesis Suite

A full description of the method of synthesis is given in a background working paper (13). In summary, the method is based on the probability with which one characteristic of an individual or household will depend on other characteristics, as revealed in a household survey. Monte Carlo sampling of the various probability distributions is then used to generate individuals within control totals derived from published census material. For each individual in the population, the following attributes were synthesized:

1. Home geocode--precise locations are specified because, in a model that addresses the interaction between neighbors, the use of zone centroids or density functions would have been unacceptably crude;
2. Workplace geocode--precise locations are specified for the same reason as that given for the preceding attribute;
3. Sex;
4. Age--under 30, 30-50, or over 50;
5. Whether head of household;
6. Driving license tenure;
7. Employment category--manual or shop floor, technical or clerical, or professional or managerial;
8. Whether car is needed at work for business use;
9. Current mode of travel to work--i.e., prior to the introduction of car-sharing scheme (possible modes are 1 = solo car driver, 2 = car driver with one passenger, 3 = car driver with two passengers, 4 = car driver with three or more passengers, 5 = car passenger, 6 = public transport, and 7 = any other mode; since the evening mode is not constrained to equal the morning mode, there are 49 possible modal combinations);
10. Normal time of arrival at work;
11. Normal time of departure from work;
12. Number of cars available in the household;
13. Number of licensed drivers in the household;
14. Total number of people in the household; and
15. Household telephone availability.

In addition to these 15 attributes, each individual is allocated a reference number that indicates the household to which he or she belongs and his or her unique identity within that household. Each individual is also allocated a random number with which to seed the Monte Carlo sampling. The 15 attributes were chosen as having a

strong bearing on an individual's reaction to and performance within organized car-sharing schemes. Clearly, there are many other attributes (e.g., smoking habits and preferences, education, income, and variability of work hours) not mentioned above that might be expected to have equal or greater influence on car-sharing schemes. Unfortunately, however, only those attributes whose distribution in the population was known and observed in the calibration surveys could be included in the modeling.

The synthesis suite has three distinct stages concerned with synthesis (a) of population, (b) of mode choice, and (c) of location within zones.

Synthesis of Population

The first model begins the synthesis by considering, in turn, every zone within the study area. For each household within the zone, it synthesizes the characteristics of each household member in turn. The synthesis proceeds within a framework of exogenously defined control totals of households per zone, but the core of the synthesis is concerned with building up an individual's characteristics, one by one, according to observed probabilities. The synthesis of each new characteristic is governed by random selection according to probabilities based on some of the previously synthesized characteristics.

The random selection is governed by cumulative probability tables disaggregated according to the different values of the data items (and combinations thereof) on which the selection is based. Thus, for example, characteristic A will be governed by a probability matrix P(A|B,C,D) in which the distribution of A will depend on the other characteristics B, C, and D. To select a value of A when B = 1, C = 2, and D = 3, a random number R is chosen from a rectangular distribution between 0 and 1. Then A is assumed to take the value at which the cumulative probability for A exceeds the value of R, subject to the maximum allowable value n. That is,

$$A = \min \left\{ n : \left[\sum_{i=1}^{n} P(A=i|B=1,C=2,D=3) \right] \geq R \right\} \quad (1)$$

The cumulative probability tables, which are the basis of the model, come from two submodels that deal with individual characteristics and trip distributions, respectively. The cumulative probabilities for individual characteristics are simply derived by appropriate summation within the household interview data. The distribution model, however, is a doubly constrained entropy-gravity model for two sexes, two person types (office and nonoffice), and 11 categories of industry. Thus, the predicted number of trips between residence zone i and work zone j (P_{ij}) is given by

$$P_{ij}^{snfk} = A_i^{snf} B_j^{snf} \exp(-\beta^s c_{ij}^k + \delta^{sk}) \quad (2)$$

where

s = sex,
n = person type (1 = office, 2 = nonoffice),
f = industrial category,
k = mode (1 = car or motorcycle, 2 = all others including walk),
A = balancing factor associated with residence (calibrated),
B = balancing factor associated with work place (calibrated),
c = generalized cost of travel in generalized tenths of minutes (generalized cost here includes in-vehicle time, excess times, and out-of-pocket costs),
β = deterrence factor (calibrated), and
δ = calibrated modal penalty for persons who have cars available.

The values of A and B are calibrated to satisfy the following constraints:

$$\text{for all isnf} \quad \sum_{jk} P_{ij}^{snfk} = O_i^{snf} \quad (3)$$

$$\text{and for all jsnf} \quad \sum_{ik} P_{ij}^{snfk} = D_j^{snf} \quad (4)$$

where O_i = observed number of work-trip origins in zone i (from 1971 census) and D_j = observed number of work-trip destinations in zone j (from 1971 census).

The values of β and δ^{sl} are calibrated to satisfy the following constraints:

$$\text{for all s} \quad \sum_{ijk} c_{ij}^k (T_{ij}^{ks} - \sum_{fn} P_{ij}^{snfk}) = 0 \quad (5)$$

$$\text{and for all s} \quad \sum_{ij} (T_{ij}^{ls} - \sum_{fn} P_{ij}^{snfl}) = 0 \quad (6)$$

where T_{ij}^{ks} = observed number of trips from i to j by mode k by person of sex s (from 1971 census).

Synthesis of Mode Choice

The second synthesis model deals with the normal mode of travel to work adopted by each member of the population synthesized in the first model. The synthesis of mode is treated as a separate operation in order that the influence of short-term transport policies can be included in the overall simulation suite. A postdistribution modal-split model can be used here because modal choices are more responsive than are distributional choices to the policy changes that are to be tested.

The model uses the observed mode of persons who have a given combination of characteristics to create a mode-choice probability matrix. The probability matrices were derived by simple summation within the household-interview data. The synthesis model then proceeds by random selection governed by these matrices, in a manner parallel to that described in Equation 1 for the first synthesis model.

Synthesis of Location Within Zones

The final synthesis model ensures that each member of our population is located at a precise point in space both at home and at work. The model uses a random number generator to generate, for each synthesized individual, one set of 0.1-km grid coordinates within his or her residence zone and another set within his or her work zone. Those coordinates are then taken to be actual locations of the home and work place, respectively. The distribution of such locations is facilitated by the assumption that all zones are circular, centered around the zone centroid, and of an area that corresponds to the zone's actual area. The distribution of activity within these circular zones is represented by a set of concentric rings centered on the zone's activity centroid, each ring of which has a known width and a known proportion of the zone's total population or employment. These data were estimated approximately by inspection of ordnance survey maps.

Performance of the Synthesis Suite

The synthesis models are based on observed probabilities and, if the explanatory variables have been correctly identified, the models are therefore constrained to give good results. However, testing of the models was required in order to validate the choice of explanatory variables and to investigate whether or not the sequential nature of the models has allowed the propagation of errors.

Ideally, the models would have been validated by testing the goodness of fit between the synthesized population and an independent description of the actual population that it represents. However, insufficient data were available to allow part of it to be held back for model testing. Any goodness-of-fit tests, therefore, have to involve the testing of characteristics of the synthesized population against characteristics of the population sample on which they themselves were based. Such tests are perhaps of questionable validity, but no better alternative was available. This problem of statistical verification is compounded by the use of two data sets that refer to the same phenomena, which makes it difficult to define the number of independent observations and thus the degrees of freedom. In the absence of a single satisfactory statistical test of these models, a range of measures was produced.

The simplest test was of households drawn at random from the synthesized population. These households were subjected to close examination in order to discover whether they had any counterintuitive attributes or internal inconsistencies. In fact, none of the households sampled showed anything untoward.

The next test was a comparison of the observed and synthesized populations with respect to the aggregate occurrences of particular characteristics or combinations of characteristics. Once again there appeared to be no serious cause to doubt the accuracy of the synthesis. Other tests sought to examine the accuracy of the distribution submodel and to search for significant biases within the results. Again, there was no reason to doubt the efficacy of the synthesis. A full account of these tests is given elsewhere (13).

The computational cost of the synthesis suite were somewhat less than 1 p (US $0.02) (at notional commercial rates set by the University of Leeds in 1979) per synthesized individual. To provide a comprehensive population base for the microsimulation model of organized car sharing, 180 000 individuals were synthesized.

THE MICROSIMULATION MODEL

Model of the Decision to Join a Car-Sharing Scheme

The assumption is made that each member of the target population will receive promotional material and an application form for an organized car-sharing scheme. The model then determines, for each member of the population, whether he or she will fill out the application form and, if so, what type of application he or she will make. There are seven types of application:

1. To carpool--alternate driving and riding,
2. To give lifts mornings and evenings,
3. To give lifts mornings only,
4. To give lifts evenings only,
5. To receive lifts mornings and evenings,
6. To receive lifts mornings only, and
7. To receive lifts evenings only.

The likelihood of an individual's making any of the various types of application is deemed to be a function of certain characteristics--length of journey to work, previous mode of travel, age, sex, economic status, work hours, driving license tenure, household license tenure, car availability, and telephone availability.

Table 1. Calibrated coefficients of decision to apply.

		Application								
			Lift Giving			Lift Receiving			Passengers	
No.	Characteristic and Values[a]	Pooling	Morning and Evening	Morning Only	Evening Only	Morning and Evening	Morning Only	Evening Only	Allow More Than One	Allow More Than Two
0	Dummy (1)	-3.53	-2.96	-4.06	-0.77	-2.62	-3.24	-1.89	0.82	0.51
1	Length of journey to work (km)	0.16	0.13	0.11	-0.09	0.09	0.00	-0.14	-0.04	-0.02
	Normal morning mode									
2	Solo driver (0-1)	0.48	0.60	0.09	-0.57	-0.20	0.81	-0.60	0.25	0.35
3	Accompanied driver (0-1)	0.09	0.30	-0.27	0.20				-0.30	0.27
4	Passenger (0-1)	-0.86	-0.18	-0.56	-0.07	-0.48	-0.77	0.14	0.16	0.26
5	Public transport (0-1)	0.64	0.02	-0.31	-0.06	-0.06	-0.23	-0.30	0.07	0.23
	Normal evening mode									
6	Solo driver (0-1)	-0.36	-0.00	0.08	-0.69	-0.40	-1.04	-0.61	0.57	0.25
7	Accompanied driver (0-1)	1.03	0.94	-0.00	0.39				0.70	0.38
8	Passenger (0-1)	0.34	0.32	-0.36	-0.13	0.11	0.09	0.07	-0.43	-0.11
9	Public transport (0-1)	-0.43	-0.40	-0.60	-0.08	0.51	0.60	0.74	0.00	0.32
10	Less than 30 years old (0-1)	-0.44	-0.18	-0.50	-0.37	0.29	-0.56	-0.17	-0.15	0.64
11	More than 50 years old (0-1)	-0.64	-0.24	-0.72	0.24	-0.08	-0.71	-0.96	0.20	-0.50
12	Household cars available (0-4)	0.21	-0.43	-0.16	-1.26	-0.69	0.14	-0.09	-0.41	-0.02
13	Full car driving license (0-1)					-0.19	-0.05	-0.53		
14	Factory or manual worker (0-1)	-1.67	-1.39	-1.77	-0.61	-1.22	-0.15	-0.76	0.14	-0.24
15	Professional or managerial worker (0-1)	-0.74	-0.35	-0.13	-0.57	-0.19	-0.12	-1.28	0.63	0.12
16	Female (0-1)	-0.36	-0.32	-0.19	-0.44	-0.19	0.67	-0.45	0.05	-0.06
17	Number of licensed drivers in household (0-8)	-0.02	-0.09	0.19	-1.31	0.17	-0.48	-0.33	0.22	0.21
18	Number of nondrivers in household (0-8)	-0.44	-0.46	-0.49	-1.31	-0.31	-0.48	-0.89	0.37	0.02
19	Morning journey driving off peak (0-1)				-0.63			-0.51	0.44	-0.10
20	Evening journey driving off peak (0-1)			0.29			-0.58		0.04	0.09
21	Household has telephone (0-1)	1.35	0.63	0.65	-0.05	0.31	0.23	0.26	0.17	-0.68

[a]Where the characteristic takes only the values 0 or 1, 1 = an affirmative answer to the question asked and 0 = a negative answer.

