# Daily Variability of Route and Trip Scheduling Decisions for the Evening Commute

S. Gregory Hatcher and Hani S. Mahmassani

The day-to-day variation of individual trip scheduling and route decisions for the evening commute is addressed on the basis of detailed 2-week diaries of actual commuting trips completed by a sample of automobile commuters in Austin, Texas. The potential impact of using alternative measures of variability in the context of the daily commute is illustrated by comparing a "day-to-day" with a "deviation from normal" approach to individual switching behavior. Models are presented to relate observed route and departure time switching patterns to the commuters' characteristics, such as workplace conditions, socioeconomic attributes, and traffic system characteristics. About 39 percent of all reported evening commutes contained at least one intermediate stop, highlighting the importance of trip linking in commuting behavior. These multipurpose trips are shown to significantly influence the route and joint switching behavior of the commuters. The emerging picture of evening commuting habits clearly suggests high variability of the daily departure time from work, in part due to the trip-scheduling flexibility associated with this trip.

The trip decisions made by daily work commuters have a determining effect on urban traffic congestion and associated air quality. The effectiveness of several important approaches and policies aimed at alleviating these problems depends on commuters' responses to those measures and thus requires an understanding of commuter behavior processes and the development of predictive models of these processes. Such approaches include peak spreading through flexible hours, trip reduction through telecommuting, and traffic management through the use of origin-based and in-vehicle real-time information (which falls under the IVHS umbrella).

In the past few years, commuter behavior has been the subject of several studies, but with a rather limited scope. Most of these have focused on the morning home-to-work journey. Much less attention has been devoted to the evening return-home commute, which is a major factor in the formation of congestion during the evening peak period. Mannering and Hamed (*1,2*) have studied the timing of the return-home trip for a small sample of commuters in the Seattle area as well as the activity patterns of workers at the end of the work day (*3*). As limited as these studies have been, they still provide useful insights into this important aspect of commuter behavior, pointing in particular to the flexibility available to commuters in such decisions and the sociodemographic factors influencing this behavior.

S. G. Hatcher, The MITRE Corporation, 600 Maryland Avenue, S.W., Suite 755, Washington, D.C. 20024. H. S. Mahmassani, Department of Civil Engineering, The University of Texas at Austin, ECJ Hall 6.204, Austin, Tex. 78712.

There appear to be virtually no published studies on the daily variability of actual trip timing and route choice decisions made by commuters with regard to their evening return-home commute. These aspects are significant for the following reasons: (*a*) there appears to be good potential for influencing such decisions to improve traffic conditions and air quality, given the apparently greater degree of flexibility that workers have in the evening; (*b*) such influence is likely to be achievable through emerging information technologies; (*c*) commuting trip patterns are generally assumed to be among the most temporally stable trip purposes, and the extent of their daily variability is not sufficiently documented; and (*d*) actual path choice decisions of individual commuters have not been documented in the past, certainly not from day to day.

A major difficulty in studying the preceding aspects pertains to the observation of the actual behavior of commuters over time, especially in terms of specifying the actual paths traveled by commuters through the network. In previous work, Mahmassani and coworkers have investigated these decisions primarily through laboratorylike experiments under controlled conditions (*4–6*). In this study, commuter decisions are observed in an uncontrolled environment, in which they are influenced by a multitude of interacting factors, including trip chaining considerations, which were controlled for in the laboratory experiments. The study is based on a detailed 2-week diary of such decisions.

## DESCRIPTION OF SURVEY AND CHARACTERISTICS OF PARTICIPANTS

This study is based on a survey of a sample of commuters in the northwest section of Austin, Texas, a moderately affluent suburban residential area adjacent to major technology-based manufacturing and R&D activities, with commuting patterns that include a large inter- and intrasuburb component. The survey was conducted in two stages: an initial short screening survey sent to 3,000 randomly selected households (all daily work commuters in a household were asked to complete separate survey forms), and a detailed trip diary. The first mailing was a short, one-page questionnaire on general commuting habits and tendencies. The second stage consisted of a 2-week work trip diary sent to 331 selected first phase respondents (all automobile commuters). A complete description of the first-stage effort, which yielded 624 (in some cases partially) completed surveys, can be found in Caplice (*7*). Detailed analyses including the estimation of switching models completed in the first stage of the survey are presented in previous

work (7,8). These analyses are based on static stated responses regarding route and departure time switching in general. Data of this nature have well-known limitations with regard to correspondence with actual behavior.

These limitations were addressed in the second stage of the survey, which consisted of very detailed diaries of actual departure and arrival times, street-by-street route descriptions, and intermediate stop (trip-chaining) information for both the morning and evening commuting trips for each day of the 2-week period. In addition, the survey asked for the official work start time for the morning commute and the official work end time and target arrival time at home (if any) for the evening commute. This information can be used to measure daily travel time, schedule delay, and departure time switching. The routes were coded using a graph representation of the 1985 network of the Austin area (obtained from the Planning Division of the Texas State Department of Highways and Public Transportation). More details on the format of the second-stage trip diaries can be found in Hatcher (9). A total of 164 participants completed at least 3 days of the diary. The analysis was limited to those trips that begin and end with the usual work and home locations (for each commuter), resulting in 1,312 usable work-to-home trips.

