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Social and Behavioral Sciences
Procedia - Social and Behavioral Sciences 104 (2013) 630 – 639

2nd Conference of Transportation Research Group of India (2nd CTRG)

Tour-based departure time models for work and non-work tours of workers

Vishnu B. [a*], Karthik K. Srinivasan [b]

a Research Scholar, Department of Civil Engineering, Indian Institute of Technology, Madras, Chennai-600036, India
b Associate Professor, Department of Civil Engineering, Indian Institute of Technology, Madras, Chennai-600036, India

Abstract

Timing of trips and tours play a very important role in travel demand modeling. To deal with issues related to congestion, the planner must have a clear understanding of the timing of travel patterns. In the literature, there is very little attention to tour-based modeling in the developing country context. The inability of the current practice in evaluating substitution of trips and tours across intra-day periods in responses to time-varying policies (flexible and staggered work hours) and system attributes (congestion or tolls) needs to be addressed. To address these shortcomings, this study uses tours as the fundamental unit of analysis to circumvent discontinuity in mode choice and independence assumption in trip-based models. For this study, tour data from nearly 1000 workers are extracted from the Chennai Household Activity and Travel Survey 2004-05. Based on the information about the peak traffic, the 24 hour time-window was split into 6 time intervals. The nominal nature of the dependent variable is captured using Multinomial Logit Model (MNL). This paper investigates the timing decisions of tours in the context of Indian city, Chennai. Three related sub-objectives are pursued towards this goal: 1. develop models of tour timing (departure times) for workers, 2. analyze the role of individual, household, work-related, modal characteristics and transportation system attributes on this timing decision, and 3. understand the differences in behavior of tour timing between work tours and non-mandatory tours of workers.

Keywords: Departure Time; Tours; Worker; Non-mandatory

1 * Corresponding author. Tel.: +919496591471

E-mail address: vishnub87@gmail.com

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Selection and peer-review under responsibility of International Scientific Committee.
doi:10.1016/j.sbspro.2013.11.157

1. Introduction

Timing of trips and tours play a very important role in travel demand modeling. To deal with issues related to congestion, the planner must have a clear understanding of the timing of the individuals travel. For example, in order to analyze the effect of travel demand management measure such as staggering of working hours, the planner must have detailed information about the type of activities that are pursued and their timing.

In the literature, there is very little attention to tour-based modeling in the developing country context. Most of the existing works focus on trip-based models. Even among the trip-based models, the choice of timing of trips has not received adequate attention. Current practice in planning models in developing countries is to exogenously divide the day into five or six time windows and model the four-step process separately for trips made in each of the time windows. This approach is problematic for evaluating substitution of trips and tours across intra-day periods in responses to time-varying policies (flexible and staggered work hours) and system attributes (congestion or tolls).

To address these shortcomings, this study uses tours as the fundamental unit of analysis to circumvent discontinuity in mode choice and independence assumption in trip-based models. For this study, tour data from nearly 1000 workers are extracted from the Chennai Household Activity and Travel Survey 2004-05. Analysis of descriptive statistics of key variables indicated that the data was representative of travel patterns of the population of Chennai city.

Based on the information about the peak traffic, the 24 hour time-window was split into 6 time intervals, viz. a.m. pre-peak (12.00 midnight-7.30 a.m.), a.m. peak period (7.30 a.m. -10.30 a.m.), a.m. post peak and afternoon period (10.30 a.m. -3.30 p.m.), p.m. pre-peak (3.30 p.m. -5.30 p.m.), p.m. peak period (5.30 p.m. 8.30 p.m.) and after p.m. peak (8.30 p.m. -12.00 midnight). The scope of the paper is limited to a study of tours of workers in Chennai city.

The nominal nature of the dependent variable is captured using Multinomial Logit Model (MNL). This uses Maximum Likelihood Estimation (MLE) to obtain the coefficients and standard errors. The effect of following explanatory variables on tour timing is investigated: individual characteristics (employment status, relation status, etc.), activity availability (timing, activity type, etc.), vehicle availability (number of available vehicles, its access) and transportation system and supply characteristics (congestion, road quality, driving safety, etc.).

