Characteristics of Urban Commuter Behavior: Switching Propensity and Use of Information

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The results of a survey of commuters in Austin, Texas, are presented. The focus is on commuting habits, particularly changes in route and departure time due to traffic conditions for both the home-to-work and work-to-home commutes. Models of commuters' propensity to switch each of these two choices are developed for both the a.m. and the p.m. commutes. The models relate switching propensity in each case to four types of factors: geographic and network condition variables, workplace characteristics, individual attributes, and use of information (radio traffic reports). The results provide insights into the relative importance of each type of factor to switching as well as differences between the mechanisms underlying a.m. and p.m. behavior.

Concern about urban and suburban mobility has motivated interest on the part of planners, policy makers, and urban residents in approaches to manage and reduce traffic congestion. In addition to the wide spectrum of demand-side and supply-side approaches that have been referred to in the past decade as transportation system management techniques, the potential for advanced telecommunications and microprocessor technologies to improve traffic conditions in urban networks is being pursued in several initiatives worldwide. A key determinant of the effectiveness of such strategies is the manner in which users might adjust their travel behavior in response to these strategies to alleviate peaking conditions through route-selection and trip-timing decisions. More needs to be learned about trip maker behavior, especially with regard to work trip commuting, the major contributor to morning and evening peak periods.

Little systematic knowledge is available regarding commuter behavior, which is surprising in light of its importance to urban congestion. Part of the reason is the inadequacy of the traditional 1-day diaries used in transportation planning studies to yield information on the dynamic aspects of the process or on the path selection decisions of commuters. The available knowledge consists mainly of scattered small-scale studies, including models of departure time choice (*1–4*) (made by commuters under steady-state conditions), and, to a lesser extent, route choice (*5*,*6*). Joint models of departure time and route choice have been formulated by Ben-Akiva et al. (*7*) and calibrated by Abu-Eisheh and Mannering (*8*) using the equilibrium choices of a small sample of commuters in a lightly congested two-route system. Insights have also been gained from activity-based approaches, which have gone a long way toward placing trip making and commuting in the context of individuals' and households' activity patterns (*9*).

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The dynamic aspects of commuter behavior have received attention in the past few years, particularly departure time choice and, to a lesser extent, route choice. In particular, laboratory experiments have been conducted at the University of Texas that involved commuters interacting within a simulated traffic system (*10–13*). The experiments have yielded both methodological and substantive insights into the mechanisms governing day-to-day switching of departure time and route in a.m. home-to-work commuting in response to trip time variability as well as exogenous information. However, obvious limitations are associated with such experiments, particularly in terms of the effect of some factors that were controlled for, the representativeness of the participants, and possible systematic differences between laboratory simulations and actual commuting corridors. Mahmassani and Herman (*12*) have highlighted the role of such experiments in bridging the gap between speculative assumptions and full-scale field studies. It is desirable to build on and proceed beyond such experiments by conducting behavioral studies that will expand the boundaries of the theoretical constructs developed to date.

Limited field surveys of commuting behavior have recently been conducted (*14–17*). Chang and Williams (*14*) examined the departure time decisions of a small sample of a.m. home-to-work commuters in Salt Lake City and related the delays experienced to socioeconomic characteristics. Mannering (*15*) examined the frequency of route switching and departure time switching reported in a survey of a small sample of Seattle commuters. In another small-scale survey of Seattle workers, Mannering and Hamed (*16*) examined the decision to delay the usual work-to-home p.m. commute and related it to the severity of prevailing congestion during the peak as well as the socioeconomic characteristics of the commuter.

The goal of this study was to document the actual departure time- and route-switching decisions of commuters, quantify the day-to-day variability of these decisions, and identify the relative importance of factors such as the characteristics of the user, the rules at the workplace, the user's experience with the traffic system, and the use of information. The approach consisted of a two-stage survey. In the first stage, general characteristics of commuting behavior for a sample of trip makers in Austin, Texas, were obtained. In the second stage, detailed diaries were maintained of actual departure times and link-by-link itineraries (including intermediate stops in a multipurpose trip chain) from a smaller group of commuters during a 2-week period. In this paper an exploratory analysis of the results of the first-stage survey is presented. The focus is on two principal aspects of commuter behavior: (*a*) users' preferences and risk attitudes, captured through their preferred arrival time at work and the factors that affect it, particularly rules at the workplace; and (*b*) the extent and determinants of departure time and route switching in anticipation of or in response to traffic conditions. In addition, the analysis examines the role of two factors on these aspects of commuting behavior: the extent to which lateness is tolerated at the workplace and the use of information. Both a.m. and p.m. commuting are addressed, revealing asymmetries in behavior and possibly different underlying mechanisms. The analysis also presents an opportunity for comparison with the results obtained in Mannering's studies of Seattle commuters (*15,16*).

SURVEY DESCRIPTION AND GENERAL COMMUTER CHARACTERISTICS

Questionnaires were mailed to 3,000 households randomly selected in an area of five zip codes in the northwest section of Austin, Texas. All daily work commuters in the household were requested to complete separate questionnaires (each household was mailed two questionnaires for this purpose). The zip codes were chosen for their large residential areas and proximity to two major congested corridors, MOPAC and Route 183. The survey area is mostly suburban, with a generally higher income level than the overall urban area. It is also close to major technology-based manufacturing and research and development activities. Thus commuting is not exclusively oriented to the central business district (CBD) but includes a large inter- and intrasuburb component. A total of 482 households responded and 156 households completed two questionnaires, yielding 638 (in some cases partially) completed surveys.

The survey consisted of three main parts: screening questions, personal characteristics, and commuting habits. The screening questions identified suitable participants for the second stage of the study, such as those who drive their car for daily commutes to and from work locations in specific zones of interest. The commuter characteristics questions included job title, sex, age, type of work hours (regular, flexible, or other), tolerance of lateness at the workplace, and dwelling tenure (own or rent). The commuting habits portion requested the commuters' preferred arrival times at work, travel times to and from work, listening habits for radio traffic reports, other information sources, and route and departure time switching (specifically because of traffic conditions) for both a.m. and p.m. trips. A copy of the mail survey is shown in Figure 1.