General commuting information for the diary participants is given in Table 1. The majority are males, are between the ages of 30 and 60, and own their place of residence. They prefer to arrive about 15 min on the average before their official work start time. About 43 percent of the commuters reported tolerance to lateness at the workplace in excess of 5 min. The average travel time from work to home for the commuters on days with no intervening stops is 23.6 min. Comparisons of the distributions of the variables in Table 1 with those in the first-stage survey indicate that the diary participants are representative of all first-stage respondents.

## TRIP-CHAINING BEHAVIOR

The variability of trip-timing and route choice decisions cannot be properly analyzed without considering the associated trip-linking behavior of the commuters. During-work trip chains (beginning and ending at work) and home-based trip chains (beginning and ending at home), not recorded in our travel diaries, have been addressed by other authors, such as Kitamura et al. (10). The trip-chaining behavior addressed in this paper corresponds to the critical evening commuting periods. Since only after-work paths are considered, all trips begin at work and end at home. These trips may or may not have intermediate stops.

Diary information available for each stop includes location, purpose, arrival time, and departure time. Stop locations were coded to the nearest node (or centroid) of the Austin network. Twenty-one initial stop purposes were coded, then subsequently combined into five major activity groups for analysis:

- Serve passenger,
- Personal business,
- Food/recreational/social,
- Shopping, and
- Other (includes meetings, medical appointments, and work-related errands).

A total of 516 (39.3 percent) out of 1,312 commutes had one or more stops. About 11 percent of all evening trips had two or more stops. In total, 719 after-work stops were documented in the diaries. The relative frequency breakdown of activity types of these stops is as follows: personal business, 24.2 percent; shopping, 23.8 percent; food/social/recreational, 19.9 percent; serve passenger, 16.8 percent; and other, 15.3 percent.

For each commuter, a stops ratio was calculated by dividing the number of trips with stops by the total number of trips reported. For example, a stops ratio of 0.5 indicates that the commuter stopped on exactly half of the evening commutes. Only about 14 percent of the commuters did not report making a stop on any of their commutes during the survey period (stops ratio = 0.0). At the other extreme, about 5 percent of them made stops on every trip (stops ratio = 1.0). A wide spread of values was observed for the stops ratio, a reflection

**TABLE 1 Characteristics of the 164 Diary Participants[a]**

| | | |
|---|---|---|
| Average Usable Trips per Commuter (164) | | 8.00 (10 is maximum) |
| Average Actual PM Travel Time (No Stops) (156) | | 23.6 minutes |
| Type of Work Hours (164) | Regular Work Hours | 84.8% |
| | Flexible Work Hours | 10.3% |
| | Scheduled Shift Work | 4.3% |
| | Other | 0.6% |
| Average Early Preferred Arrival Time at the Work Place (159) | | 15.6 min |
| Percentage with Lateness Tolerance (>5 min) at Work (162) | | 42.6% |
| Commuters Listening to Radio Traffic Reports (164) | | 67.7% |
| Gender (male) (164) | | 67.7% |
| Age (164) | Under 18 | 0.0% |
| | 18-29 | 4.3% |
| | 30-44 | 48.8% |
| | 45-60 | 42.6% |
| | over 60 | 4.3% |
| Commuters Renting Their Residence (164) | | 8.5% |

[a] Sample size of diary participants for each response is in parentheses.

of both different commuter trip-linking habits and daily variability in the commuting pattern of each participant (both inter- and intrapersonal variability).

Some workers routinely make a stop during their evening commute; for example, a parent may pick up a child at school or a day care center on the way home from work. The behavior of routine stoppers may vary significantly from that exhibited by those making nonroutine stops. With this in mind, the set of all stops was separated into routine and nonroutine stops. Though several definitions are possible, a stop was classified as routine if it is made (for a given commuter) (*a*) at the same location and (*b*) with a frequency of at least three in five commuting trips (the location had to be visited at least three times to be considered). This definition is based on the location and not the purpose of the stops, although most stops at a given location will have the same purpose. Huff and Hanson (*11*) used "core stops" to describe a similar phenomenon and studied the effect of three core-stop definitions.

By our definition, 115 (15.9 percent) of the evening stops are routine. Furthermore, 21.7 percent of the trips with stops contained routine stops. Sixteen commuters (9.7 percent of all commuters, 11.3 percent of those with stops) had at least one routine stop (one had two). As expected, the majority of these routine stops are made to serve a passenger (62.6 percent of all routine stops). More detail on the observed trip-chaining characteristics can be found in related work (*9,12*).

## TRIP-SCHEDULING AND ROUTE DECISION VARIABILITY

Critical to the modeling of commuter behavior are the mechanisms by which users choose routes and departure times, and the factors that determine the variability of these decisions from day to day. In this section, we analyze the departure times and street paths taken by each commuter for the evening work journey over the 2-week survey period.