In order to establish the importance of these characteristics, a series of binary logit models was calibrated based on the results of a field survey. The survey, which is described in a companion report (2), simulated the distribution of car-sharing promotional material among a population of known characteristics and then analyzed the characteristics of the resulting applicants.

The logit models used were regression transformations of the form:

$$P_j = \exp\left(\sum_{i=0}^{21} a_{ij}x_i\right) \bigg/ 1 + \exp\left(\sum_{i=0}^{21} a_{ij}x_i\right) \quad (7)$$

where

P_j = the probability of making an application of type j,
x_i = the value of the ith characteristic of the individual being considered (21 characteristics were considered in total), and
a_{ij} = the calibrated coefficient.

Application of this logit model for each individual in the population produces a probability of the individual's making each type of application to join a car-sharing scheme. In order to represent the stochastic element of choice, this probability is then compared with a random number drawn from a rectangular distribution between 0 and 1. If the probability exceeds this random number, then an application is deemed made; in this way the probabilities are transformed into binary choices.

The calibration process involved evaluation of binary logit models of the form shown above in order to give values of a_{ij} that would reproduce the results of the survey (i.e., that would produce the same number of applicants that have the same average characteristics from a synthesized population designed to replicate the population surveyed). Table 1 shows the resulting values of a_{ij}. The dummy characteristic (numbered 0) corresponds to the basic decision, aggregated across the entire population, of whether or not to apply. This probability is then modified cumulatively according to the coefficients of the various characteristics.

The mechanism by which the microsimulation model uses these calibrated coefficients can perhaps be appreciated by considering the example of one individual chosen from the synthesized population base. This individual has the following characteristics:

1. Location of home is GR 847 237 and location of work is GR 295 299; therefore, the length of the journey to work is 8.09 km;
2. Normal mode of travel to work is solo driver;
3. Normal mode of travel from work is solo driver;
4. Age is 30-50;
5. One car in household;

Table 2. Regression coefficients: components of match utilities.

Value Coefficient (a_n)	Number of Observations	Transformation Used (y =)[a]	R^2	Residual (e_n)	Characteristics of Individuals (p_m) (p/week): Constant	Female	No Phone	Age: <30	>50
For prospective passengers, the value of									
1. Standard driver	68	$\sqrt{x}$	0.34	2.46	11.68	-1.56	0.04	-0.73	-0.81
2. Driver female	68	$\sqrt{-x + 51}$	0.27	1.70	8.10	-0.57	-0.41	-0.07	0.41
3. Early departure in morning (min)	67	$\sqrt{-x + 7}$	0.13	0.54	2.53	0.01	0.13	0.10	0.13
4. Late return in evening (min)	55	log (-x + 2)	0.33	0.63	0.21	-0.04	-0.05	-0.07	0.39
5. Driver has no phone	67	log (-x + 21)	0.26	0.77	3.06	-0.05	-0.05	-0.29	0.29
6. Work separation (mile)	55	$\sqrt{-x + 51}$	0.36	4.40	11.38	-1.97	-3.00	-0.25	1.00
7. Home separation (mile)	67	$\sqrt{-x + 68}$	0.25	3.39	8.87	-1.05	-1.34	-0.06	1.73
8. Driver >50	42	$\sqrt{-x + 46}$	0.21	1.68	7.46	-0.08	-0.29	0.68	-0.59
For driver offering lifts, the value of									
9. Standard passenger	51	$\sqrt{x - 401}$	0.21	4.82	19.33	1.76	-1.18	-1.01	0.03
10. Passenger female	51	$\sqrt{x - 26}$	0.15	1.47	5.15	0.60	0.08	-0.13	-0.65
11. 1 min early morning	41	log (-x + 1)	0.54	0.95	0.52	1.46	0.36	0.66	-0.26
12. 1 min late evening	30	log (-x + 1)	0.62	1.04	1.15	1.49	-0.09	-0.52	0.72
13. Passenger has no phone	46	$\sqrt{-x + 101}$	0.32	2.16	9.46	2.19	0.96	0.91	0.63
14. Work separation (miles)	33	$\sqrt{-x + 1}$	0.62	3.68	10.63	3.63	-1.83	4.80	-3.65
15. Home separation (miles)	15	log (-x + 1)	0.90	1.32	4.64	0.00	0.36	0.88	-1.49
16. Passenger >50	33	$\sqrt{-x + 51}$	0.54	1.57	5.66	3.07	-0.92	2.13	-0.38
17. Diversion (miles)	46	log (-x + 1)	0.40	1.52	3.91	1.19	-0.54	1.33	-0.63
18. Passenger is not the first	46	x	0.32	70.67	27.62	-16.94	0.70	48.96	-32.05
For prospective poolers, the value of									
19. Standard pooler	63	$\sqrt{x - 301}$	0.21	5.33	20.20	1.18	1.40	-2.36	-0.95
20. Copooler female	62	x	0.21	17.91	-10.06	2.70	18.37	5.66	2.02
21. 1 min early morning as passenger	34	x	0.50	29.46	-41.41	18.88	4.63	4.18	-25.25
22. 1 min late evening as passenger	23	x	0.53	28.50	14.89	-5.5	-0.23	-10.96	-11.30
23. 1 min early morning as driver	63	x	0.11	29.46	2.72	-1.71	-11.67	1.79	-2.85
24. 1 min late evening as driver	36	log (-x + 1)	0.40	1.77	3.32	0.75	0.66	0.48	1.55
25. Copooler having no phone	61	$\sqrt{-x + 101}$	0.18	5.58	17.84	0.91	0.24	-1.35	1.36
26. Work separation (miles)	37	$\sqrt{-x + 101}$	0.40	4.89	12.82	4.02	-4.40	-3.66	-3.23
27. Home separation (miles)	20	$\sqrt{-x + 134}$	0.40	7.47	21.07	3.91	3.75	-5.16	3.35
28. Copooler >50	37	x	0.32	145.45	59.17	-149.22	7.85	2.94	131.94
29. Diversion (miles)	58	$\sqrt{-x + 1}$	0.17	7.97	14.18	1.43	-1.96	0.30	1.43
30. Partner is not the first	55	x	0.34	150.09	-155.83	56.14	-61.91	122.43	-84.61

[a]Transformation converts observed distribution of utilities to approximate normal shape.

6. Driving license held;
7. Professional worker;
8. Male;
9. Two licensed drivers in household;
10. Two nonlicensed members in household;
11. Work hours are 8:00 a.m.-5:00 p.m.; and
12. Household has a telephone.

With these characteristics, his likelihood of making each of the seven types of applications is achieved by substituting in Equation 7 the elements from the following rows of Table 1: 0,1 (length = 8.09), 2, 6, 12, 13, 15, 17 (number = 2), 18 (number = 2), and 21. The other rows are not applicable to this individual. Thus, the probability (P_1) of applying to pool will be

$$P_1 = \exp(x)/1 + \exp(x) \quad (8)$$

where, by using the first column of Table 1 (for carpoolers),

$$x = -3.53 + (0.16 \times 8.0) + 0.48 - 0.36 + 0.21 - 0.74 - (0.02 \times 2) - (0.44 \times 2) + 1.35 = -2.216.$$

Therefore $P_1 = 0.098$.

For the other six applications, the P values will be 0.07, 0.037, 0.000 05, 0.028, 0.005, and 0.0002, respectively. Seven random numbers between 0 and 1 are then chosen. In this example they are 0.03, 0.84, 0.62, 0.85, 0.08, 0.46, and 0.19. The seven P values are then compared with these seven random numbers to estimate the likelihood of an individual's applying. Only for the application of type 1 (pooling) does the P value exceed the random number and, therefore, the individual is deemed to apply for pooling but for nothing else.

Modeling the Matching of Applicants

This submodel is a direct representation of the matching process that is fundamental to organized car-sharing schemes. As such, it accepts a file of applicants and, as far as is possible, produces for each applicant a list of people whose journey-to-work characteristics and expressed interest in car sharing make them feasible traveling companions. Within the simulation suite the submodel will therefore consider all those individuals deemed to have applied in the preceding model and will attempt to find potential traveling companions for each of them from among their fellow applicants. The matching programs used in this project are similar to ones used in real schemes. They are described in more detail elsewhere (14).