Several items are important in the analysis and appear to be unique to this survey. For instance, tolerance of lateness addresses the penalty function for late arrival at the workplace, which is a central concept in departure time choice modeling (*7,18,19*). Trip makers were given a choice of three responses on this item: "I am expected to arrive on time," "I am allowed to arrive up to __ minutes late," and "It does not matter if I am late." The second item of particular interest is the preferred arrival time at work, subject to the official start time. Unlike the previous laboratory experiments (*10–13*), the wording of the question did not specify that the reported preferred arrival time should be independent of traffic congestion conditions. It was thought that commuters would have already adapted their behavior to the existing congestion patterns and might not be able to separate the congestion factor. Because of the interest in information use and its effect, respondents were asked if they listened to radio traffic reports. Finally, the questions on switching behavior were directed separately at departure time and route for each of the a.m. and p.m. commutes, unlike other studies, which addressed one or the other. It was specified that the changes of interest in either choice were those associated with traffic conditions. The particular survey area is affected by continuing highway construction. Respondents were not asked for the frequency of either type of change, as in Mannering's study (*15*), which asked for the number of monthly route changes and departure time changes. It was believed, and subsequently confirmed in pilot testing, that respondents may encounter definitional problems, especially with regard to what constituted a route change, in addition to the possible unreliability of recall of the exact number of changes. Some of these concerns could be better addressed in a telephone survey, which was used in the Mannering study (*15*), than in a mail survey such as the present one. Much of the motivation for the second-stage survey is to observe, in a longitudinal study, actual changes made by commuters, thereby obviating the need for reliability of recalled responses. Summary statistics for the survey results are presented in Table 1, and the various items asked are explained in greater detail hereafter.

The majority of respondents were male, between ages 30 and 44, and owned their own home. Virtually all (98.8 percent) used their own car to commute to and from work and only 2.4 percent belonged to a carpool. Less than 1 percent of the respondents indicated a steady use of public transportation for their daily work commute, accurately reflecting the sociodemographics of the study area and the difficulty of providing competitive transit service from this essentially suburban area to a diversity of work destinations. Just under one-third of the respondents worked in the CBD, which is dominated by financial and government offices. Another one-third worked in the northern section of the city, outside of the loop, which consists mainly of technology-oriented industries and research laboratories. The remaining third was scattered throughout the surrounding areas, with 12 percent commuting outside of Austin's city limits. The average reported home-to-work trip time was just under 21 min and the return commute averaged slightly more at 24.4 min. The distributions are shown in Figure 2; the differences in the distributions were found to be statistically significant using a chi-squared comparative test.

The majority of the commuters (77 percent) had regular work hours. Only 17 percent indicated flexible work hours, and the rest indicated either scheduled shift work (3.5 percent) or other (2.5 percent). Of those commuters with regular work hours, the majority had work start times between 7:30 and 8:00 and work end times between 4:00 and 5:30 (Figure 3).

TRANSPORTATION SURVEY |__|__|__|__|__|

Thank you for participating in our survey. Before you begin, are there any other people in the household who also commute to work? If so, please have them complete the additional enclosed survey. Please answer all questions to the best of your knowledge. All answers, of course, will be kept strictly confidential. Thank you.

1. What is your work (parking) address?

______________________ Street Address ______________ City

2. Do you normally drive your own car (automobile, pick up, van etc) to work? __ Yes __ No

3. If not, how do you normally commute to and from work?
__ Carpool __ Capital Metro (Bus)
__ Park & Ride __ Other __________

4. How would you best describe your work hours?
__ Regular Work Hours: (____ am to ____ pm)
__ Scheduled Shift Work
__ Flexible Hours: (____ hours a week)
__ Other __________

5. How many minutes before your work actually starts do you prefer to arrive at your workplace? ____ Minutes

6. How important is it for you to not be late to work?
__ I am expected to arrive on time.
__ I am allowed to arrive up to ______ minutes late.
__ It does not matter if I am late.

7. On a typical day, how long is your driving time:
from home to work? ____ Minutes
from work to home? ____ Minutes

8. During your usual drive to and from your workplace, do you listen to:
traffic reports on the radio? __ Yes __ No
CB radio for traffic information? __ Yes __ No

9. Do you normally adjust the <u>time</u> at which you leave specifically with traffic conditions in mind on your trip:
from home to work? __ Yes __ No
from work to home? __ Yes __ No

10. Do you normally modify the <u>route</u> you drive specifically with traffic conditions in mind on your trip:
from home to work? __ Yes __ No
from work to home? __ Yes __ No

The next four questions will only be used in determining our test sample demographics.

1. What is your job title? ______________________
(Example: Store Manager, Professor, Secretary, Coach)

2. Do you rent or own your home? __ Rent __ Own

3. What is your gender? __ Male __ Female

4. What is your age?
__ Under 18 __ 18-29 __ 30-44
__ 45-60 __ Over 60

Would you be willing to assist in providing more detailed information on your commuting habits? __ Yes __ No

PLEASE RETURN THIS SURVEY IN THE ENCLOSED ENVELOPE, *regardless of whether or not you choose to participate in any further studies. Thank you for your promptness and cooperation. Your assistance will help us better understand the problems of traffic congestion. If you have any questions, please feel free to enclose them or call us at 471-4379. Thank you again for your time and effort.*

FIGURE 1 Mail survey form.

TABLE 1 SUMMARY STATISTICS FOR SURVEY RESULTS

Characteristic	Survey Result
Commuters using their own cars (%)	98.8
Commuters (%)	
With regular work hours	77
With flexible work hours	17
Average PAT (min)	14
Tolerance to Late Arrival at the Workplace (%)	
None	58.5
Unlimited	33.9
Given time (average 19 min)	7.6
Average daily travel time (min)	
From home to work	21.7
From work to home	24.4
Commuters who listen to radio traffic reports (%)	65.8
Commuters who modify their time of departure (%)	
From home to work	54.4
From work to home	31.1
Commuters who switch their route (%)	
From home to work	50.8
From work to home	53.4
Male (%)	62.9
Age (%)	
18–29	8.7
30–44	56.2
45–60	30.3
Over 60	4.7
Commuters renting their residences (%)	12.9

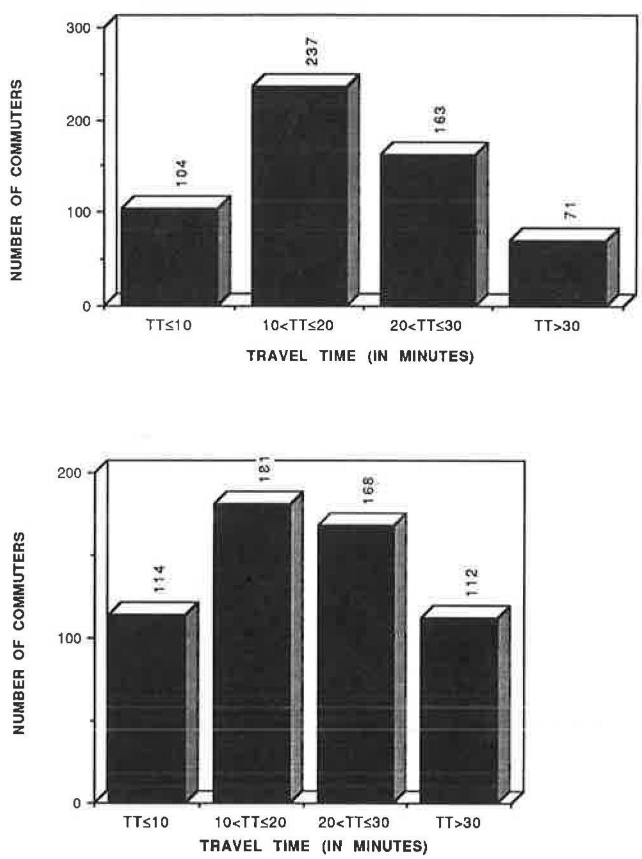

FIGURE 2 Travel time distribution (*top*) for the home-to-work commute and (*bottom*) for the work-to-home commute.