A departure time switch can be defined in several ways. In previous work, Mahmassani et al. (*4*) defined a departure time switch in a dynamically evolving context as a day-to-day change of a certain magnitude (e.g., 5 min). Mannering (*13*) described a time change as a deviation from a "normal" departure time with the "intent of avoiding traffic congestion and/or decreasing travel time." In this study, we compare alternate switching definitions and thresholds and illustrate the dependence of certain behavioral conclusions on these definitional issues. Two ways of capturing departure time switching behavior are discussed here: (*a*) switching from a commuter's median departure time (median switching) and (*b*) switching from a user's previous day's departure time (day-to-day switching). Median switching is intended to capture deviations from a usual daily routine. The median was chosen for this purpose instead of the mean to avoid the undue influence of outliers in a commuter diary. By the day-to-day definition, the current day is considered a switch from the previous day if the absolute difference between their respective departure times exceeds (or meets) some minimum threshold. This definition is important in modeling the day-to-day evolution of flows in the commuting system and dynamic equilibrium processes (*14*).

We also explore two definitions of a route switch. First, we define a mode route switch as a deviation from the normal or mode (most frequently used) network route (a route is a unique sequence of network nodes), in which the commuter follows a "different than usual" set of nodes to arrive at work. This criterion recognizes the observed dominance of one route over all others for most commuters. Second, we define a day-to-day route switch as a route that is different from the previous day's route. To minimize capturing trivial route switches, minor deviations around the trip ends (neighborhood streets) or a network node (e.g., a minor cutoff street to avoid an intersection) are not considered route switches.

Results of the departure time and route switching analysis are presented in Table 2. Departure time switching thresholds of 3, 5, and 10 min are considered: deviations (absolute value) greater than or equal to the thresholds are considered switches. We attempt to control for departure time switching that is directly induced by a different work end time by limiting the analysis to commuter trips with the same work end time (for median switching, Definition 2) or trips in which the work end time is within 5 min of the previous work end time (for day-to-day switching, Definition 4).

Table 2 clearly indicates that workers engage in a substantial amount of evening departure time switching. As expected, the day-to-day definition results in a higher percentage of switches than does the median definition. In fact, additional analysis indicates that more than 40 percent of these commutes are 20-min day-to-day switches. The 3-min threshold tends to confound what may be considered "noise" with actual intended changes in departure time. The 5- and 10-min thresholds appear to be the most plausible for the purpose of this study. These two thresholds are also appealing because they correspond better with clock times than the 3-min threshold.

Route switching is not as frequent as departure time changing for the evening commutes. Less than two in five trips use a nonmode (i.e., other than the most frequent) route, suggesting the existence of a usual route for most commuters. When trips with stops are excluded from the data (Definition 2), nonmode trips account for only 12.7 percent of the remaining trips. Again, the day-to-day definition captures more switching than other definitions. The lower frequency of route switching relative to departure time switching is consistent with the results of stated preference experiments under simulated traffic conditions (*5*).

A joint switch consists of both a departure time and route switch on a given trip. Two definitions of joint switching are explored (corresponding to the definitions for the individual choice dimensions). First, a median/mode joint switch is defined as a median departure time switch together with a mode (all days) route switch. Second, a day-to-day joint switch is defined as a day-to-day departure time switch together with a day-to-day route switch. As shown, a significant amount of joint switching occurs during the evening commute. More than two in five evening commutes are joint 5-min day-to-day switches.

This variability at the individual level suggests a high potential for variable aggregate temporal and spatial demand patterns during the evening peak period. In addition, the sensitivity of behavioral conclusions to definitional and measurement issues is highlighted by these results. Note that our

**TABLE 2 Results of Departure Time and Route Switching Analysis**

**Percent of Trips that are Switches**

**Departure Time Switching**

| Definition | Switch Threshold (minutes) 3 | 5 | 10 | Number of Trips |
|---|---|---|---|---|
| 1. median | 70.3 | 63.0 | 50.0 | 1298 |
| 2. median (WEC[a]) | 63.8 | 55.7 | 40.8 | 961 |
| 3. day-to-day | 85.7 | 79.8 | 65.8 | 1136 |
| 4. day-to-day (WEC) | 81.9 | 74.6 | 58.8 | 878 |

**Route Switching**

| Definition | % Switches | Number of Trips |
|---|---|---|
| 1. mode (all days) | 36.1 | 1312 |
| 2. mode (days with no stops only)[b] | 12.7 | 796 |
| 3. day-to-day | 53.2 | 1148 |

**Joint Switching**

| Definition | Departure Time Switch Threshold (minutes) 3 | 5 | 10 | Number of Trips |
|---|---|---|---|---|
| 1. median/mode[c] | 26.7 | 24.3 | 19.3 | 1298 |
| 2. median/mode (WEC) | 24.8 | 22.3 | 16.9 | 961 |
| 3. day-to-day[d] | 46.6 | 43.9 | 37.6 | 1136 |
| 4. day-to-day (WEC) | 44.9 | 41.6 | 34.6 | 878 |

[a] WEC= work end controlled
[b] Mode routes were redefined by selecting only days with no stops.
[c] Median definition used for departure time switch, mode (all days) definition used for route switch.
[d] Day-to-day definition used for departure time and route switch.

results correspond to actual decisions observed in the network regardless of the underlying motive. As such, these results provide a characterization of the natural variability of commuter decisions in a real system.