Modeling the Acceptance of Matches

This part of the simulation suite is the most ambitious and is closest to the ideal of microsimulation. It represents the consideration,

Manual	Professional	Distance (km)	Previously an Accompanied Driver	Previously Nondriver	More Licenses Than Cars in Household	One-Way Journey
-0.89	-0.97	0.3	NA	0.47	0.20	-0.72
-0.27	-0.25	0.1	NA	-0.81	-0.75	-0.25
-0.26	-0.08	0.0	NA	0.14	0.20	0.09
-0.56	-0.09	0.0	NA	0.91	0.09	0.03
-0.45	0.17	0.0	NA	0.49	-0.23	-0.41
-4.40	-3.33	0.2	NA	1.51	2.11	-0.93
-2.33	-1.81	0.1	NA	1.90	0.66	-0.28
-0.41	-1.24	0.0	NA	-0.69	0.70	-0.18
3.74	0.67	-0.2	-1.77	2.47	-1.02	-0.57
0.23	0.66	-0.0	-0.17	0.09	0.11	0.07
0.72	0.53	-0.0	-0.78	1.28	0.22	0.54
0.84	0.58	-0.0	-1.09	2.43	-0.55	0.05
-1.80	0.99	0.1	-0.90	-1.02	0.21	-0.49
-3.56	-4.25	-0.2	0.94	-0.77	0.73	2.14
2.69	1.65	-0.1	-2.72	-1.14	-2.09	-0.28
0.74	-0.29	0.1	-0.52	0.38	0.33	0.16
0.54	0.50	-0.1	0.00	1.18	-0.82	0.51
-5.92	3.31	4.4	-23.04	-118.86	-2.62	-24.37
-0.17	-0.25	0.3	0.89	-0.08	-2.35	NA
-1.00	8.71	-0.2	2.93	6.95	1.29	NA
16.94	-11.75	0.4	39.07	4.84	28.95	NA
-7.22	-25.92	-0.0	-11.48	-53.94	31.45	NA
-5.22	5.64	-0.9	-10.57	-2.24	6.04	NA
-1.82	0.27	-0.1	-0.77	-0.87	-1.22	NA
-2.18	1.00	-0.2	-3.54	-4.59	-0.18	NA
6.95	2.23	0.0	0.38	-2.49	1.01	NA
-4.96	-0.45	-0.3	0.20	-1.13	-3.89	NA
-83.77	72.17	-8.3	-38.05	-12.63	-27.69	NA
-2.90	-1.08	-0.3	0.01	4.81	1.86	NA
13.29	6.19	-8.6	76.06	84.33	34.41	NA

by each applicant, of the list of potential traveling companions sent by the organizers of car-sharing schemes. This consideration is assumed to involve an evaluation by the applicant of the net expected utility associated with each possible arrangement presented by the individual's list of potential partners. This evaluation is made on the basis of the known and expected characteristics of the arrangement postulated. If an arrangement has a positive net expected utility to all participants within it and has a higher utility than any other arrangement to at least one of them, then it is deemed a successful car-sharing arrangement. All participants in that arrangement are then withdrawn from the system.

The model is thus based on utility maximization subject to a satisficing constraint. The utility to a given person (P) of a given arrangement (A) is a function of the personal characteristics of the person P, of the personal characteristics of his or her partners in arrangement A, and of the operational consequences of the arrangement (e.g., delays or diversions) on the participants. These utilities can be represented as

$$U_{AP} = \sum_{n=1}^{N} \sum_{m=1}^{M} a_n p_m x_{nm} + e_{nP} + \text{fee paid} \qquad (9)$$

where

U_{AP} = utility of the arrangement A to person P;

$a_1 \ldots a_n$ = attributes of the arrangement A, including a description of the would-be partners and the consequences that the arrangement would have for the respondent;

$x_{11} \ldots x_{nm}$ = components of utility associated with any person who has characteristic m engaging in an arrangement that has attributes n;

$e_i \ldots e_{nP}$ = stochastic elements associated with the utility to person P of an arrangement that has attributes n; and

fee paid = the net sum of money, if any, that passes to this person in respect of participation in the scheme.

The calibration of the components x was on the basis of data from the special field survey (2). Within the survey, respondents were asked to put values on arrangements that have given attributes. By comparing a respondent's evaluation of arrangements with differing attributes, utilities could then be imputed to each attribute. The distributions of utilities assigned by the various respondents were analyzed by using regression techniques to relate them to the characteristics of the respondents. Since may of these distributions were very skewed, they were transformed prior to the regression in order to bring them closer to a normal distribution.

The residual term from the regression was used in the model to impart a stochastic element (e_{nP} in Equation 9) to the individual decisions. This was done by random sampling from a normal distribution with mean zero and standard deviation equal to the standard error of the residual.

Table 2 contains the resulting regression coefficients and residuals. The mechanisms by which the microsimulation model uses these coefficients may be appreciated if the same individual as in the example above is considered.

Given this individual's characteristics, it can be seen that, in considering the utility to him of a pooling arrangement, a linear combination is required of the values of the constant, professional, and distance columns of Table 2 (length = 8.09) and whether the household has more drivers' licenses than cars. These combinations are then supplemented by the stochastic element obtained by multiplying each residual by a standard unit normal random number. This process is completed by retransformation of the resulting values. Values are required for the pooling rows from Table 2. They are as follows: 477, 24, -16.81, 0, -13.1, -138, -59, -219, 152, -41, and -284 (the derivation of these values from the coefficients given in Table 2 is tedious to follow; space restrictions have precluded inclusion of the workings in this paper). Having derived these values for the individual in this example, the model then uses them as determined by the characteristics of the carpooling arrangements he is to consider. Thus, for example, suppose he is to consider pooling with a female who causes him, when he is the passenger, to set out 1 min early and to arrive home 2 min late and, when he is the driver, to set out 5 min early and to arrive home 5 min late. Suppose also that the proposed partner has a household telephone, works at the same place as he does but lives 1.6 km away from him, is less than 50 years of age, and will cause him to drive 1.6 km out of his way each day in order to pick her up. The utility would be 477 + 24 - (16.81 x 1) + (0 x 2) - (25.86 x 5) - (13.1 x 5) - (219 x 1) - (41 x 1) = 23.39 p/week (US $0.53).

If the woman in question also puts a positive value on the arrangement, and if this arrangement appears to our individual to be the best on his list, then the arrangement is deemed made. Note that if the woman had had no telephone at home then the utility of the arrangement would have been reduced by 138 p/week (US $3.10) and, since the net value of the arrangement would have been negative (-108.61), it is assumed that it would not come into operation.

If the utility of an arrangement to give lifts (as opposed to alternating driving) had been under consideration, then any deficit in the individual's utility might have been made up from a surplus utility that accrued to his potential passenger. This transfer of utility might be by means of cash (a fare paid) or through some other medium (e.g., periodic gifts). The model will calculate the magnitude of any such transfers of utility and will assume that they take place. However, it does not have to consider how they would be effected.

In early runs of the model, a small minority of individuals in the system seemed to behave in a peculiar manner (for example, by showing an eagerness to get up very early in the morning or to make considerable detours in order to give someone a lift to work). (One of the strengths of microsimulation is that such strange behavior is readily detectable rather than being lost in a formula that represents aggregate behavior.) Apparently, some of the utility formulations were given counterintuitive values for certain match attributes, but subsequent investigation of this phenomenon showed this to be due primarily to the occasional addition of an unusually large stochastic element. Sometimes, however, this behavior was due to the coincidence of a set of attributes and characteristics each of which, when taken separately, militate against a strongly intuitive valuation. For example, if young people, manual workers, and women tend to dislike getting up early in the morning less strongly than do other people, then young female manual workers might be predicted

Table 3. Comparison of observed applicants with simulation model predictions.

Category	Observed	Prediction[a] Average	SD (σ_n)
Applicants for carpooling			
Number	129	126.9	6.98
Number as a percentage of theoretical total[b]	5.8	5.74	0.32
Length of journey to work (km)	8.49	8.88	0.50
Percentage previously public transport users	6.2	7.00	2.61
Percentage previously solo drivers	61.2	59.20	5.23
Percentage previously accompanied drivers	27.9	25.33	3.00
Percentage female	20.2	19.18	4.17
Percentage having a home telephone	90.7	86.54	2.65
Percentage professional workers	45.7	44.83	3.60
Percentage <30 years of age	28.7	28.70	3.93
Applicants to give lifts			
Number	162	168.1	11.07
Number as a percentage of theoretical total[b]	5.28	5.48	0.36
Percentage offering morning and evening lifts	69.1	68.70	4.21
Percentage offering morning lifts only	30.9	33.57	3.89
Mean length of journey to work (km)	8.23	8.41	0.20
Percentage previously public transport users	1.9	2.02	0.94
Percentage previously solo drivers	70.4	65.23	2.69
Percentage previously accompanied drivers	25.3	25.35	2.45
Percentage female	22.2	23.20	2.75
Percentage having a home telephone	84.6	79.33	2.98
Percentage professional workers	54.9	50.49	4.01
Percentage <30 years of age	29.0	27.99	2.80
Applicants to receive lifts			
Number	184	173.9	26.94
Number as a percentage of theoretical total[b]	3.9	3.87	0.85
Percentage wanting morning and evening lifts	77.2	73.82	2.79
Percentage wanting morning lifts only	20.1	21.83	3.53
Mean length of journey to work (km)	6.45	6.43	0.45
Percentage previously public transport users	60.3	65.07	3.64
Percentage previously solo drivers	13.0	16.52	2.74
Percentage previously car passengers	17.4	6.56	1.77
Percentage female	53.8	53.03	1.46
Percentage having a home telephone	72.3	69.72	2.70
Percentage professional workers	26.6	27.33	2.60
Percentage <30 years of age	39.7	36.17	3.97
Percentage having no household car	53.8	52.92	3.00
Percentage having no driving license	60.9	63.06	3.46

[a] Due to the stochastic element in the simulation model it was decided to run the model 10 times and to present here the mean value and its standard deviation.
[b] The theoretical total number of applications assumes one application from each eligible member of the population (i.e., after taking account of items such as license tenure, car availability, and work hours). These theoretical totals are 2212 for pooling, 3067 for lift giving, and 4703 for receiving lifts.

to actually enjoy getting up early in the morning. After several solutions to this problem were considered (14), it was decided to impose a constraint that any valuation that was clearly counterintuitive should be set to zero.

Performance of the Microsimulation Model

In order to test the first stage of the microsimulation suite, the model was run by using the calibrated coefficients and acting on a synthesized population that represents the sample subjected to the car-sharing survey.

Table 3 shows a comparison of the applicants predicted by this model with applicants observed in the field survey. Clearly, the simulation model has reproduced the observed applicants with a fair degree of accuracy. The only discrepancy of any significance is a 10 percent underprediction (6.56 percent instead of 7.4 percent) of the proportion of requesters who previously traveled as car passengers, but this will result in an extremely marginal overprediction of the net effectiveness of a car-sharing scheme. When the model is run several times with different sets of random numbers, the standard deviations of the model predictions are generally low. This indicates that, overall, the model is not highly sensitive to changes in the stochastic element.

Investigation of the performance of the matching routines and the decision-to-match model are best carried out in the context of a full run of the model. For this purpose a possible car-sharing scheme was defined based on the central business district (CBD) of Leeds (an area somewhat less than 1 km^2 that has a workforce of 21 000). The results of running the model for this scheme are presented in Table 4. Full discussion and analysis of these predictions is included in a companion report (3). For the purposes of this paper, it suffices to say that the predictions are well in line with empirical observations of organized car-sharing schemes in Britain [see, for example, Bonsall (15)] and the United States (16).

Table 4. Summary of the results of a full run of the microsimulation suite on the Leeds CBD.