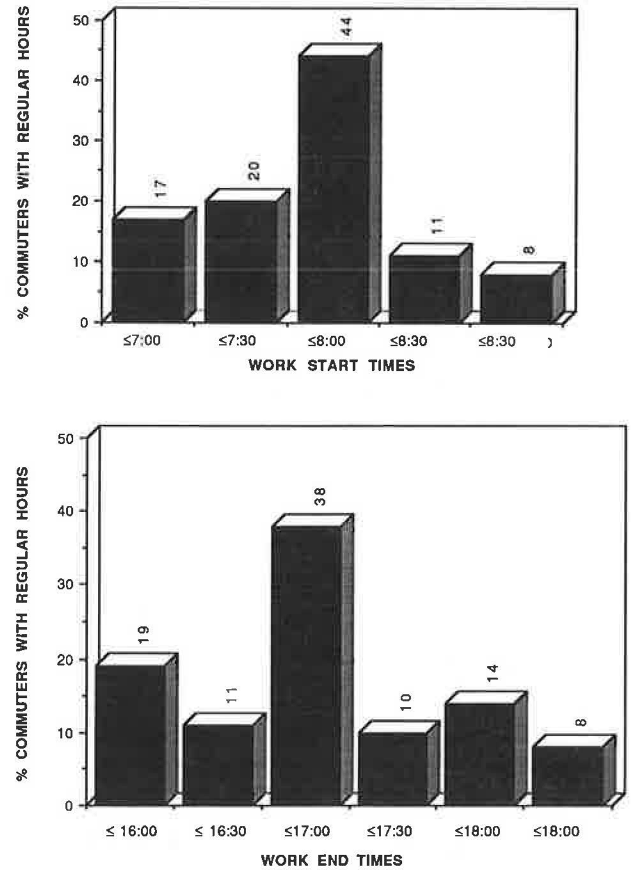

FIGURE 3 Distribution of (*top*) work start times and (*bottom*) work end times for regular commuters.

Those with flexible work hours were split about evenly as indicated in the following table:

Work Hours per Week	*Percentage*
Less than 30	21
30–40	25
41–50	25
51–60	23
More than 60	6

The relatively low fraction of commuters with flexible hours indicates a potential for reducing congestion through peak spreading. In recent simulations of a commuting corridor with real-time in-vehicle information availability, Mahmassani and Jayakrishnan (*20*) found greater potential to reduce congestion through peak spreading (where feasible) than through route control.

Whereas more than half of the respondents stated that there was no tolerance for lateness at their workplace, one-third stated that they had unlimited tolerance (as defined earlier in this section). The remaining 7.6 percent reported a time ranging from 5 to 60 min, with an average of 19 min and a mode of 15 min. Commuters working in the CBD, female commuters, and those with scheduled shift work were more likely to have no lateness tolerance at the workplace, as shown in Figure 4. The data in Figure 4c confirm that commuters with flexible work hours were the least likely to have no lateness tolerance at work. Commuters with work starting times in the congested

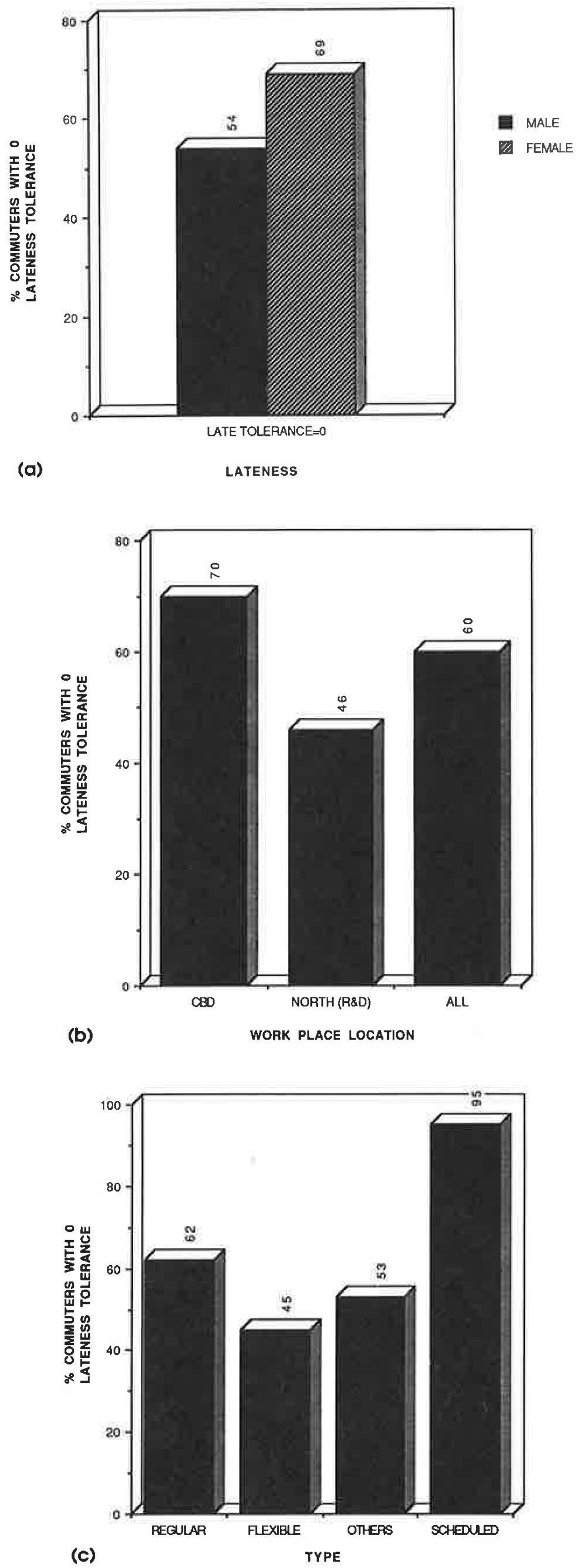

FIGURE 4 Percent of commuters with no lateness tolerance by (*a*) sex, (*b*) work location, and (*c*) type of work hours.

peak period of 7:31 to 8:30 appear to have greater tolerance for lateness at the workplace than commuters outside those peak times, as shown in Figure 5.

Two-thirds of the commuters reported listening to radio traffic reports during their commutes. Those with longer travel times were more likely to listen to traffic reports, because they had more opportunity to use the information and avoid potentially long delays due to traffic conditions. The in-vehicle information fad of the 1970s, CB radio, was reportedly used by only three respondents. No question was included in the first-stage survey on the availability of cellular telephones to obtain traffic information. This item was, however, included in the second-stage survey.