Consistent with the stated preference experiments of Mahmassani and Stephan (*5*), departure time and route switching decisions are not independent of each other, as confirmed by chi-squared tests for the various definitions. The tests confirm that the dependence increases as the departure time switch threshold increases (as reflected in higher computer chi-squared values).

The values in Table 2 do not highlight differences across individuals, especially since different commuters reported different numbers of trips during the survey period. Switching ratios were obtained by dividing the number of switches by the number of possible switches, for each individual, for each departure time and route switching definition (a ratio of 1.0 indicates a switch on every possible day). Figure 1 shows the differences between departure time switching definitions by showing the cumulative relative frequency distributions (across commuters) of the alternative departure time switching ratios (for controlled work end times). For example, the percentage of workers never switching departure time is approximately 19 percent according to the 10-min median definition, 11 percent by the 10-min day-to-day definition, 5 percent by the 5-min median definition, or 3 percent by the 5-min day-to-day definition. These discrepancies underscore the importance of definitional issues with regard to departure time switching. According to the conservative 10-min median definition, 37 percent had a switch ratio of 0.5 or higher. The emerging picture of evening commuting habits clearly suggests high variability of the daily departure time from work.

The cumulative relative frequency distributions of the three route switching ratios are also shown in Figure 1. When all days are analyzed, only 15.5 percent of the users never switch routes during the p.m. commute. About 28.6 percent of commuters switch from this mode with a frequency of more than 1 in 2 days. Significantly less switching relative to the mode route occurs if only no-stop routes are considered, because 64.3 percent of the users never switch routes under these circumstances, and only 7.9 percent have a switch ratio greater than 0.5. Under the day-to-day definition, 52.9 percent of commuters have a switch ratio greater than 0.5. Clearly, the need to link one or more activities along the commute influences path selection and causes a substantial amount of route switching, even for those who would not change routes otherwise. The variability in switching behavior exhibited by the commuters provided the impetus for the modeling efforts presented in the next section.

## SWITCHING FREQUENCY MODELS

Insights into the factors that influence route and departure time switching behavior in connection with the evening commute would contribute to the ability to develop and analyze

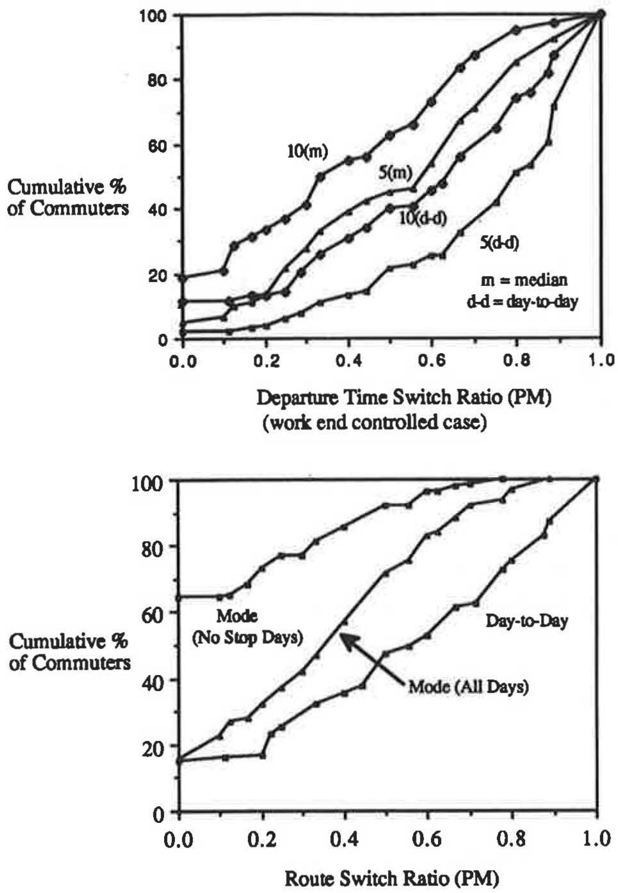


**FIGURE 1 Cumulative distributions of (*top*) departure time and (*bottom*) route switching ratios, by definition.**

demand management policies. In this section, we employ Poisson regression methodology to investigate the effect of the characteristics of the commuter and of the commuting environment on the observed departure time, route, and joint switching behavior.