Category	Value
Target population	
Number of eligible work trippers	21 235
Modal split as a percentage of public transport	47.83
Peak-period work-trip vehicle use (km/week)	453 896
Peak-period work-trip public transport use (passenger-km/week)	600 750
Work-trip parking space requirement (spaces/day)	6981
Applicants	
Number	1688
Percentage of target population	8.0
Percentage that are for true pooling	30
Percentage that are for lift giving	32
Percentage that are for lift receiving	38
Percentage that previously drove solo	40.4
Percentage that previously used public transport	35.07
Matching system	
Number of persons for whom a match list was created	1586
Percentage of total applicants	94
Arrangements actually formed[a]	
Number of participants	327
Participants as a percentage of applicants	19
Participants as a percentage of target population	1.5
Percentage of participants engaged in true carpooling	15
Percentage of participants previously solo drivers	37
Percentage of participants previously public transport users	41
System effects[a]	
Net reduction in peak-period work-trip vehicle use (km/week)	1423
Percentage of before situation	0.31
Net reduction in peak-period work-trip public transport use (passenger-km/week)	10 708
Percentage of before situation	1.78
Net reduction in car-park space requirement (spaces/day)	24
Percentage of before situation	0.34

[a] These values are averages derived from 12 separate runs of the model (the stochastic elements in the choice process being the source of variation between runs). Confidence limits for these predictions are included in the background working paper (14).

The computational costs of the microsimulation (at notional commercial rates set by the University of Leeds) are approximately £4 (US $9.00) each time that a new scheme location or intensity is to be tested plus 1 p/applicant (US $0.02) each time that new match lists are to be created and 6 p/applicant (US $0.14) each time that matching decisions are to be made. These costs are clearly very reasonable.

CRITIQUE OF THE SYNTHESIS MODELS

With the wisdom of hindsight, it is possible to point to a number of shortcomings in the synthesis models and to suggest how they might be remedied. These points are discussed in some depth in the background working paper (13), but it is appropriate to summarize them here:

1. Isolation of significant variables in the synthesis process should perhaps have involved analysis of variance in addition to inspection and intuition, and
2. When synthesizing the characteristics of the journey to work, a serious problem, and one that would benefit from a substantial research effort, is the difference between behavior observed on a

particular day (i.e., the usual household interview snapshot) and habitual behavior. In our synthesis we have had to use the former as if it were the latter.

CRITIQUE OF THE MICROSIMUATION MODELS

I will here summarize recommendations discussed more fully in a background paper (14).

1. It must be admitted that the amount of data obtained from the calibration surveys is less than I would have wished and that this has put severe strain on the calibration procedures. This deficiency is, however, one of judgment rather than methodology: The survey cost less than £2400 (US $5500) to mount and, in retrospect, the volume of data could have been increased substantially at little extra cost.
2. The model was designed to simulate organized car-sharing schemes, but it has since become apparent (16) that increasing ad hoc car sharing can be just as important an element in a car-sharing promotional strategy. It would have been wise to have pressed for an extension of the original project brief in order that the model framework could have been extended to deal with ad hoc car sharing (this would clearly have involved a major change in the survey technique).
3. The model predicts the initial acceptability and establishment of car-sharing arrangements; more research is required to study their long-term survival.
4. More rigorous sensitivity analysis of the decision algorithm in the decision to match is required.
5. An attempt should have been made to obtain more data in order that additional important variables (e.g., smoking habits) could have been included in the model.

CONCLUSION

Even with the deficiencies noted above, I believe that the microsimulation model presented in this report is the best model yet developed for the prediction of the performance of organized car-sharing schemes and that its methodology also represents a contribution to the development of improved travel demand models. In particular

1. The synthesis of a realistic population base to provide actors for a microsimulation model has proved possible and tolerably efficient.
2. The model predictions, briefly presented in Table 4 but discussed elsewhere (3), suggest that the model accords well with empirical evidence of the performance of organized car-sharing schemes.
3. The unconventional calibration base (from the field-simulation survey) has proved to be a very useful device.
4. The fact that the model deals with individual decision makers rather than populations has allowed the predictions to be closely scrutinized and verified in a manner that is impossible with conventional models.
5. In short, a microsimulation model calibrated on stated-intention data has proved an attractive device that can be at once behaviorally based and yet computationally tractable. One of its particular attractions is its treatment of system constraints (in this case the compatibility of potential carpool partners). It is this treatment of constraints, rather than any sophistication in the decision models, that is responsible for the close correspondence between model predictions and empirical evidence.

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Estimating Behavioral Response to Peak-Period Pricing

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The concept of applying peak-period pricing policies to highways and other urban transportation facilities has been proposed as one means of reducing rush-hour congestion and compensating for the social costs of travel. This research was designed to assess the potential impacts of rush-hour pricing on the six toll bridges and tunnels between New York City and New Jersey that are operated by the Port Authority of New York and New Jersey. Elasticity coefficients were computed by using data obtained from 943 respondents to detailed telephone attitude surveys. Peak-period crossing patrons, categorized by market segment, were asked to give their likely behavioral responses to off-peak discounts or peak-period surcharges. Several options were identified, including ridesharing, transit, and time-of-day shift. Approximately 16 percent of all passenger-car motorists would change travel time to avoid a $1.00 toll surcharge, but less than 20 percent of these would be willing to shift time by more than one hour. Work trips were found to be less sensitive to toll changes than were nonwork trips, and a substantial cost disincentive was found to be somewhat more effective in removing vehicles than was an off-peak incentive. To avoid higher toll charges, the average motorist would react in the following order of preference: (a) switch to another crossing, (b) switch time of travel, (c) switch to transit, (d) travel less often or not at all, and (e) join a carpool.

This paper summarizes the results of a behavioral research study conducted in 1978 to determine the feasibility and impacts of adjusting toll rates during peak periods (1,2). Elasticity and cross-elasticity coefficients are developed from a detailed telephone attitude survey of motorists by using the six Port Authority vehicular crossings between New York and New Jersey for (a) peak-period toll surcharges, (b) off-peak-period toll discounts, and (c) differential tolls between vehicular crossings.

The Port Authority of New York and New Jersey operates six vehicular crossings between New York and New Jersey. These facilities include three crossings of the Hudson River into Manhattan [the George Washington Bridge (I-95), the Lincoln Tunnel (I-495), and the Holland Tunnel (I-78)] and three bridges between Staten Island and New Jersey. Together, the six facilities accommodate approximately 400 000 automobiles and 50 000 trucks and buses daily.

The eastbound traffic pattern at each crossing is similar and differs only in magnitude. Traffic starts to build up about 6:30 a.m., reaches a peak between 8:00 and 9:00 a.m., and then reduces to midday levels. At the three Hudson River crossings, demand exceeds capacity, which results in queues by 7:00 a.m. that may persist beyond 10:00 a.m. A similar pattern exists during the evening peak period.

In May 1975, the passenger-car cash toll, collected in only one direction on all six vehicular crossings, was raised from $1.00 to $1.50, and various changes were introduced relative to the reduced-rate ticket books. On November 7, 1977, the Federal Highway Administration affirmed a previous ruling that the revised toll structure was acceptable pending recommendations of a further Port Authority study. These investigations were to include an evaluation of the economic feasibility, traffic management and environmental effects, and impact on mass transit of various alternative rate structures of commuter and carpool discounts and of peak-period pricing.

PEAK-PERIOD PRICING

The concept of applying peak-period pricing policies to highways and other urban transportation facilities has been suggested as one means of reducing rush-hour congestion and compensating for the social costs of travel.

Peak-period pricing assumes that, as more vehicles use a roadway system during a given period, each additional vehicle will interfere with the free flow of others in the stream, which will cause them to reduce speed and lead to congestion. As additional vehicles try to enter the system, they further congest the total flow and impose additional costs and loss of time on vehicles that are already in the system. The total additional delay and discomfort forced on all vehicles generally exceeds the delay and discomfort to those marginal vehicles that enter a system that is approaching capacity.

In economic terms, drivers who enter a congested traffic stream do not realize the total cost to society generated by their trips because they pay only the average cost of the trip. If these drivers actually paid the true cost, each would face an economic decision as to whether or not to make the trip at that time. A driver who values traveling during a peak period sufficiently would theoretically pay for these additional costs through a surcharge or, in the case of this study, a higher toll during the congested periods. A driver who did not so value his or her travel would change travel time or mode. In theory, the surcharge or toll should vary directly in proportion to the degree of congestion.

Although there have been several instances of peak-period pricing in the transit industry, experience in highway applications is limited. The most notable example is the Singapore traffic-restraint scheme, which requires special payment to legally operate vehicles in the designated central zone during peak periods (3). This lack of precedents made it necessary to derive elasticity

coefficients for specific application in the New York area.

STUDY DESIGN AND APPROACH

Key steps in the overall study design include market segmentation, roadside and telephone surveys, analysis of results, and development of elasticity coefficients.

The population of cross-river automobile drivers includes a number of diverse groups that could differ in their responsiveness to peak-period tolls. Accordingly, six market segments were defined to facilitate a meaningful, yet manageable, level of analysis. The market was stratified by trip purpose (work, company business, or other) and location of activity [Manhattan central business district (CBD), which is defined as Manhattan Island south of 59th Street; New York non-CBD; or New Jersey].

Market Segment	Trip Purpose	Destination
A	Work	Manhattan CBD
B	Work	East of crossing (NY) except Manhattan CBD
C	Work	West of crossing (NJ)
D	Company business	Any
E	Other	Manhattan CBD
F	Other	East or west of crossing except Manhattan CBD

A two-phase survey approach was employed. A direct roadside survey at all six crossings identified a pool of candidate respondents for subsequent in-depth telephone interviews by market segment.

Initial Contact Survey

Automobile drivers were intercepted at toll plazas. Information was obtained on trip purpose, trip frequency, category of toll payment (cash or discount plans), and whether the trip began or ended in the Manhattan CBD. The vehicle occupancy and the registration number were also noted.

A total of 21 278 roadside interviews were obtained--13 014 during peak periods. Of these, approximately 8000 interviews were selected at random, distributed proportionally among market segments and split between New York and New Jersey. More than 5500 were successfully matched with motor vehicle registration data. After leased or company cars and unlisted telephone numbers were eliminated, 2471 candidates were identified for detailed interviews.

Telephone Attitude Surveys

Three study scenarios related to toll changes were tested by telephone interviews. The telephone survey questionnaire was developed to eliminate potential respondent bias, including pretesting among residents of the metropolitan New York area.

Some 943 telephone interviews were successfully completed, which represents approximately 38 percent of the available listed telephone numbers. The highest sample was obtained relative to the Manhattan CBD and New Jersey work trips (market segments A and C), and the response error terms were generally less than 10 percent based on a 95 percent confidence level.

Attitude Versus Behavior

A major shortcoming of attitudinal surveys is the frequent disparity between an individual's expressed attitude and the actual act that follows. A variety of factors may intervene, including difficulties with the accurate perception of real costs and the practical problems of actually changing travel habits.