PREFERRED ARRIVAL TIMES

The survey asked for the commuter's preferred arrival time (PAT) at the workplace before work actually starts. PAT was found to be an important determinant of the dynamics of commuter behavior in the previous experiments conducted at the University of Texas (*10,12*). It serves as a goal for anchoring users' adjustment of departure time in response to experienced congestion (*21*). In addition, as an indicator of preferences and risk attitudes, it is a good predictor of a commuter's initial indifference band of tolerable schedule delay, which governs the acceptability of the consequences of departure time decisions (*10,22*). However, other than in those experiments, no previous attempt has been made to measure this quantity. The results of the present survey are unique in this regard and contribute to characterizing the distribution of this quantity across the commuting population and to identifying the factors that affect it.

The distribution of PAT, expressed as the number of minutes before the official start time, is shown in Figure 6. The average was 14 min and the standard deviation was 13.9 min; 16 percent reported a PAT of zero. Although PAT can be viewed as a reflection of a commuter's individual preferences, it is useful to examine its variation with respect to two factors:

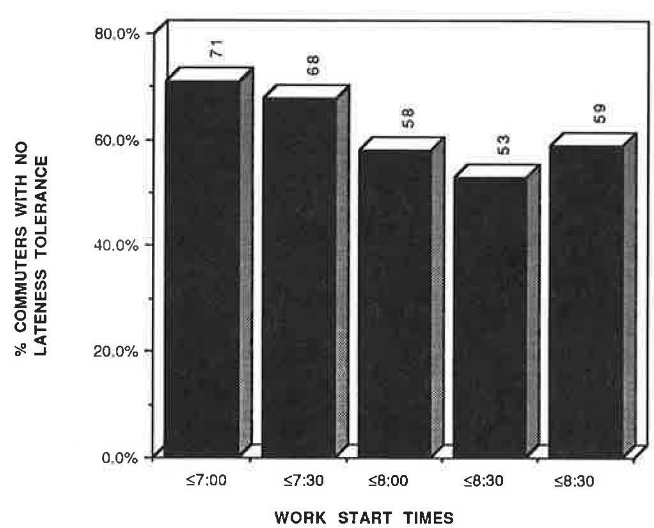

FIGURE 5 Percent of commuters with no lateness tolerance by work start time.

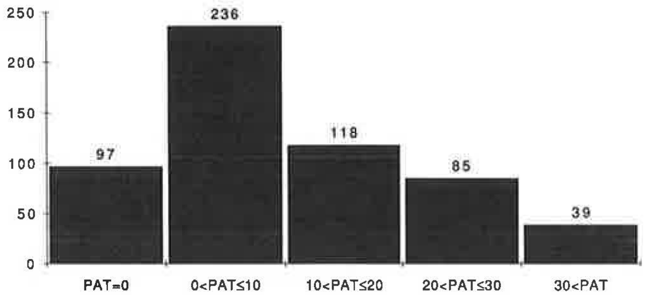

FIGURE 6 Distribution of PAT.

(*a*) the type of work schedules and rules of the workplace and (*b*) the traffic conditions and level of congestion prevailing during the commute. Figure 7a shows the PAT distribution for the four types of work hours described earlier, indicating that those with regular work hours had essentially the same distribution as those with flexible hours. This conclusion was confirmed by a chi-squared test of the corresponding hypothesis. The distributions shown in Figure 7a for those with scheduled shift work and "other" work hours were not meaningful because of the relatively small samples on which they were based.

A more dramatic difference in the PAT distribution was associated with lateness tolerance at the workplace. Figure 7b shows this distribution for commuters with a lateness tolerance of 5 min or less and those with a tolerance of more than 5 min. A chi-squared test indicates that the two distributions are significantly different at any reasonable confidence level. Commuters who work for companies with a lateness tolerance in excess of 5 min exhibited a significantly lower PAT (mean of 9.7 min and standard deviation of 11.9 min) than those with a low tolerance for late arrivals (mean of 16.9 min and standard deviation of 14.4 min). This conforms to intuition—commuters who are not allowed much slack for lateness would rather arrive early than incur a penalty by arriving late. The strong relationship between PAT and lateness tolerance was also reflected in the variation of the PAT distribution with workplace location, shown in Figure 8. Commuters working in the CBD had a higher-than-average PAT, in contrast to those working in the northern areas, due to the differences between work-rule policies in downtown businesses and government offices (no lateness tolerance) and those at the research-and-development and technology-based industries in the suburbs (greater lateness tolerance).

The effect of the second factor, traffic conditions, was examined by testing the variation of the PAT distribution by travel time and by work start times (as an indicator of peak-period congestion). No significant differences were detected with respect to either of these factors. The PAT distribution for different travel time categories, shown in Figure 9, appears to suggest an increasing trend of PAT with travel time. This is probably due to the higher likelihood of encountering congestion and thus experiencing greater trip time variability on longer trips, which the commuter might accommodate by a larger PAT.

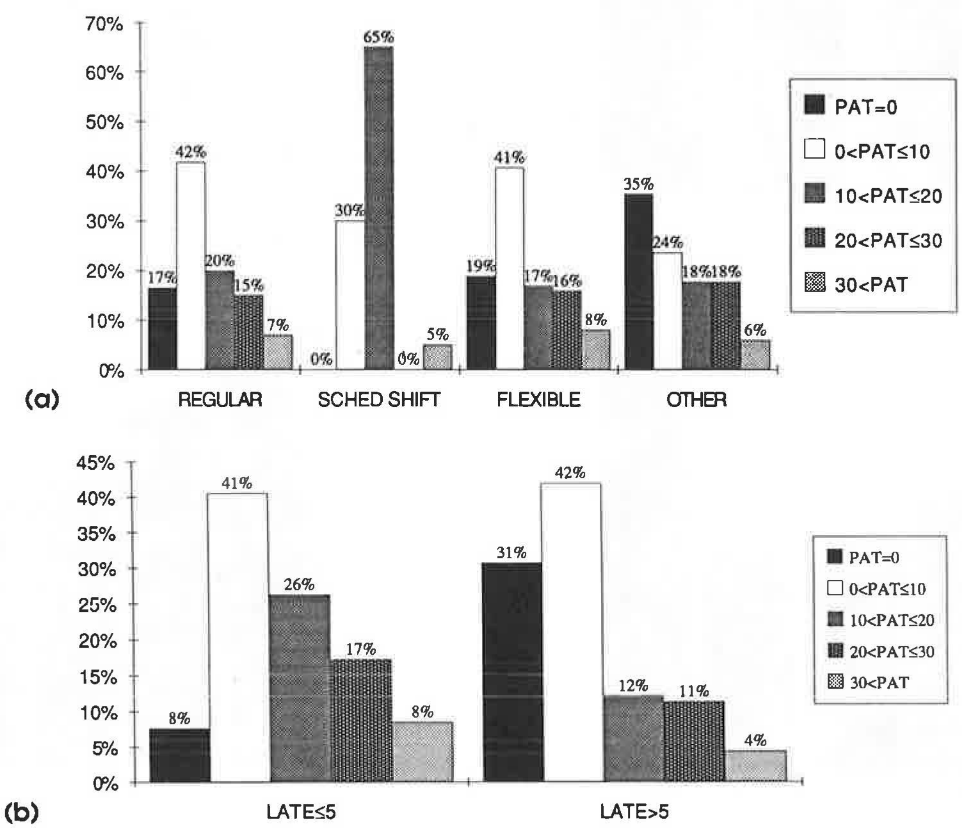

FIGURE 7 PAT distribution (*a*) for different types of work hours and (*b*) under different lateness tolerance policies.