### Background for Poisson Regression Models

The development of the Poisson regression model of the number of daily switches made by commuters is described in this subsection. Given the nature of the process and the inherent randomness in the number of switches made by different commuters, the Poisson distribution is likely to provide a reasonable description of the total number of switches made by a commuter during the study period. This distribution is particularly appropriate because the dependent variable naturally assumes nonnegative integer outcomes, including a relatively large number of commuters with zero switches (a problem that makes OLS regression biased).

One difficulty encountered here and in surveys of this type is that participants may have completed an unequal number of days for analysis (e.g., some participants completed the full 10 diary trips, but for various reasons others completed only 8 or 9). Standard Poisson regression applications assume an equal number of trials. For this work, the model was derived for different numbers of observed days per commuter. For Commuter $i$, let $d_i$ denote the total number of days recorded, $y_i$ the total number of switches made, $\lambda_i = E(y_i)$, and $\alpha_i$ the mean number of daily switches (i.e., $\alpha_i = \lambda_i/d_i$). The model postulates that the mean daily switching frequency (or rate) for Commuter $i$ can be related systematically to the characteristics of the commuter. Assuming a specification of the form

$$\log \alpha_i = \beta \mathbf{X}_i$$

then

$$\log \lambda_i = \log \alpha_i d_i = \beta \mathbf{X}_i + \log d_i$$

where $\beta$ is a vector of estimable parameters and $\mathbf{X}_i$ is a vector of commuting and socioeconomic attributes for Individual $i$. Note that the value of $\exp(\beta \mathbf{X}_i)$ represents the mean daily number of switches for Individual $i$. Therefore, the probability of a commuter making $y_i$ switches in $d_i$ days is given by

$$P(y_i) = [\exp(-\lambda_i)\lambda_i^{y_i}]/y_i!$$

The parameter vector $\beta$ can be estimated by the maximum likelihood method. The log-likelihood function for the preceding specification (substituting for $\lambda_i$) is given by

$$\log L(\beta) = \sum_i [-\log y_i! - \exp(\beta \mathbf{X}_i + \log d_i) + y_i(\beta \mathbf{X}_i + \log d_i)]$$

The change from the initial log-likelihood value ($\beta = 0$) to the final log-likelihood value (at convergence) provides an informal measure of the model's goodness of fit. The log-likelihood value for a specification consisting of only a constant term (i.e., assuming that all individuals in the sample have the same mean daily switching frequency) is also provided for each of the models in this section. In each of the calibrated models, the constant term is expected to be negative to compensate for the addition of the log $d_i$ term required for the estimation of a mean daily frequency.

The principal explanatory variables considered in the switching frequency models are given in Table 3. These include workplace, personal, commuting, and network variables. To show the effect of trip chaining, the stops ratio (number of trips with stops to total trips) was explored as a potential explanatory variable in the model specifications. Commuters with less than three trips or less than three switching opportunities were excluded from the following models, because (*a*) several essential explanatory variables could not be meaningfully calculated for these users (e.g., the stops ratio and travel time variability measures), and (*b*) the behavior of these individuals did not provide the multiday character that was intended by the specifications. Those left out of the models are a random subsample of the other commuters, since the factors that caused people to report fewer days were not correlated with the same characteristics that determine the modeled behavior (e.g., the individual was sick, on vacation, or on a business trip). Therefore, the exclusions did not create endogeneity in the model specifications.

Note that the developed models correspond to actual switching behavior and are not simply describing a propensity

**TABLE 3 Independent Variables Tested in Evening Departure Time, Route, and Joint Switching Frequency Models**

| Independent Variable | Description/ Remarks |
|---|---|
| work end time | official work end time (median), not actual |
| type of work hours | regular, flexible, shift, and other |
| early preferred arrival time | preferred arrival time before the official work start |
| lateness tolerance at workplace | describes perceived ability to arrive at work after the official work start |
| stops ratio (PM) | ratio of number of PM trips with stops to total number of PM trips |
| routine stopper indicator (PM) | describes a commuter that makes a stop at the same location during at least 3 of 5 commutes |
| alternate route availability | indicator variable that describes the availability of meaningful route choices in the network |
| average travel time (PM) | travel time for days without stops only |
| standard deviation of travel time (PM) | for days without stops only |
| coefficient of variation of travel time | standard deviation divided by the mean tt |
| average speed | average travel speed for trips without stops |
| average travel time on mode route | travel time for days on which the mode route was taken (for route switching model) |
| average speed on mode route | average travel speed for days on which the mode route was taken |
| travel distance on mode route | network travel distance of mode route |
| radio traffic report listening indicator | describes whether or not commuter usually listens to radio traffic reports during commute |
| job power (as a function of job title) | indicator variable which represents the degree of schedule control, power, and responsibility associated with a particular job title |
| home ownership indicator | describes whether the participant's place of residence is bought or rented |
| gender | male/female |
| age | 5 age group categories were available |

to switch one's departure time or route, as in the models developed for the first-stage questionnaire of this research effort (*7,8*). General comparisons of the models developed here to describe actual behavior with those describing reported propensity to switch (with traffic conditions in mind) will be made where appropriate. Some disagreement between switching propensity and actual switching frequency is expected. This disagreement will be a result of definitional issues as well as the complex human behavioral considerations (including trip chaining) present in a real commuting system. Note that the models developed for the first-stage survey were calibrated for those with regular work hours only, whereas those developed here did not explicitly exclude other types of work hours.