A growing amount of literature deals with response validity and, in particular, the relationship between intended and actual behavior (4,5). Although the absolute level of response varies, the relative positions of the different population groups appear valid.

Accordingly, actual transportation-related experience in the New York area was used as a guide in discounting motorists' response. A special before-and-after survey that evaluated responses to a 1975 increase in subway prices in New York City indicated that only about 40 percent of those who claimed that they would switch travel modes actually did (6).

In recognition of this disparity between attitude and behavior, a response deflation factor of 0.5 was applied to those survey answers that indicated avoidance of the initial increment of toll surcharge. The actual response differential between toll surcharge increments was retained, again due to the theory that the relative distribution of response is accurate. All response values reported herein reflect this deflation factor.

SURVEY RESPONSE

Motorist attitudes, as reflected in the survey response to each of three scenarios, are summarized below.

Scenario 1--Off-Peak Discounts

This scenario assumes that tolls would be reduced by \$0.50 and \$1.00 during the off-peak period. The estimated behavioral responses (adjusted to reflect the difference between attitude and behavior) are shown in Table 1. Approximately 15 percent of all motorists who fall within the market segments defined could be expected to change their travel times to take advantage of a \$0.50 toll discount during off-peak periods. If the discount were raised to \$1.00, about 19 percent would shift.

As might be expected, the market segments associated with the journey to work (A, B, and C) were found to be somewhat less flexible and shifts of 11 and 14 percent, respectively, were expected. The highest potentials for time shifts were found for nonwork trips--about 25 and 30 percent for market segments E and F, respectively. This is logical because these categories deal with travel that is more discretionary and flexible in nature.

Scenario 2--Peak-Period Surcharge

This scenario assumes that tolls would be increased during peak periods by surcharges of \$1.00, \$3.00, and \$5.00. The estimated behavioral responses are summarized in Table 2 and detailed in Table 3. Some 27 percent of the motorists interviewed would make some change in travel habits with a \$1.00 toll increase; corresponding figures were 41 and 53 percent for \$3.00 and \$5.00 toll surcharges. With a \$1.00 surcharge, almost 66 percent would change travel time, 4 percent would form carpools, 4 percent would divert to transit, and about 1 percent would not make the trip at all.

Diversion to public transit becomes much more significant at the \$3.00 and \$5.00 surcharge increments. Little increase in time-of-day shifts was reported. This suggests that drivers who can

Table 1. Estimated behavioral response to off-peak period discount—scenario 1.

Market Segment	No Change in Driving Habits (%)		Change Time of Day to Begin Trip (%)	
	Discount		Discount	
	$0.50	$1.00	$0.50	$1.00
A	89	88	11	12
B	88	85	12	15
C	88	85	12	15
D	84	74	16	26
E	75	69	25	31
F	74	72	26	28
All	85	81	15	19
Work only	89	86	11	14

Table 2. Estimated behavioral response to peak-period toll increases—scenario 2, all crossings.

Response	Patrons from Market Segments A-F (%)			Patrons from Market Segments A, B, and C (%)		
	Increase			Increase		
	$1	$3	$5	$1	$3	$5
Make no changes in driving habits	73	59	47	77	61	47
Changes						
Join or start carpool	4	4	5	4	4	5
Begin taking public transit	4	14	18	4	14	20
Change time of day when trip begins	16	15	15	11	13	14
Would not make trip as often	2	2	3	2	2	1
Would not make trip at all	1	6	12	2	6	13
Total	27	41	53	23	39	53
Net change in peak-period vehicle trips—assumption 1[a]	24	38	49	20	36	50
Net change in peak-period vehicle trips—assumption 2[a]	13	28	44	12	28	12
Net change in daily vehicle trips—assumption 3[a]	3	9	14	4	9	14

Note: Assumption 1 = peak period is short enough to accommodate all drivers who wish to shift (i.e., all time-of-day shifts would be to the off-peak period; assumption 2 = about one-third of time-of-day shifts would be to the off-peak period; assumption 3 = peak periods account for about 40 percent of total daily traffic in each market segment.
[a]Percentages reflect a 0.5 discount factor applied to the response of motorists who indicated they would carpool or would not make trips as often.

conveniently alter the time of trip making would do so at the $1.00 surcharge. As the penalty increases, transit becomes a more feasible alternative for those who must continue to travel during peak periods.

This is particularly true for work trips oriented to the CBD (market segment A) where bus and rail services provide good access to transit. A $1.00 surcharge would result in a 7 percent shift to transit, and approximately 23 and 27 percent would shift to transit for $3.00 and $5.00 surcharges, respectively. A somewhat similar pattern is indicated for nonwork trips to the CBD, market segment E.

Carpooling produced a steady response of about four to six percent for the various toll surcharges. This suggests that motorists who could readily carpool would do so to avoid even a $1.00 surcharge. Little or no additional ridesharing was induced by incremental pricing penalties.

The estimated net changes in vehicle trips (shown in Tables 2 and 3) were computed by assuming that those who would not make the trip as often would cut their trip making in half and that one vehicle trip would be eliminated for each carpool formed. A reduction of about 24 percent in peak-period vehicle trips would result, in theory, from a $1.00 surcharge if the critical period were limited to 1 h. Because most of the vehicular loss would result from a shift in time of day, the net reduction in daily eastbound vehicle trips within the six market segments identified would be only 3 percent.

Motorists who indicated a preference for changing the time of day when their trips begin were asked about the maximum shift in time they would be willing to make. Most drivers would be willing to change their arrival and departure time by as much as 1 h to avoid a $1.00 increase; only 20 percent would change by more than 1 h. This finding is important because it implies that reaction to peak-period pricing would be relatively small where the peak extends over several hours.

Because the peak period extends for up to 3 h at most New York-New Jersey river crossings, the actual reductions in peak-period travel would be considerably less--about 10-15 percent for a $1.00 surcharge.

Scenario 3--Peak-Period Surcharge on Specific Crossings

This scenario assumes that the peak-period toll surcharges of $1.00, $3.00, and $5.00 would be applied only at the survey respondents' crossing. Motorists were asked what course of action they would take if rush-hour tolls were raised only on the crossing they used but not on the adjacent facilities. The estimated behavioral responses are shown in Table 4.

Given the option to change routes, a slightly higher percentage of all motorists would make some change in driving habits. Specifically, assuming a $1.00 surcharge, 30 percent of the drivers would switch, as compared with 24 percent under scenario 2.

Almost half of those who change would switch routes to another bridge or tunnel. Eight percent would change the time of travel, compared with 16 percent if the penalty were imposed on all crossings. Diversion to carpools and transit would be lower.

Respondents who would change routes were asked how much extra driving time they would be willing to add to their trips to use the alternate crossing. Under the $1.00 increment, 49 percent claimed they would be willing to add 15 min to the trip, and an additional 20 percent said they would increase travel time by 30 min; the overall weighted average was 19.4 min.

ELASTICITY COEFFICIENTS

Elasticity coefficients (E) in the form of shrinkage factors were computed from the survey data, based on the following relationship:

$$E = \%\Delta Q / \%\Delta P \quad (1)$$

where $\%\Delta Q$ = estimated percentage change in vehicle trips as reported in the survey and $\%\Delta P$ = percentage change in price or trip cost.

Table 3. Detailed behavioral response to peak-period toll increases—scenario 2, all crossings.

	Market Segment A (%)			Market Segment B (%)			Market Segment C (%)			Market Segment D (%)			Market Segment E (%)			Market Segment F (%)		
	Increase			Increase			Increase			Increase			Increase			Increase		
Responses	$1	$3	$5	$1	$3	$5	$1	$3	$5	$1	$3	$5	$1	$3	$5	$1	$3	$5
Make no changes in driving habits	77	54	42	78	64	51	77	66	49	73	59	54	62	49	49	63	59	43
Changes																		
Join or start carpool	4	4	5	4	4	4	5	5	6	1	2	2	2	4	4	4	6	6
Begin taking public transit	7	23	29	3	11	16	2	8	13	3	14	14	7	18	19	4	10	14
Change time of day when trip begins	9	12	12	12	14	16	13	13	13	21	21	21	27	22	17	26	14	14
Would not make trip as often	2	2	2	1	1	1	1	1	1	1	1	1	1	1	2	3	8	10
Would not make trip at all	1	5	10	2	6	12	2	7	18	1	3	8	1	6	9	-	3	13
Total	23	46	58	22	36	49	23	34	51	27	41	46	38	51	51	37	41	57
Net change in peak-period vehicle trips[a]	20	43	54	20	34	47	20	31	48	26	39	44	37	48	48	34	34	45
Net change in daily vehicle trips[a,b]	4	12	17	3	8	12	3	7	14	2	7	9	4	10	12	3	8	12

[a]Percentages reflect a 0.5 discount factor applied to the response of motorists who indicated they would carpool or would not make trips as often. It is assumed that all time-of-day shifts would be to the off-peak period.
[b]Assumes in addition that peak periods account for approximately 40 percent of total daily traffic in each market segment.

Table 4. Estimated behavioral response to peak-period toll increases—scenario 3, individual crossings.

	Patrons from Market Segments A-F (%)			Patrons from Market Segments A, B, and C (%)		
	Increase			Increase		
Responses	$1	$3	$5	$1	$3	$5
Make no changes in driving habits	69	55	46	71	56	46
Changes						
Join or start carpool	2	3	3	2	3	4
Begin taking public transit	3	7	10	2	8	12
Change route to another bridge or tunnel	16	22	24	15	22	24
Change time of day when trip begins	8	9	10	8	7	7
Would not make trip as often	1	1	2	1	1	2
Would not make trip at all	1	3	5	1	3	5
Total	31	45	54	29	44	54
Net change in peak-period vehicle trips—assumption 1[a]	30	43	51	28	42	51
Net change in peak-period vehicle trips for specific crossing assumption 2[a]	28	37	44	22	40	46
Net change in daily vehicle trips—assumption 3[a]	2	5	7	2	5	8

Note: Assumption 1 = peak period is short enough to accommodate all drivers who wish to shift (i.e., all time-of-day shifts would be to the off-peak period; assumption 2 = about one-third of time-of-day shifts would be to the off-peak period; assumption 3 = peak periods account for about 40 percent of total daily traffic in each market segment.
[a]Percentages reflect a 0.5 discount factor applied to the response of motorists who indicated they would carpool or would not make trips as often.

Table 5. Summary of elasticity coefficients.