This study attempts to contribute to research by modeling the choice of departure time for both mandatory and non-mandatory tours of workers in the context of a developing country.

This rest of the paper is divided into five sections. The first section deals with the literature review followed by results from the exploratory analysis and a section on the methodology. The next section deals with the modeling results and the last section summarizes the findings from the research.

2. Literature Review

Abkowitz (1981) used an MNL model to analyse the departure time for work-trip. They were chosen such that the expected arrival time is early/ late by as early as 40 minutes to as late as 15 minutes. Twelve discrete time intervals were considered, with the duration of each interval considered being 5 minutes. In this work, the effect of work arrival time flexibility, occupational characteristics, income, mode chosen, age, gender, location of the respondents residence and work, travel time and expected loss/ gain (in minutes due to the late arrival) were found to be influential. This research identified the differences in behaviour across people with different designations, income, and age. McCafferty and Hall (1982) also used the MNL to model the time of travel to and from work. In the analysis, three discrete evening peak time intervals were considered, pre-peak [3:45 pm-4:30 pm], peak [4:30 pm-5:30 pm] and post-peak [5:30 pm-6:15 pm]. In addition to the independent variables considered by Abkowitz (1981), the number of work trip made per week and the number of kids were considered. Bhat (1998) analysed the mode chosen and departure time for urban shopping trips jointly using Multinomial-Logit Ordered Generalised Extreme Value (MNL-OGEV) model. For mode chosen, the alternatives such as drive alone, shared drive and transit were considered. A.m. peak times, a.m. off-peak, pm peak, pm off-peak and evening were the alternatives considered for departure time. For modelling departure time, employment status, age, gender, race, household income, location for destination, travel cost, travel time and out-of-vehicle travel times were considered. Mode choice was modelled as a function of the number of cars and presence of children.

Jong et al. (2003) also modeled the time-of-day decision along with mode choice using error components logit model. The model was also compared with MNL and nested logit (NL) models. The set of independent variables considered in the analysis included, travel time and cost (by different modes) and penalty for early/ late arrivals. Habib et al. (2009) using a joint discrete continuous model to investigate the dependence between the trip timing and mode choice. In their research, a combined model using MNL-continuous hazard rate function was used. The explanatory variables included work duration, the number of stops made in the different legs of the home-work home commutes, income, individual demographics such as gender, type of employment, age, zonal characteristics such as type of land-use and trip characteristics such as the in-vehicle time, cost. An accelerated hazard function was used by Bhat and Steed (2002) to model departure time choice as a continuous function. Here, the departure time, starting from midnight (in minutes) is used as the dependent variable. Socio-economic characteristics of the individual (gender, ethnicity, education level, age, income), household characteristics (household size, number and age of children, household income, number and employment status of the adults), employment related characteristics of the individual (employment type, number of hours per week), trip related characteristics such as travel time and travel cost were found to influence the decision regarding the departure time. A continuous logit model for departure time choice was developed by Lemp and Kockelman (2010). A continuous representation of time over the day was used for estimation. Variables such as age, gender and employment status (part-time or not) were found to influence the departure time. In addition the number of tours and travel cost were also considered. From the analysis, it was observed that men and older individuals were found to depart earlier than others. Surprisingly, the average travel time and travel time variance had little effect on the departure time for work trips.

The above review shows that analysis of departure time at tour level is limited as compared to trip level. The literature is even sparser in relation to developing countries. Thus, there is a need to address the above mentioned shortcomings. In order to address these issues, the following objectives have been identified. 1. Develop models of tour timing (departure times) for workers, 2. Analyze the role of individual, household, work-related, modal characteristics and transportation system attributes on this timing decision, and 3. Understand the differences in behavior of tour timing between work tours and non-mandatory tours of workers.

3. Data description and exploratory analysis

Tour level data extracted from the Chennai Household Activity and Travel Survey (CHATS 2004-05) is used for this analysis. Details about the survey are presented in Bhargavi et al. (2007). Based on the information about the peak traffic, the 24 hour time-window was divided into 6 time intervals, viz. a.m. pre-peak (12.00 midnight-7.30 a.m.), a.m. peak period (7.30 a.m. -10.30 a.m.), a.m. post peak & afternoon period (10.30 a.m. -3.30 p.m.), p.m. pre-peak (3.30 p.m. to 5.30 p.m.), p.m. peak period (5.30 p.m. -8.30 p.m.) and after p.m. peak (8.30 p.m. 12.00 midnight). The results of the exploratory analysis are given below.