## Departure Time Switching Frequency

Because the alternative departure time definitions exhibit the same general trends, the model is presented only for the day-to-day switches that exceed a 10-min threshold, for days with the usual work end time. The work end time is controlled here so that the observed switching behavior is not a result of different work schedules. Thus, some commuters with shift work hours were excluded from the estimation data set.

Table 4 contains the attributes found to be important in the evening departure time switching frequency model (and the route and joint switching frequency models) and their corresponding parameter estimates and *t*-statistics. Workplace attributes, individual characteristics, and traffic system characteristics influence departure time switching behavior in the evening.

Lateness tolerance and travel time variability (expressed here as the coefficient of variation) increase the expected number of departure time switches of trip makers. It is interesting that lateness tolerance increases the likelihood of p.m. time switching, even though it is generally used to describe flexibility in the a.m. work start time. This may be a result of workplace rules (in terms of working a specified number of hours). It may also be capturing other job characteristics (such as job power or overall flexibility). The only other workplace variable included in the specification is a late work end time indicator, which can be interpreted as a traffic system characteristic. The negative coefficient indicates that those with work end times of 6:15 p.m. or later are expected to make fewer departure time switches than those whose work ends earlier. Therefore, those with late work end times are less willing to further delay their departure. Of course, there is no need for them to do so because the p.m. rush hour in Austin typically ends by 6:15 or 6:30.

The socioeconomic and individual attributes included in the model correlate negatively with departure time switching. Those making at least one routine stop during the evening trip are likely to make fewer switches, probably because they are constrained by their stop (which is likely to be a serve passenger stop). Males over 44 years of age also make fewer switches than others. This finding could be an indication that older males are inclined to be risk averse and creatures of habit and may have fewer household responsibilities that require deviating from an established routine. The home ownership indicator variable suggests that those renting make fewer evening time switches than those owning. Perhaps this variable is capturing a group of socioeconomic and life-style effects that determine risk aversion and habit persistence.

**TABLE 4 Estimation Results for Poisson Regression Models of Daily Switching Frequency for P.M. Commute (Calibrated for Those with at Least Three Switching Opportunities)**

| | DEPARTURE TIME[a] | | ROUTE[b] | | JOINT[c] | |
|---|---|---|---|---|---|---|
| Independent Variable | Estimated Coefficient | t-statistic | Estimated Coefficient | t-statistic | Estimated Coefficient | t-statistic |
| constant | −0.730 | −7.01 | −2.018 | −18.02 | −2.283 | −8.35 |
| lateness tolerance at workplace (1 if over 5 min) | 0.241 | 2.27 | | | 0.237 | 1.81 |
| late work end time indicator[d] (1 if work end time ≥ 6:15) | −0.609 | −2.23 | | | | |
| late PM peak hour indicator[d] (1 if work end is between 5:46 and 6:15) | | | 0.534 | 2.26 | | |
| PM peak period work end time indicator[d] (1 if work end time is between 5:15 and 6:15) | | | | | 0.268 | 1.35 |
| PM routine stopper indicator (1 if makes a routine stop on PM commute) | −0.436 | −2.84 | | | | |
| PM stops ratio, if less than 0.75 (0.75 if ratio ≥ 0.75) | | | 2.190 | 8.41 | 1.724 | 6.08 |
| additional PM stops ratio over 0.75 ([ratio−0.75], if ratio ≥ 0.75) | | | −2.295 | −2.84 | −4.159 | −2.28 |
| coefficient of variation of non-stop PM travel time (std. deviation travel time / mean travel time) | 1.595 | 2.82 | | | 0.930 | 1.51 |
| PM mode route medium length travel time indicator (1 if average tt is between 20 and 30 minutes) | | | 0.222 | 2.01 | | |
| home ownership indicator (1 if renting, 0 otherwise) | −0.431 | −2.54 | | | | |
| male over 44 indicator (1 if male and over age 44) | −0.150 | −1.43 | | | | |
| age indicator (1 if age is between 30 and 60) | | | | | 0.332 | 1.35 |
| Log-likelihood at zero | −335.38 | | −700.76 | | −465.59 | |
| Log-likelihood for constant only | −263.71 | | −346.38 | | −243.07 | |
| Log-likelihood at convergence | −244.82 | | −289.33 | | −212.32 | |
| Number of observations | 121 | | 160 | | 121 | |

[a] 10-minute day-to-day definition, work end controlled
[b] mode route switching (all days definition)
[c] 10-minute day-to-day (WEC) departure time and day-to-day route definition
[d] Median PM departure time used for five individuals without official work end times (flexible hours).