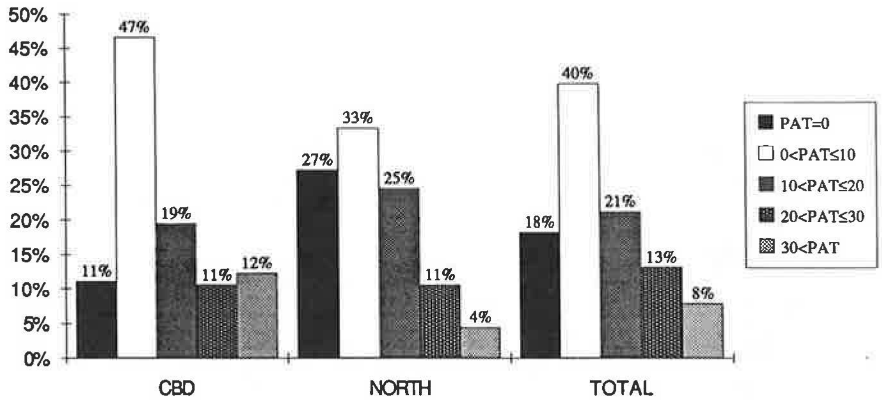

FIGURE 8 Distribution of PAT for different work locations.

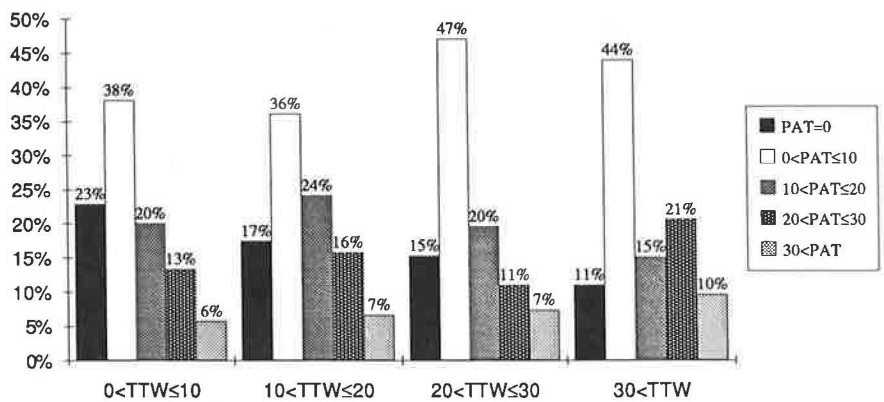

FIGURE 9 Distribution of PAT for different travel time categories.

In the next section, the effect of some of these factors on commuters' propensity to change routes and departure times is examined.

ROUTE AND DEPARTURE TIME SWITCHING

General Characteristics of Reported Switching Habits

The survey asked if the commuter normally adjusted the time of departure or modified the route "specifically with traffic conditions in mind" for both the home-to-work and work-to-home commutes. This wording was chosen to exclude route deviations due to multipurpose trip chains or side trips during the morning and evening commutes. The results are summarized in Table 1. The results indicate that considerably more commuters adjust their departure time for the home-to-work commute than for the return trip. A slightly higher fraction switches routes in the work-to-home commute than in the morning. Interestingly, a significantly larger fraction of commuters reported switching routes than time in the work-to-home commute. Relatively few commuters appear to be willing to delay their departure from work. However, a somewhat larger fraction may adjust departure time than switch routes in going from home to work. These results cannot be compared directly with those of the laboratory experiment reported by Mahmassani and Stephan (*13*). In the latter, the actual numbers of switches were monitored. In the present survey, only a reported indication of whether the commuter deviates from some usual time and route to accommodate traffic conditions is available, and no information is available on the frequency of such switching of either choice.

Additional insight into commuters' habits is obtained by further breaking these results into the following four categories: both route and departure time switching, route only, departure time only, and neither. Figure 10 shows the respective distributions of the home-to-work and return commutes of the four categories. It confirms that few work-to-home commuters change their departure time only, probably because they are not supposed to leave earlier than their work end time, and the vast majority do not appear to be willing to stay longer to avoid traffic. The largest fraction (41 percent) of home-bound commuters changes neither. A chi-squared test confirmed that these differences between the home-to-work and work-to-home distributions are statistically significant at better than the 1 percent level.

The results suggest that the considerations governing home-to-work commuter switching behavior may be different from those governing the work-to-home commute. Similarly, different considerations may affect route versus departure time switching.

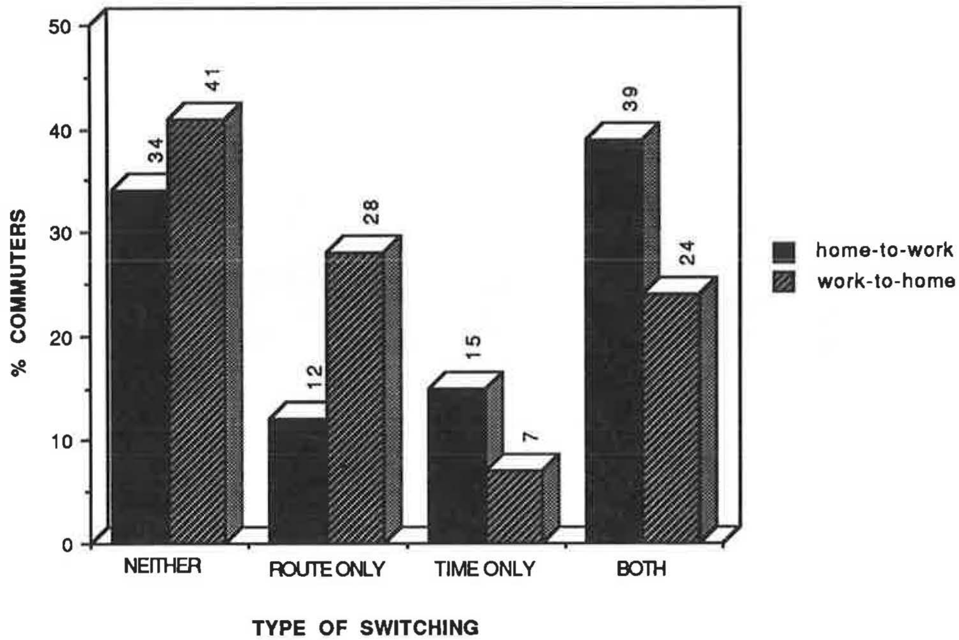

FIGURE 10 Route and time switching for home-to-work and work-to-home trips.