			Basis of Computation	
Change	Scenario	Market Segments	Total Trip Cost[a]	Toll Cost[b]
Net peak-hour traffic change	1	A-F	-1.23	-0.24
		A,B, and C	-0.81	-0.17
		E and F	-2.18	-0.37
	2	A-F	-1.55	-0.30
		A,B, and C	-1.16	-0.25
		E and F	-2.63	-0.44
	3	A-F	-1.94	-0.37
		A,B, and C	-1.62	-0.35
		E and F	-2.74	-0.47
Time-of-day shift only	2	A-F	-1.04	-0.20
		A,B, and C	-0.64	-0.14
		E and F	-1.96	-0.33
Diversion to transit cross-elasticity	2	A-F	+0.26	+0.05
		A,B, and C	+0.23	+0.05
		E and F	+0.41	+0.08

Note: Elasticities for scenario 1 based on $1.00 discount during off-peak period; scenarios 2 and 3 are based on $1.00 surcharge.
[a]Total costs for all markets = $6.47, work markets = $5.80, and nonwork markets = $7.40.
[b]Toll paid on Port Authority crossing only estimated at $1.25.

Two separate percentage changes in price were used to compute elasticities. These were the toll increase as (a) a percentage of the total trip cost and (b) a percentage of the Port Authority facility toll cost only. Results are presented in Table 5 for a $1.00 discount in scenario 1 and a $1.00 surcharge in scenarios 2 and 3. (Arc elasticities would be somewhat less than these shrinkage factors.)

The elasticity coefficients get larger as one proceeds from scenario 1 to 3. This is a logical outcome, since the elasticity coefficient should increase when a larger number of substitute actions are available to the users. That is exactly what occurs in the progression from scenario 1 to 3. In a similar context, the time-of-day coefficents are smaller than the coefficients for total peak-hour

changes, since only those who would switch time of day were included in the %ΔQ.

Trip Costs

The questionnaire included references to various components of trip cost, including expenses related to parking tolls, gasoline, and other items. The average trip cost varied between market segments from $4.71 for non-CBD work trips destined east of the crossing to $8.01 for nonwork or business destined for the CBD.

Large differentials in the estimated cost of parking were responsible for most variations among market segments. The base trip costs developed were $6.47 for all markets, $5.80 for the work markets (A, B, and C), and $7.40 for the nonwork markets (E and F).

Toll Costs

The cash toll for passenger cars is $1.50. When the discount tickets are considered, the average toll is approximately $1.25.

Net Peak-Hour Traffic Change

The first group of elasticity values in Table 5 shows the net decrease in peak-period traffic that results from various toll surcharges if the peak were limited in duration to accommodate all the time-of-day shifters.

Scenario 1

The lowest impacts would result from reducing tolls during off-peak hours. Elasticities for all market segments are estimated at -1.23 for total trip costs and -0.24 computed on the basis of toll charge alone. Again, work trips are considerably less elastic than nonwork trips.

Scenario 2

A $1.00 toll surcharge during peak periods would have a higher impact than an off-peak discount, which suggests that a substantial pricing disincentive is somewhat more significant than an incentive, at least as perceived by the telephone respondents. Elasticities for market segments are estimated at -1.55 for all trip segments and -0.30 for toll costs alone.

Scenario 3

Given the additional option of changing routes, the estimated elasticity coefficients for scenario 3 appear higher than those under scenario 2. The trip cost elasticity for all market segments combined was estimated at -1.94, and the toll elasticity was computed at -0.37.

Time-of-Day Shift

Elasticity coefficients for the shift in time of day were calculated by using the response percentage only for all drivers who said that they would switch time of day. This implies that the peak toll surcharge period would accommodate those who would shift a maximum of 30 min. The cost elasticity for all market segments is estimated at -1.03, with the associated toll elasticity computed at -0.20 for scenario 2. The coefficients shown under scenario 3 are somewhat less, because a higher proportion of diverted drivers would change routes rather than the time of the trip.

Transit Cross-Elasticities

The cross-elasticities to transit (i.e., the percentage change in automobile users who would switch to transit as a result of a 1 percent change in the price of tolls) or total trip costs are also shown in Table 5. These cross-elasticities are low relative to those for reductions in peak-hour traffic or time-of-day shifts. They suggest a very small impact of tolls on transit ridership--perhaps because transit already dominates the CBD journey-to-work market. Even though good transit accessibility is provided for many trips, the transit impact of rush-hour pricing policies would be minimal.

Comparison with Previous Elasticity Findings

To provide a basis for comparison with past experience, estimated behavioral reactions to scenario 2 were adjusted to recognize the removal of the option to shift the time of day. This was accomplished by taking the time-shift option response and distributing it over the remaining choices. Resulting elasticities for a $1.00 toll increase are as follows:

	Basis of Computation	
Market Segment	Total Trip Cost	Total Cost
A-F	-0.70	-0.18
A, B, and C	-0.62	-0.17
E and F	-0.86	-0.22

These elasticities are within the range of -0.07 to -0.29 commonly reported for increases in toll rates on bridges and tunnels. For all market segments, the toll elasticity of -0.18 conforms favorably with the toll elasticity of -0.20 cited by Kulash (7) as representative of toll increases on urban bridges.

PLANNING IMPLICATIONS

The telephone survey responses and elasticity coefficients quantify the impacts of various concepts of peak-period pricing on the six Port Authority crossings. They suggest that the average motorist would react in the following order of preference to avoid a higher toll:

1. Switch to another crossing,
2. Switch time of travel,
3. Switch to transit,
4. Travel less often or not at all, and
5. Join a carpool.

The choices of alternative route or time of travel vastly exceeded those choices that would take people out of their cars. More significantly, most motorists would make no change in their driving habits for toll increases of $3.00 or less.

In terms of reduced traffic, a $1.00 peak-hour toll surcharge would result in a 24 percent reduction in peak-hour trips if the surcharge period were limited to 1 h and if there were no other convenient facilities to use. However, there would be only a 3 percent decline in total daily vehicle trips. These benefits should be assessed in terms of additional costs, operational complexity, and public reactions associated with toll increases.

Care should be exercised in transferring these specific findings to other urban facilities. The unique characteristics of the New York-New Jersey travel market must be recognized--the high income levels, high existing trip costs, and long average trip lengths may not be representative.

It is important to recognize qualifiers for the two most frequently stated travel habit shifts--(a) to another facility and (b) to another time of day. The average time loss required for a shift to another facility was about 20 min; the maximum time-of-day shift for most users was about 60 min. In addition, Port Authority round-trip tolls are collected in one direction only. Therefore, time-of-day shifts are required during only one peak period, unlike most other urban situations.

In application of these survey findings, the Port Authority estimated that very little traffic could be shifted out of the peak period with toll surcharges because the heavy traffic demand extends over long time periods, which makes it necessary to consider peak surcharge periods of at least 3-4 h.

The use of attitudinal surveys to assess impacts of price changes and derive elasticity coefficients should be transferable; however, additional research is needed to better correlate actual behavior with reported attitudes.

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Simplified Approach to Downtown Travel Simulation

HERBERT S. LEVINSON

This paper analyzes the relation between downtown land use and travel based on a series of major generator surveys conducted in downtown Providence, Rhode Island. Trip rates obtained at nine buildings were applied to inventories of floor space and employment to provide a picture of daily trips to the city center. The surveys found 0.8 primary central business district (CBD) destinations/employee for work trips, 3.0 primary CBD nonwork destinations/1000 ft^2 of office-building floor space, and 9.7 destinations/1000 ft^2 of major retail floor space. This results in some 54 700 primary destinations in the CBD on a typical weekday (7:00 a.m.-6:00 p.m.). A small-sample home-interview survey, conducted in 1970, identified 54 100 destinations in a 24-h period. Additional studies of a greater mix of downtown land uses in other cities are suggested to further refine and validate the assumptions and methodology.

Travel to and from the city center reflects the types and intensities of downtown land use. This paper analyzes these relationships based on a series of major-generator surveys conducted in downtown Providence, Rhode Island. Trip rates obtained at various buildings applied to inventories of floor space and employment provide a picture of daily trips generated by the city center.

CONTEXT

Traditional methods of measuring travel demands in the central business district (CBD) include the downtown cordon count, postcard surveys of car occupants and transit riders, and home-interview surveys. Cordon studies do not differentiate between trips to and through the center. The other surveys are often costly and time consuming and do not provide indices for use in relation to new development. These deficiencies are largely overcome through the use of major-generator surveys at various downtown buildings. The surveys can provide a basis for developing trip rates that can be applied to new downtown land uses. They also can be used to simulate daily travel to the city center. Both of these uses were applied in downtown Providence as part of a traffic circulation and development study (1).

The comprehensive study was designed to (a) identify transportation problems and opportunities in the 350-acre CBD, (b) prepare a downtown transportation plan, and (c) develop methods to monitor and update the plan. The 1983 transportation plan applied transportation system management measures to a major urban center. It contained an integrated system of traffic, parking, pedestrian, and public transport improvements.

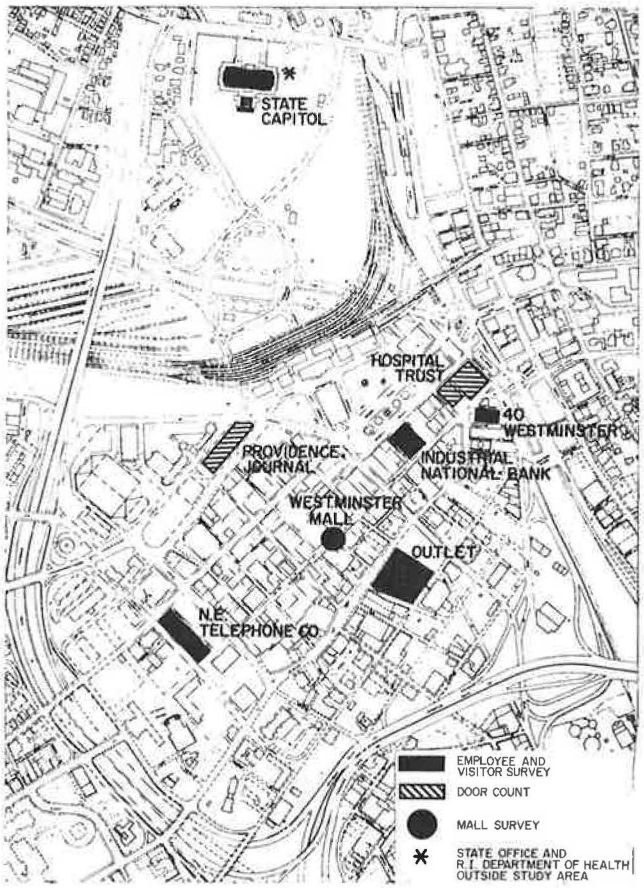
Key steps leading to plan preparation included the following:

1. Analysis of existing transportation conditions,
2. Surveys of existing travel patterns,

3. Forecasts of future travel patterns based on anticipated changes in downtown land use,
4. Analysis of alternative circulation concepts, and
5. Development of a 1983 transportation plan.