Surprisingly, job power, an indicator variable intended to capture the degree of schedule control, power, and responsibility associated with a particular job title, was not found to significantly influence the p.m. departure time decision. It was thought that those with low-power jobs would make fewer switches than those with high-power jobs, but the hypothesis was not supported by the results. The effect of job type may have been confounded with other variables, such as age, gender, and housing tenure. Perhaps a finer grouping of job type would have been necessary to detect such significance. Flexible work hours also did not significantly influence the frequency of switches, though the effect may already be captured by other related variables.

Estimation results for the binary logit models of evening departure time and route-switching propensity from the first-stage survey are given in Table 5 (7). Comparison of our results with the first-stage binary model of p.m. departure time switching propensity reveals two similarities. First, males have a lower propensity for switching than females in both models. Also, two p.m. peak-hour indicator variables in the first-stage model indicate an increased switching propensity for those with work end times between 4:45 and 6:15 p.m. This is consistent with the finding here that users with late work end times switch less frequently than others. The other three varibles in the first stage model are reported travel time (positive effect), an alternate routes indicator (positive effect), and preferred arrival time for those without lateness tolerance (negative effect). These three variables were found to have no significant influence on actual departure time switching frequency for the p.m. commute.

**Route Switching Frequency**

The route switching modeled here is obtained with the mode route (all days) definition, which captures switches relative to a commuter's usual route (regardless of the magnitude of the switches). Table 4 contains the attributes included in the specification of the route-switching frequency model, along with their corresponding coefficient estimates and *t*-statistics. The p.m. stops ratio is the most important explanator of route-switching behavior. Two traffic system (or commute) attributes are included in the specification: a late peak-hour indicator and a medium length travel time indicator.

As expected, the route-switching frequency increases as the stops ratio increases, up to a point (0.75 in this model). Beyond this threshold, the likelihood of route switching actually decreases (as illustrated by the negative coefficient for the additional stops ratio), because routine stoppers (or others with a high stops ratio) may travel the same route on most trips. The late p.m. peak-hour indicator reveals that those having work end times between 5:46 and 6:15 make more route switches than other commuters. This is probably a reflection of the congestion experienced during this period, as commuters make more route switches in order to avoid delays. The last variable to display significance in the model is a mode route medium length travel time indicator, because those with travel times between 20 and 30 min switch more frequently than others. This variable may reflect the lack of opportunity in the network for significant improvements for very short or very long trips. It may also reflect a fundamental behavioral tendency: travelers with short trips may see no need for al-

**TABLE 5 Estimation Results for Binary Logit Models of Departure Time and Route Switching Propensity for the Evening Commute from Work to Home[a]**

| PM SWITCHING PROPENSITY MODELS: (Stage 1 Sample) (values shown are the estimated coefficients) | | |
|---|---|---|
| Independent Variable | DEPARTURE TIME | ROUTE |
| Constant | -1.396* | -1.227 |
| Reported Travel Time in Minutes (tt) (0 if tt< 10, tt if ≥ 10) | 0.025* | |
| Reported Travel Time in Minutes (tt) (0 if tt< 10, tt if 10 ≤ tt ≤ 35, 35 if tt > 35) | | 0.046* |
| Approximated Travel Speed in mph (spd) | | -0.018 |
| Lateness tolerance at the Work Place (1 if unlimited tolerance, 0 Otherwise) | | 0.343 |
| Early PM Peak Hour Indicator (1 if work end time is between 4:45 and 5:45, 0 Otherwise) | 0.282 | |
| Late PM Peak Hour Indicator (1 if work end time is between 5:46 and 6:15, 0 Otherwise) | 0.854* | |
| Preferred Arrival Time (pat) in minutes before work starts for commuters with no lateness tolerance at the Work Place (PAT if no lateness tolerance, 0 Otherwise) | -0.017* | |
| Abundance of Alternate Routes Indicator (1 if available, 0 Otherwise) | 0.666* | 0.744* |
| Age Group ( 1 if age<18, 2 if 18≤ age <30, 3 if 30≤age<45, 4 if 45≤ age ≤ 60, 5 if age >60 ) | | -0.185 |
| Radio Traffic Report Listening Indicator (1 if listens, 0 Otherwise) | | 1.311* |
| Gender (1 if male, 0 if female) | -0.557* | |
| Number of observations | 393 | 365 |
| Log-likelihood at zero | -272.40 | -253.00 |
| Log-likelihood at convergence | -221.70 | -223.01 |

* Estimate has t-statistic of 1.85 or higher.
[a] Calibrated for commuters reporting regular work hours only.

Source: Caplice (1990), Tables 4.10 and 4.11.

tering routes (small absolute time savings), whereas those with long trips may face too much uncertainty with regard to travel time variability to distinguish one route's superiority over another. Surprisingly, the alternate route availability and travel time variability attributes did not show significance by themselves or in combination with other variables. However, the effect of these attributes may have been confounded with that of the late p.m. peak-hour indicator. No other attributes were found to significantly influence route-switching behavior for p.m. trips (including route speed).