Switching Models: Background

To gain insight into the factors that influence departure time and route switching and the motivations that underlie the asymmetry between a.m. and p.m. commuting, models were calibrated that related the propensity for switching to four principal types of factors: (*a*) characteristics of the commute itself, such as travel time, congestion, and network features; (*b*) work rules, such as lateness tolerance and type of work hours; (*c*) individual characteristics, such as sex, age, and income; and (*d*) information use, captured here by whether or not the commuter listens to radio traffic reports.

A simple formulation was adopted to analyze switching habits. For each of the four decision situations considered (route and departure time switching for a.m. and p.m. separately), the decision to switch was modeled as the result of a latent variable crossing a threshold (*23*). Let Y_i denote the latent variable governing the response of user *i* to a particular decision situation (for example, a.m. route switching). Two states are possible for the response: $d_i = 1$ (i.e., switch) if and only if $Y_i \geq 0$, and $d_i = 0$ (no switching) otherwise. The variable Y_i can be interpreted as the propensity to switch for the particular choice under consideration. It consists of (*a*) a systematic component, which is a function $f(X_i)$ of a vector of attributes X_i of commuter *i*, capturing the four types of factors mentioned previously; and (*b*) a random disturbance term ε_i capturing unobservables that vary across commuters. Thus $Y_i = f(X_i) + \varepsilon_i$. Assuming that the random term ε_i follows the logistic distribution, the probability $\Pr(d_i = 1) = \Pr(Y_i \geq 0)$ is given by the usual binary logit model form (*24*).

In this analysis, different specifications of the function $f(X_i)$ were developed and calibrated separately for the commuters' responses to the a.m. route-, a.m. time-, p.m. route-, and p.m. time-switching questions. All specifications considered were linear in the parameters; thus $f(X_i) = \beta X_i$, where β is a vector of parameters that can be estimated by maximum likelihood. The analysis allows the identification and assessment of the relative importance of the factors influencing propensities for switching route and departure time as well as differences between the home-to-work and work-to-home trips. In interpreting the results, it is important to note that the dependent variable in each case is not an actual decision to switch for a given trip, but the response to the question of whether the commuter normally switches route or departure time. The results are discussed for each of the four cases.

Morning Route Switching

Because the type of work hours (regular versus flexible) was thought to affect commuting behavior in a manner that would not be properly captured by an additive term in the specification of $f(.)$, models were calibrated separately for those commuters with regular work hours and those with flexible or "other" hours. As seen later, this stratification was meaningful—it was not possible to obtain plausible and significant models for those without regular work hours because of the absence of systematic patterns underlying the high degree of variability in their behavior and the relatively small subsample (and sparse exogenous data) available to study it.

Table 2 describes the variables included in the specification of the a.m. route-switching response model along with the corresponding coefficient estimates and *t*-statistic values obtained for commuters with regular work hours. Of the four categories of variables discussed in the previous section (commute characteristics, individual attributes, workplace conditions, and information use), it was found that those describing the characteristics of the commute itself had a dominant effect relative to workplace rules or individual characteristics (captured somewhat weakly with the age variable here). The use of information in the form of radio traffic reports also exerted a strong effect, indicating that regular listeners to traffic reports

TABLE 2 ESTIMATION RESULTS FOR A.M. ROUTE-SWITCHING MODEL FOR COMMUTERS WITH REGULAR WORK HOURS

Variable Description	Estimated Coefficient	t-statistic
Constant	-1.215	-0.63
Travel time (tt), in minutes, if 10 ≤ tt ≤ 35 (0 if tt < 10, 35 if tt > 35)	0.055	3.48
Travel time in excess of 35 minutes (0 if tt ≤ 35)	-0.059	-0.99
Average travel speed, in mph, if 20 < tt ≤ 30 (0 otherwise)	-0.063	-1.00
Alternate route availability indicator (1 if available, 0 otherwise)	1.267	3.19
Age category index (1 if age < 18, 2 if 18≤ age ≤ 29, 3 if 30 ≤ age ≤ 44, 4 if 45 ≤ age ≤ 60, 5 if age > 60)	-0.221	-1.53
Radio traffic report listening indicator (1 if yes, 0 otherwise)	1.090	4.36
Number of observations	372	
Log-likelihood at zero	-257.85	
Log-likelihood at convergence	-227.75	

had a greater propensity to switch routes. This suggests that commuters may deviate from their regular routes in response to in-vehicle information.

With regard to the dominant type of factor affecting a.m. route-switching propensity, commute characteristics, four variables were included in the specification. The first two were reported trip time variables, which together captured some nonlinearities in the effect of trip time. The first nonlinearity was a threshold at about 10 min, below which no systematic pattern could be discerned, thereby providing the base or reference level against which the effect of higher trip times was measured. A further justification for this particular threshold is that the trip time used here was a reported "usual" value, and may thus exhibit some inaccuracy because of perceptual factors, especially for low values. Beyond this threshold, trip time had a significant positive effect on route switching, as expected, because longer trips imply more meaningful savings due to switching and greater exposure to variability due to incidents.

This effect held to about 35 min, when the second nonlinearity appeared. The marginal effect of increasing trip time became negative. The net effect of trip time on the latent propensity (Y_i) remained positive relative to the above-mentioned reference level, though, because of the combined effect of the two trip time variables [the first was set equal to 35 for $tt > 35$, whereas the second was set equal to $(tt - 35)$, i.e., the trip time in excess of 35 min]. This nonlinearity reflected a tapering off of the previously mentioned opportunities for improvement; for long trips, there was a tendency for one particular facility to dominate all alternative routes. Although the statistical significance of this coefficient was not particularly convincing, in-depth analysis of the data indicated the necessity to include it in the specification. Statistical significance would undoubtedly improve with a larger sample. Though the particular value at which this nonlinearity appeared was specific to the Austin network (and consistent with the authors' experience), a similar phenomenon may be present in other areas' networks as well. On the other hand, the magnitude of the first threshold, which is rooted in behavioral considerations, is probably more directly transferable to other commuting populations. Both threshold values were first identified, as is usually the case, through exploratory analysis followed by the estimation and testing of alternative model specifications. The estimation model confirmed their significance.