The major-generator surveys described in this paper were used to develop existing travel patterns and to forecast future requirements of the transportation system. Trip rates derived from the surveys were applied to anticipated future land uses to estimate the travel and traffic generated by planned land use. Estimates were made of the additional daily and peak-hour person trips by mode. The peak-hour vehicular trips were superimposed on the existing flow and assigned to the downtown street system on a block-by-block basis to assess the impacts of alternative circulation concepts.

Figure 1. Downtown Providence survey locations.



TRAVEL SURVEYS

Door counts and travel-pattern surveys were conducted at nine major buildings during June and July 1977. Figure 1 shows the location of the buildings within the downtown area, and Table 1 (2) gives the location, floor space, door counts, and size of the survey sample for each building.

The nine buildings surveyed contained more than 2.3 million ft^2 of floor space and employed 9000 people. Collectively, they account for about 25 percent of the total floor space (9 633 500 ft^2) and 35 percent of the total employment (25 600 people) in downtown Providence.

Employee and visitor surveys were conducted at seven of the nine locations: two general-purpose office buildings, a restricted-use office building, two government office buildings, the state capital, and the major department store. Approximately 4700 travel surveys were completed by some 2700 employees and 2000 visitors. Although 472 of the government employees interviewed work outside the study area in the state office building and Rhode Island Department of Health, the interviews are used for statistical purposes. Information was obtained for 10 percent of all downtown workers. The proportions of various types of CBD employees interviewed are shown in the table below (1).

Type of Employment	Total Employment	Interviews Number	Interviews Percentage of total
Office and business	11 574	1642	14.2
Retail	4 400	426	9.7
Government and institution	5 195	621	12.0
Other	4 462		
Total	25 631	2689	10.5

The surveys obtained information on characteristics of respondents (age and sex), car

Table 1. Interview and door-count sample size.

Place in CBD	Primary Function	Occupied Floor Space 1976-1977 (ft^2)	Employment 1976-1977	Total No. of Persons Entering	Visitor Survey Patterns	Employee Survey Attitudes	Employee Survey Patterns	Travel Surveys as Percentage of Reported Employment
40 Westminster	General office	285 597	1015	2 936	135	36	551	54.3
Industrial National Bank	General office	350 000	1500	4 791	310	83	646	43.1
New England Telephone Company	Restricted office[a]	407 847	931	1 578	12[b]		445	47.8
Outlet	Retail sales	431 249	583	8 732	735		426	73.0
State capitol	State office	146 139	300	1 295	97		149	49.7
State office building[c]	State office	NA	600	4 225	350		275	45.8
Rhode Island Department of Health[c]	State office	NA	500	1 340	80	—	197	39.4
Subtotal		1 620 832	5429	24 897	2041	119	2689	49.5
Hospital Trust	General office	537 940	2321	7 030				
Providence Journal	Special office	161 616	1250	2 299	—	—	—	—
Total		2 320 388	9000	34 226	2041	119	2689	29.9

[a] Authorized visitors only.
[b] Only 12 nonemployees entered this building; this sample is too small for meaningful evaluation.
[c] Lies outside of study area on far side of street that bounds study area.

ownership status, trip origin, mode of travel, purpose of visit to building, purpose of visit to downtown, and trip frequency. Table 2 summarizes some of the planning data obtained from the surveys. Comparisons of trip purposes to the buildings and to the CBD provided a means of estimating the number of primary trip destinations at various buildings. This information was then expanded to represent the total daytime downtown population.

PEDESTRIAN TRIP RATES

Pedestrian trip characteristics at the nine buildings are given in Table 3 (2). Approximately 34 000 people entered the buildings on a typical weekday. Some 5600 were within these buildings by 9:00 a.m. and about 7300 by midday. Overall, about 4.7 persons entered the buildings during the day per peak person accumulated (i.e., a turnover of almost 5).

Pedestrian trip rates for the four general office buildings and the major department store are summarized below.

1. The number of people who entered the office buildings averaged 12.8 persons/1000 ft^2 of floor space or 2.7 persons/employee. If each employee makes a trip at lunchtime, this figure suggests 0.7 visitor/employee. The maximum accumulation approximated 0.7 person/employee or 3.2 persons/1000 ft^2 of floor space. The turnover (entrants per peak accumulant) averaged 4.

2. The number of people who entered the department store totaled 20.2 persons/1000 ft^2; however, the maximum accumulation was 2.3 persons/1000 ft^2 of floor space or 1.7 persons/employee, which resulted in a turnover of 8.8.

PRIMARY CBD DESTINATIONS

The strength of the CBD stems from its compactness and the interaction among its various activities. Many people visit several buildings in the course of a single trip to the area (for example, lunchtime shopping trips by employees). The extent of this interaction is, in many respects, a measure of the vitality of the CBD. Therefore, in simulating travel to the city center, it was necessary to identify the number of primary destinations in each building as well as the total number of daily arrivals (entrants).

The primary destination is defined as the reason for making the trip to the city center. This is not necessarily the same as the reasons for visiting a specific building. In effect, it is the beginning end of an interzonal trip with the CBD viewed as a single zone. More specifically

1. Workers were assumed to have their primary destination in the buildings where they work and
2. The trip purposes of visitors to downtown Providence were compared with reasons for visiting specific buildings. Where the two trip purposes were identical, it was assumed that these trips represented primary destinations to the city center.

Table 4 summarizes the number and proportions of primary visitor trips at each building. Overall, approximately 61 percent of the visitors made primary destinations, usually for personal business or for shopping. The state office buildings located on the perimeter of the downtown area had the highest percentages of primary visitors (76-91 percent). Primary destinations to the two downtown general-purpose office buildings represented about 43 percent of the total visitors and they accounted for slightly more than 50 percent of the total trips to the major department store. [A similar study conducted during October 1957 reported that about 60 percent of all people in downtown stores throughout the day came primarily to shop (3).]

DERIVING TRIP ATTRACTION RATES

Attraction rates for trips to the downtown areas and the procedures used to derive them are shown in Table 5 (2). The basic steps were as follows:

Table 2. Illustrative travel characteristics.

Place	Percentage Who Live in Providence		Percentage Who Traveled by Bus		Percentage From Households That Have No Cars Available	
	Visitors	Workers	Visitors	Workers	Visitors	Workers
40 Westminster	34.8	24.3	6.7	21.6	2.2	3.8
Industrial National Bank	44.2	36.1	32.6	26.2	13.5	2.9
New England Telephone Company	NA	28.5	NA	14.2		5.2
Outlet	51.0	33.3	40.7	30.8	22.2	10.6
State capitol	27.8	28.2	8.2	4.7	7.2	4.0
State office building	31.7	27.3	2.6	7.6	3.7	5.4
Rhode Island Department of Health	40.0	27.9		1.1	5.0	2.0

Table 3. Door counts and pedestrian generation rates.

Place	Accumulation of Persons: At 9:00 a.m.	Accumulation of Persons: Maximum	Daily Turnover of Entrants	Persons Entering: Per 1000 ft^2 of Floor Space	Persons Entering: Per Employee	Maximum Person Accumulation: Per 1000 ft^2 of Floor Space	Maximum Person Accumulation: Per Employee
40 Westminster	654	815	3.6	10.3	2.9	2.9	0.8
Industrial National Bank	842	1097	4.4	13.7	3.2	3.1	0.7
New England Telephone Company	618	655	2.4	3.9	1.7	1.6	0.7
Outlet	392[a]	992	8.8	20.2	15.0	2.3	1.7
State capitol	237	407	3.2	8.9	4.3	2.9	1.4
State office building[b]	467	538	7.9		7.0		0.9
Rhode Island Department of Health[b]	338	388	3.5		2.7		0.8
Hospital Trust	1655	1923	3.4	13.1	3.0	3.6	0.8
Providence Journal	400	515	4.5	14.2	1.8	3.2	0.4
Total	5603	7330	4.7	12.4	3.8	2.8	0.8

[a]Person accumulation at 10:00 a.m. [b]Lies outside study area.

1. The number of different employees who entered each building was estimated based on the number of people accumulated between 9:00 and 9:30 a.m. In the case of the Outlet department store, the number of employees was based on the people who used the employee entrance.

2. The nonwork trips to each building were assumed to equal the total number of persons who entered the building minus twice the number of different employees entering the building. This assumes that each employee leaves the building for lunch and subsequently returns. The number of employees at work at about 9:15 a.m. was about equal to the number of people who left major office buildings [the figures for employees' entrances and departures, respectively, were 40 Westminster = 720, 770; Industrial National Bank = 970, 1210; Rhode Island Department of Health = 380, 360; Hospital Trust (Bank 1) = 1780, 1760].

3. The primary nonwork destinations as a percentage of the total reflect the results of the visitor surveys.

4. The primary nonwork destinations were computed by applying the percentages shown in column 4 to the values shown in column 3. The results are shown in column 5.

5. The total primary destinations represent the sum of columns 2 and 5.

Steps 1 through 5 can be expressed analytically as follows:

$$D = W_1 + P(E - 2W_1) \quad (1)$$

where

W_1 = estimated number of different work trips,
E = total number of persons who enter building, and
P = primary nonwork destinations as percentage of the total.

Table 4. Estimated number of primary visitor trips by building.

Place	No. of Persons Interviewed	Estimated Primary Visitor Trips Based on Survey		Approximate 95 Percent Confidence Limits[a]	
		No.	Percent	No.	Percent
40 Westminster	135	59	43.7	35.3	52.1
Industrial National Bank	310	132	42.6	37.1	48.1
Outlet	735	388	52.8	49.2	56.4
State capitol	97	74	76.3	67.8	84.8
State office building	350	317	90.6	87.6	93.6
Rhode Island Department of Health	80	72	90.0	83.4	96.6
Total	1707	1042	61.0	58.7	64.7

[a]Confidence limits approximated by formula $\hat{p} \pm (1.96\sqrt{pq/n})$.

Table 5. Person-trip generation rates for primary destinations.

Place	Person Accumulation 9:00-9:30 a.m.	Estimated Employees Entering Building for Primary Work Destinations	Estimated Nonwork Trips to Building[b]	Primary Nonwork Destinations As Percentage of Total	Primary Nonwork Destinations No.	Total Primary Destinations	Primary Destinations per 1000 ft^2 of Floor Space Work	Non-Work	Total	Primary Destinations per Employee Work	Non-Work	Total
40 Westminster	720	720	1 496	43	643	1 363	2.5	2.3	4.8	0.7	0.6	1.3
Industrial National Bank	970	970	2 851	43	1 226	2 196	2.8	3.5	6.3	0.6	0.8	1.4
New England Telephone Company	630	655	268	43	115	770	1.6	0.3	1.9	0.7	0.1	0.8
Outlet	390[a]	440	7 852	53	4 162	4 602	1.0	9.7	10.7	0.8	7.1	7.9
State capitol	320[a]	240	815	76	619	859	1.6	4.2	5.8	0.8	2.1	2.9
State office building	520	520	3 185	90	2 866	3 386	NA	NA	NA	0.9	4.8	5.7
Rhode Island Department of Health	380	380	580	90	522	902	NA	NA	NA	0.8	1.0	1.8
Hospital Trust	1780	1780	3 470	43	1 492	3 272	3.3	2.8	5.1	0.8	0.6	1.4
Providence Journal	420	800[b]	699	43	300	1 100	5.0	1.9	6.9	0.6	0.2	0.8
Total	6130	6505	21 216		11 945	18 450						

[a]10:00 a.m. for outlet; 9:00 a.m. for state capitol. [b]Estimate based on two effective shifts.