Comparison with the binary logit model of evening route-switching propensity for the first-stage survey reveals no direct similarities (see Table 5). The most important variables in the first-stage model are travel time, availability of alternate routes, and the radio traffic report listening indicator, all exerting positive influence on route-switching propensity. These variables were not found to influence actual switching frequency. The only potential similarity in the model of actual switching frequency is to travel time, since the stops ratio is highly correlated with travel time (*9*). The other three variables in the first-stage model specification were approximate travel speed (negative effect), age (negative effect), and lateness tolerance at the workplace (positive effect). These three variables also had no significant influence on route-switching frequency for the evening commute.

### Joint Route and Departure Time Switching Frequency

A joint switch is modeled here by a day-to-day route switch and a 10-min day-to-day departure time switch (with controlled work end times). Because the multinomial logit models developed for the joint departure time and route-switching propensity for the first stage contained no new variables other than those included in the individual models, no further comparisons are made between actual switching and reported propensity for joint switching.

Estimation results for the day-to-day joint switching frequency model for evening commutes are also given in Table 4. As expected, most of the explanatory variables in the joint model are derived from the two individual p.m. switching models. The stops ratio variable is specified as in the evening route-switching model, with similarly signed and equally significant variables. The lateness tolerance indicator and coefficient of variation of p.m. travel time (for trips without stops), significant in the evening departure time switching model, are moderately significant in the joint model.

The other transportation system and workplace attribute in the model is the p.m. peak period work end time indicator. Those with work end times between 5:15 and 6:15 are likely to make more joint switches than those with other work end times, although the coefficient is not strongly significant. This finding again stresses the importance of actual work end times, since those with these work end times find themselves returning home during the peak p.m. traffic period, which may provoke them to seek alternate routes and departure times. The two individual p.m. switching models also contain a work end time indicator variable, in slightly different forms, which are consistent with the joint switching behavior captured here. The last and only other new variable is a socioeconomic attribute: commuters between the ages of 30 and 60 tend to make more frequent joint switches than older or younger trip makers. This may reflect more complex activity and work patterns for middle-aged commuters, resulting in the need for more joint switching.

The models presented in this section provide helpful insight into the factors affecting commuter switching behavior and peak-period variability. The workplace, commuter, and transportation system variables exhibit plausible signs and significance in all three models. The significance of the stops ratio variable in the route and joint switching models emphasizes the need to understand trip-chaining behavior in a commuting context. A daily stop frequency model for the evening commute, based on the Poisson techniques described here, can be found in Hatcher (*9*).

## CONCLUDING REMARKS

This study has provided insight into the trip-scheduling and route choice behavior of commuters for the trip from work to home. The presentation focused on the observed variability of the work trip, which has traditionally been treated as a stable and repetitive phenomenon. About 39 percent of all reported commutes contained at least one intermediate stop, underscoring the importance of trip linking in commuting behavior. Furthermore, trips with stops are much more likely to involve route or joint switching than trips without stops. Trip-scheduling flexibility for the evening commute appears to contribute to a substantial amount of departure time switching. In general, commuters tend to change departure times more frequently than routes, possibly a reflection of a limited route choice set in comparison with a broader set of available departure times.

Emphasis was placed on the definitional issues that arise when studying these behaviors. The analysis used both a "day-to-day" and a "deviation from normal" approach to switching behavior. The day-to-day definition captured a higher frequency of switching than did other definitions.

The models of daily switching frequency related the characteristics of the commuter, workplace, and transportation system to the switching behavior exhibited by the users. The stops ratio is an important determinant in all of the switching models except the evening departure time switching model (in which a routine stopper indicator is contained). Commuting trip time variability is an important determinant in all of the reported switching models except the evening route-switching model, where a medium length travel time indicator displayed significance without interacting with a variability indicator.

Workplace variables such as lateness tolerance and work end time otherwise dominate evening departure time, route, and joint switching behavior. Socioeconomic variables such as gender, age, home ownership, and interaction variables containing gender also display explanatory power, but their effect is not as clear-cut. The lack of agreement and strong significance for socioeconomic variables indicates that they may not be as important in the models as the other variables. Other personal and household characteristics may be important, but the limited availability of personal and socioeconomic exogenous variables precludes their inclusion in the model specifications. Furthermore, some of these characteristics may be indirectly reflected through their effect on trip-chaining patterns, as well as commuter preference indicators.

Although the data are somewhat limited, the behavioral insights gained from this study are important in that actual behavior was observed over a 2-week period rather than only 1 or 2 days. Furthermore, the documentation of actual switching habits is subject to fewer problems than a phone or mail survey, which involves recall or stated intentions by the respondent. Route and departure time switching were shown to be already taking place in actual systems, implying that users may be willing to shift commuting patterns if they were to benefit from these changes. In addition, this study has provided valuable confirmation of insights previously suggested in stated preference experiments involving actual commuters in a simulated traffic system. These findings contribute to the increasingly important task of understanding commuter behavior in real systems.

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