Other than the trip time variables, a powerful explanatory variable is an indicator that captures the availability or abundance of meaningful major route alternatives to the commuter. This particular variable reflects the network under consideration and the relative locations of the origin and destination of the trip. This variable captures the abundance of alternative routes, not the presence of any alternative route. As noted, the sample of commutes was representative of metropolitan commuting patterns in that only part of it was CBD-oriented (the CBD is located to the southeast of the survey area). Nonnegligible proportions of the destinations were located in suburban locations that involved travel in all directions from the survey origin area. In this case, for instance, much of the CBD-oriented travel had access to several alternative facilities for the commute, whereas travel in the northwest or northeast directions had only one major facility to anchor path formation. As expected, the sign of the coefficient of this variable was positive, with high statistical significance, reflecting that an abundance of alternatives increases the propensity to switch routes in the a.m. commute. Although it would have been desirable to have more descriptive variables on the relative quality of the various alternatives, particularly trip time variability, such detailed information was not available for this analysis.

The fourth term included here is a measure of congestion in the form of an estimated average speed for the commute (obtained by dividing an estimated network distance by the reported trip time). Its contribution as a separate term was limited to medium-length trips, for which the data were sufficient to allow a separate estimate for this term. As expected, for a given trip time, the propensity to switch decreased with increasing perceived average speed (i.e., lower congestion). Congestion (captured by the average speed) and the reported trip time were generally positively correlated, precluding the identification of a separate congestion effect other than in the indicated range.

The only sociodemographic attribute included in this model was age. It had somewhat lower statistical significance than the dominant variables, though with the correct sign, confirming that older commuters have less inclination to switch routes. Those variables not included in the specification are equally noteworthy. In particular, sex and job type category had no significant effect on route switching, nor did lateness policies at the workplace, suggesting the preeminence of geographic factors and network conditions, in addition to the use of information, as determinants of route-switching propensity.

These results are generally consistent with and complementary to those of Mannering's Poisson regression model of reported switching frequency by a smaller sample of Seattle commuters (*15*). Though the exact variable definitions were different, the results confirm Mannering's findings on the relative importance of trip time and network condition measures. Similarly, age was significant for both Mannering's and the Austin commuting populations. The principal difference was that sex was definitely not significant in explaining route-switching propensity in the Austin data; it is possible that the effect of sex on the frequency of switching is significant or that the data may be capturing patterns in recall, perceptions, and reporting of frequency by the two sexes.

Morning Departure Time Switching

The specification and estimation results for the departure time-switching propensity of a.m. commuters with regular work hours is presented in Table 3. Compared with the a.m. route-switching model, workplace-related variables and individual attitudes exerted greater influence. Whereas travel time was still significant, geographic variables and other network condition indicators did not yield improved explanatory capability. The threshold effect associated with reported trip times below 10 min was present here as well. However, the nonlinearity beyond 35 min was not present here, as the propensity of departure time switching continued to increase with trip time. Longer commutes offer greater time-savings potential than shorter trips, and switching departure time is possible (and even more important) when there are no route alternatives for the trip.

The new group of variables in this model pertain to the commuter and the workplace. Lateness tolerance at the workplace was discussed in a previous section; a binary indicator variable was included in the specification to capture its effect. The estimated coefficient, which exhibited strong statistical performance, indicates that commuters working in an environment with a high tolerance for late arrivals had lower switching propensity than commuters whose environment is without such tolerance. In the absence of a penalty for late arrival, there appears to be less incentive to change departure times to beat traffic. Beyond its significance for commuting behavior, this finding may have broader implications from the standpoint of the effect of rules at the workplace on the employee's lifestyle, morale, and productivity.

Interestingly, commuters with lateness tolerance who still prefer to arrive at the workplace before the official start time had greater departure time-switching propensity than those, also with tolerance, who prefer to arrive "as work starts." This effect was captured by the PAT variable (for those with tolerance) included in the specification. Apparently, these commuters set a target for themselves and thus behave more like those who do not have such flexibility at work, probably a reflection of inherent preferences and attitudes (work ethic), including risk aversion. A similar effect was captured in the laboratory experiment results of Chang and Mahmassani (*21*). However, considering the effect of this variable together with

TABLE 3 ESTIMATION RESULTS FOR A.M. DEPARTURE TIME-SWITCHING MODEL FOR COMMUTERS WITH REGULAR WORK HOURS

Variable Description	Estimated Coefficient	t-statistic
Constant	-1.267	-3.95
Travel time (tt), in minutes, if tt ≥ 10 (0 if tt < 10)	0.042	3.83
Lateness Tolerance at workplace indicator (1 if yes, 0 otherwise)	-0.891	-3.33
Preferred arrival time, in minutes prior to official work start time, if lateness tolerated at workplace (0 otherwise)	0.025	1.72
Job type indicator for category 3 workers, i.e., with low power or strict schedules (if category 3, 0 otherwise)	0.290	1.15
Radio traffic report listening indicator (1 if yes, 0 otherwise)	0.965	4.19
Number of observations	412	
Log-likelihood at zero	-285.58	
Log-likelihood at convergence	-253.63	

that of the lateness tolerance indicator, it was found that even commuters with lateness tolerance and a large PAT still had lower switching propensity than commuters with no lateness tolerance. A similar PAT term, but for those without lateness tolerance, exhibited no significant explanatory capability.

An attribute that captured both individual attitudes and workplace considerations was the worker's job status and whether the work was constrained to a particular schedule. All job titles reported in the survey were divided into three categories: professionals and supervisors; blue collar and semitechnical; and support, clerical, and schedule-bound. Clearly, those in the third category had less control of their work schedules. Whereas some of this effect was captured by the lateness tolerance variable, an indicator variable for workers in the third category was included in the model, though it exhibited moderate statistical performance. Typical reported job titles included in this category were secretary, teacher, clerk, paralegal, and administrative assistant. Other attributes, such as age and sex, did not exhibit significant explanatory power.

As in the route-switching model, commuters who listen to radio traffic reports had greater propensity to switch their time of departure for work. The statistical performance of this variable was strong, as in the a.m. route-switching model. This effect is important from the standpoint of in-vehicle navigation systems. Whereas one would assume that real-time information might only influence path selection (because the commuter would have already left home), the results obtained here suggest that such information could significantly influence trip timing decisions as well, possibly through repeated exposure to the information over time. This would enhance the desirability of such information, given the previously mentioned relative effectiveness of peak spreading versus route control suggested by simulation results described elsewhere (*20*).

The conclusions pertaining to the effect of trip time are similar to those of Mannering (*15*) (trip time was included in both specifications, though with no threshold effect in the Seattle case). However, there appear to be conflicting indications regarding the effect of "flexibility" at the workplace. Part of the apparent contradiction may be definitional. Mannering included an indicator for "flexible work start time," which exhibited a positive coefficient (i.e., those with flexibility switch more), though with unconvincing statistical significance (*15*). The Austin model explicitly differentiated between commuters with regular and flexible work hours. The results pertain to the former group; the latter group eludes explanation given the sample information. The notion of flexibility included in the Austin model is tolerance for late arrivals relative to the regular work hours. Its effect has consistently emerged with the proper sign and convincing statistical significance. The age and marital status variables, included in Mannering's model, were not significant for the Austin sample.