Table 6. Major categories of Providence floor space.

Zone	Office or Business (ft^2)	Major Retail (ft^2)	Other Retail Services (ft^2)	Total Retail Space (ft^2)	Government or Institution (ft^2)	Other Nonresidential (ft^2)	Total Nonresidential (ft^2)	Residential (ft^2)	Total (ft^2)
390	72 884		1 400	1 400	519 127	162 843	756 254	81 035	837 289
391	45 000	30 000		30 000			75 000		75 000
392	112 493		55 400	55 400	235 792	598 720	1 002 405		1 002 405
393	1 569 205	22 621	222 358	244 979	148 557	136 416	2 099 157		2 099 157
394	165 000	35 000		35 000			200 000		200 000
395	252 769	9 603	74 111	83 714	274 199	404 840	1 015 522	343 095	1 358 617
396	128 951	373 430	100 899	474 329	168 039	54 948	826 267		826 267
397	198 089	179 511	195 570	375 081	90 413	239 263	902 846	800	903 646
398	595 589		4 266	4 266	18 111	148 215	766 181	29 004	795 185
399	37 901	43 888	47 455	91 343	201 614	185 417	516 275	221 750	738 025
400	171 130	413 856	17 603	431 459	94 398	369 956	1 066 943		1 066 943
401	192 458	34 915	72 912	107 827	33 579	72 773	406 637	2 481	409 118
Total	3 541 469	1 142 824	791 974	1 934 798	1 783 829	2 373 391	9 633 487	678 165	10 311 652

Table 7. Primary destinations by analysis zone.

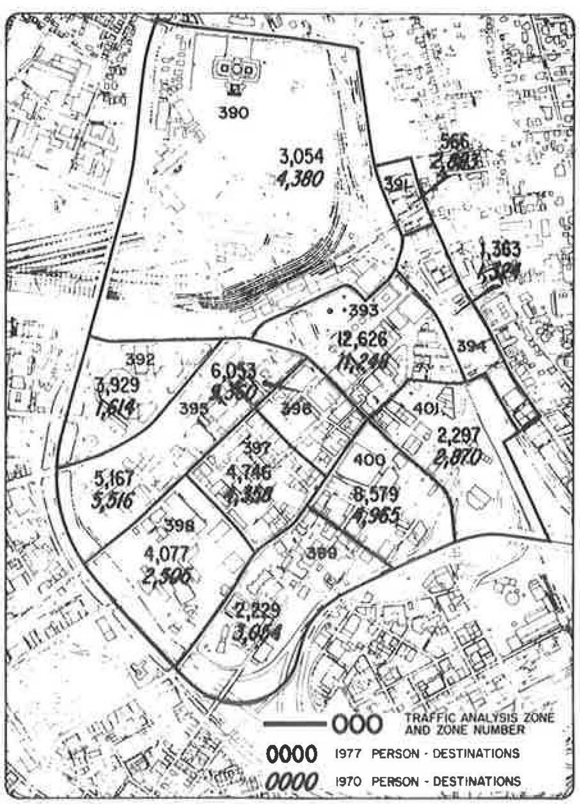
Zone	Employment	Work Trips (0.8 x Employment)	Office, Government, and Other Nonresidential Floor Space	Other Nonwork Trips at 3.0/1000 ft²	Major Retail Floor Space (ft²)	Shopping Trips (9.7/1000 ft²)	Total Nonwork Trips	Total Destinations
390	986	789	754 854	2 265			2 265	3 054
391	175	140	45 000	135	30 000	291	426	566
392	1 360	1 088	947 005	2 841			2 841	3 929
393	8 555	6 844	1 854 178	5 563	22 621	219	5 782	12 626
394	660	528	165 000	495	35 000	340	835	1 363
395	2 849	2 279	931 808	2 795	9 603	93	2 888	5 167
396	1 719	1 375	351 938	1 056	373 430	3 622	4 678	6 053
397	1 778	1 422	527 765	1 583	179 511	1 741	3 324	4 746
398	2 238	1 791	761 915	2 286			2 286	4 077
399	660	528	424 932	1 275	43 888	426	1 701	2 229
400	3 323	2 659	635 484	1 906	413 856	4 014	5 902	8 579
401	1 328	1 062	298 810	896	34 915	339	1 235	2 297
Total	25 631	20 505	7 698 689	23 096	1 142 824	11 085	34 181	54 686

Table 8. Comparison of 1970 and 1977 downtown trip destinations.

Zone	Work Trips 1970[a]	Work Trips 1977[b]	Work Trips Difference	Nonwork Trips 1970[a]	Nonwork Trips 1977[b]	Nonwork Trips Difference	All Trips 1970[a]	All Trips 1977[b]	All Trips Difference
390	805	789	−16	3 575	2 265	−1310	4 380	3 054	−1326
391	1 189	140	−1049	1 694	426	−1268	2 883	566	−2317
392	921	1 088	167	693	2 841	2148	1 614	3 929	2315
393	6 165	6 844	679	5 083	5 782	699	11 248	12 626	1378
394	652	528	−124	672	835	163	1 324	1 363	39
395	3 037	2 279	−758	2 479	2 888	409	5 516	5 167	−349
396	2 804	1 375	−1429	6 556	4 678	−1878	9 360	6 053	−3307
397	1 302	1 422	120	3 056	3 324	268	4 358	4 746	388
398	1 289	1 791	502	1 216	2 286	1070	2 505	4 077	1572
399	66	528	462	2 988	1 701	−1287	3 054	2 229	−825
400	1 221	2 659	1438	3 744	5 920	2176	4 965	8 579	3614
401	1 090	1 062	−28	1 780	1 235	−545	2 870	2 297	−573
Total	20 541	20 505	−36	33 536	34 181	+645	54 077	54 686	+609

[a]Based on Rhode Island Statewide Planning Program 1970 origin-destination study.
[b]Based on Wilbur Smith and Associates field surveys, June-July 1977.

Figure 2. Comparison of persons and destinations in downtown Providence by analysis zone for a typical weekday, 1970 versus 1977 data.



Trip attraction rates based on these analyses are summarized in the table below.

Item	General Office	Government Office	Major Retail
Work trips			
Per employee	0.7	0.8	0.8
Per 1000 ft² of floor space	2.9	2.1	1.0
Nonwork trips			
Per employee	0.7	1.0-1.8	7.1
Per 1000 ft² of floor space	2.9	3.6	9.7

APPLICATION TO DOWNTOWN LAND USE

By using these rates as a guide, the following rates were applied to the various downtown land uses listed in Table 6 (2):

For work trips--all nonresidential uses = 0.8 destinations/employee.
For nonwork trips = 3.0 destinations/1000 ft² for office, business, governmental, and other; 9.7 destinations/1000 ft² for retail.

To derive Table 6, it was necessary to differentiate between major retail and secondary retail space. It was assumed that major department stores and general apparel-furnishing stores would attract trips to the city center. Other stores and service establishments would depend almost entirely for trade on the downtown's daytime population. Restaurants and bars, office supply stores and stationers, drug stores, dry cleaners and laundries, newsstands and smokeshops, and many other small

shops and repair services are in this category.

Distinction was made, therefore, between types of retail activities that attract customers on their own and those that are essentially satellites to the work force and shoppers attracted by the larger-scale retailing establishments (i.e., primary versus secondary destinations). Analysis of block-by-block land-use data found that major retailing space constitutes about three-fifths of the floor space devoted to retail and service uses in the CBD. It was assumed that the Outlet department store, which accounts for about 35 percent of the floor space used for major retailing, generates trips in a way that is representative of all major downtown retailing. The percentages of land use in the CBD are 34.3 percent for office or business, 11.1 percent for major retail, 7.7 percent for other retail services, 17.3 percent for government or institutions, 23.0 percent for other nonresidential purposes, and 6.6 percent for residential.

The computations derived from the above are shown in Table 7. Overall, there were 54 700 primary person destinations during the working day. Of this total, about 20 500 were work trips, 11 100 were shopping trips, and 23 100 were other nonwork trips.

COMPARISON WITH 1970 SURVEY

Downtown work and nonwork trips by traffic zone are compared with travel data obtained in a 1970 home-interview sample in Table 8 and Figure 2. The 1970 data show 54 100 total destinations (24 h) as compared with 54 700 in 1978. Both sets of data appear to provide consistent estimates of the total travel to the center, although there are major differences in many analysis zones. In zone 390 there was little or no change; however, the estimate may understate the state capitol. Much of zone 391 has been cleared since 1970. In zone 392 an arena and some other improvements have been added. New office towers are located in zone 393. Zone 394 shows little change except for the addition of some East Side offices. In zone 395 new apartments have been built and the Biltmore closed. In zone 396 Shepards and Grants have been closed. A new telephone company annex, housing, and other improvements have been added to zone 398. Zone 399 shows some change due to new housing.

Many of these differences can be rationalized by changes in land use during the seven-year period, clearance of areas, closing of department stores, or construction of new office buildings. However, the 1977 data represent an 11-12 h period; when expanded to a 24-h period, there is some overstatement of nonwork trips. Relative to the 1970 sample data, this is further denoted by the reported decline in the maximum number of people accumulated downtown from 30 000 in 1968 to 25 600 in 1976.

SUMMARY AND SIGNIFICANCE

The major-generator surveys produced important information on the dimensions and characteristics of travel to buildings in downtown Providence. Trip rates obtained from these surveys provided a basis for estimating total travel by analysis zone to the CBD and for assessing the impacts of changes in land use. The results seem reasonable when compared with travel-pattern data obtained from conventional home-interview surveys, but they can be obtained more quickly and economically.

Additional research is needed to refine and further verify the assumptions and methodology. These efforts should focus on the following:

1. Determining the lunchtime travel behavior of downtown employees;
2. Extending the analysis to other cities to encompass a greater variety of land uses, including personal business and recreational generators;
3. Verifying the relationships between primary and secondary destinations; and
4. Establishing more definitive criteria to differentiate between major and secondary downtown land use.

Additional data on a cross section of cities would provide a valuable reference source on downtown trip generation and pedestrian rates.

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