Evening Route Switching

The specification and estimation results for the p.m. route-switching model are shown in Table 4. Essentially the same variables as the a.m. route-switching model were included in the specification. The principal differences were that the tapering off of route-switching propensity for trip times in excess of 35 min could not be picked up and that there was no need to restrict the effect of average travel speed to medium-length trips. In addition, the specification included the previously described lateness tolerance indicator. Commuters with tolerance appeared to be more inclined to switch routes in the p.m. commute. This may have been due to their ability to leave earlier to take advantage of opportunities on alternative routes or to the capture of other geographic characteristics that could not be otherwise identified. The effect of radio traffic reports on switching propensity remained strong in this case as well.

TABLE 4 ESTIMATION RESULTS FOR P.M. ROUTE-SWITCHING MODEL FOR COMMUTERS WITH REGULAR WORK HOURS

Variable Description	Estimated Coefficient	t-statistic
Constant	-1.227	-1.76
Travel time (tt), in minutes, if $10 \leq tt \leq 35$ (0 if $tt < 10$, 35 if $tt > 35$)	0.046	3.83
Average travel speed, in mph (0 otherwise)	-0.018	-1.01
Alternate route availability indicator (1 if available, 0 otherwise)	0.744	1.96
Lateness tolerance at workplace indicator (1 if yes, 0 otherwise)	0.343	1.44
Age category index (1 if age < 18, 2 if $18 \leq$ age ≤ 29, 3 if $30 \leq$ age ≤ 44, 4 if $45 \leq$ age ≤ 60, 5 if age > 60)	-0.185	-1.09
Radio traffic report listening indicator (1 if yes, 0 otherwise)	1.311	5.129
Number of observations	365	
Log-likelihood at zero	-253.00	
Log-likelihood at convergence	-223.01	

Evening Departure Time Switching

The last model relates the propensity to switch departure time in the p.m. commute to the four types of factors discussed earlier. As noted previously, relatively fewer commuters reported changing the time at which they leave work for home than in the other three decision situations analyzed. Table 5 summarizes the model specification and corresponding parameter estimates. Several differences from the other three cases can be noted. First, the radio traffic report indicator did not significantly influence commuters to change their work leaving time, even though it may have induced them to switch routes. Second, female commuters had a greater propensity to adjust their work leaving time than males, possibly because of more stringent constraints associated with picking up children from school. This finding is consistent with Mannering and Hamed's results in their study of commuters' decisions to delay their work-to-home trips (*16*).

Compared with the a.m. departure time-switching model, this model included additional terms to capture network conditions. Two indicators for work end time captured commuters' greater propensity to adjust their work leaving time when the official work end time falls during the evening peak period. A differential effect appears to be present within the peak. Commuters with later work end times (but still within the congested peak) tended to switch more, possibly because they could avoid the worst by slightly delaying their departure. The alternative route availability indicator was also included in this specification. The positive sign suggests that the same trips for which several alternative routes were available experienced generally higher congestion than the rest of the network. Another difference from the a.m. departure time-switching model was the significance of the PAT for those with no lateness tolerance at the workplace. Commuters with greater PAT and no lateness tolerance were less likely to change their p.m. departure time. This variable appears to capture individual risk preferences. Commuters with high PAT were likely to be more risk averse and thus less likely to want to change the time at which they leave work.

In general, congestion appears to be the major determinant of commuters' propensity to change the time at which they leave work. The majority of commuters do not appear willing to stay later at work to beat the traffic, and most cannot leave earlier. Listening to traffic reports does not appear to exert additional influence on this behavior.

CONCLUDING COMMENTS

The analysis presented in this paper has provided useful insights into the trip making behavior of commuters, particularly with respect to departure time- and route-switching behavior for both the home-to-work and work-to-home commute. The relative effects of geographic considerations, network conditions, rules at the workplace, individual characteristics, and use of information on this behavior were analyzed. Generally, a.m. route switching appears to be primarily motivated by geographic considerations and network considerations rather than by sociodemographic characteristics (other than age) or rules at the workplace. On the other hand, a.m. departure time switching is clearly more influenced by factors such as lateness tolerance at the workplace, job position, and other individual characteristics. For the p.m. commute, congestion is the main motivator for both route and departure time switching. The main asymmetries between a.m. and p.m. were observed for departure time switching.

The use of information, captured through the radio traffic reports indicator, exerted a significant positive effect on the propensity for switching in all cases with the exception of p.m. departure time switching. The indirect implication for in-vehicle information systems is that users who receive such information tend to respond through path selection and may even

TABLE 5 ESTIMATION RESULTS FOR P.M. DEPARTURE TIME-SWITCHING MODEL FOR COMMUTERS WITH REGULAR WORK HOURS

Variable Description	Estimated Coefficient	t-statistic
Constant	-1.396	-3.92
Travel time (tt), in minutes, if tt ≥ 10 (0 if tt < 10)	0.025	2.60
Early PM peak indicator (1 if work end time between 4:45 and 5:45, 0 otherwise)	0.282	1.06
Late PM peak indicator (1 if work end time between 5:46 and 6:15, 0 otherwise)	0.854	2.41
Alternate route availability indicator (1 if available, 0 otherwise)	0.666	1.87
Preferred arrival time, in minutes prior to official work start time, if no lateness tolerance at workplace (0 otherwise)	-0.017	-1.89
Gender (1 if male, 0 female)	-0.557	-2.29
Number of observations	393	
Log-likelihood at zero	-272.4	
Log-likelihood at convergence	-221.7	

adjust their departure time in the morning. However, the scope for spreading the evening peak period (by having commuters with regular work schedules alter their work leaving time) appears to be more limited.

As noted earlier, this analysis is primarily exploratory in nature. The limitations in the data are recognized, and the self-reported nature of the variables used in the analysis introduces unavoidable inaccuracies. Nevertheless, the insights obtained appear plausible and complementary to other findings in the limited body of knowledge available on commuting behavior. It is hoped that this analysis will provide insight into the interaction between the choices. Some of the data concerns have motivated the second stage of the survey, described earlier, which will provide detailed diaries of commuters' actual trip time and path selection decisions, though for a smaller sample. With increasing concern for urban and suburban congestion in cities worldwide and interest in the potential of advanced technologies, it appears that further attention should be directed at commuting and trip making behavior.

ACKNOWLEDGMENTS

This paper is based on work conducted as part of a study funded by the General Motors Research Laboratories. The authors are grateful to Robert Herman and Richard W. Rothery for many fruitful interactions regarding this survey and helpful comments on the survey form. The assistance of Gregory Hatcher in conducting the survey is appreciated. The authors remain solely responsible for the analysis and conclusions presented in this paper.

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Publication of this paper sponsored by Committee on Traveler Behavior and Values.