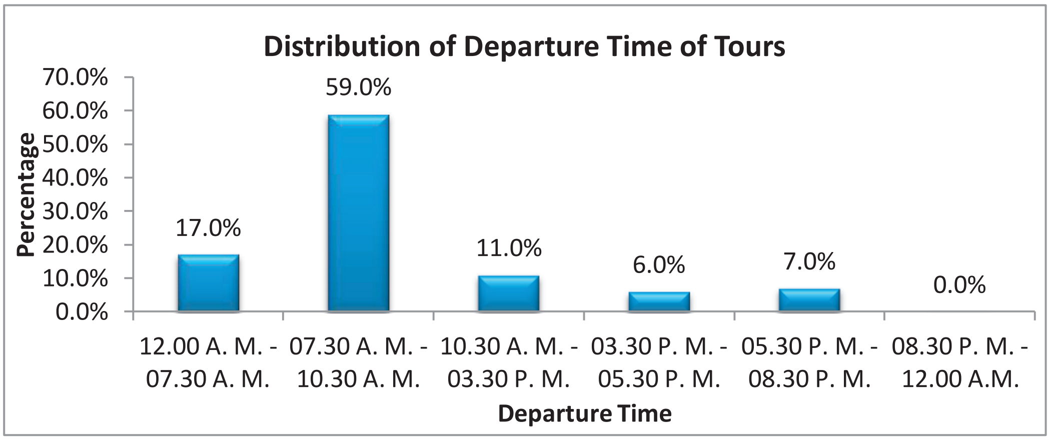

Fig 1. Frequency Distribution of Departure Time of Tours

About 60% of the tours start during the a.m. peak period, a majority of which may be performed for the mandatory activities, such as work or school tours. Another 17% of the tours start during a.m. pre-peak, and could involve maintenance tours such as tours to serve passengers that are associated with the mandatory activities. More than 10% of the tours start during the a.m. post peak & afternoon period and could be intended to pursue maintenance activities available during this time period. About 6% of tours are performed during the p.m. pre-peak period and this is mainly to serve passengers. During p.m. peak period, about 7% of tours are reported and this is for the various maintenance activities. The sample size of tours undertaken after the p.m. peak period was very small and hence, the p.m. peak and after p.m. peak periods are combined for the analysis.

In the analysis of activity patterns of workers, it was observed that about 70% of the tours were single stop work tours. The other major patterns were the Home-Shopping-Home (about 6%) and Home-Social-Home (3.5%). They also undertook a significant percentage of multi-stop tours (11.3%).

In order to examine whether the departure time of tours vary based on the purpose of the tour, the frequency distribution of the timing of tours segmented by purpose was studied. The work tours were further classified based on work time flexibility of the individual. The results of the analysis obtained are given below. From the descriptive statistics, there were no substantial differences in the departure times of workers with and without flexible timings except during a.m. post peak & afternoon period. Based on this, in the modeling of departure time for tours, the mandatory tours of the workers with and without flexible working hours have been grouped together. It was found that most of the tours undertaken by workers for mandatory activities start during the a.m. peak period. It can be seen, workers (with or without flexible working hours), start at about the same interval for work tours.

The frequency distribution of tour timing indicates that most of the activities are undertaken during the pre-a.m. peak and a.m. peak. The activities for which tours were performed include mandatory, shopping, serving passengers, social and recreational activities. An analysis of the trip-chaining reveals that multi-stop work tours are mostly undertaken during the a.m. pre-peak and a.m. peak periods. However, multi-stop tours for other activities are mostly undertaken during the pre-p.m. peak period.

About 70% of the work tours start during the a.m. peak period and about 18% during the pre-a.m. peak period. In the case of non-mandatory activities, shopping tours are mostly undertaken during the a.m. peak period (35.71%) and a.m. post peak & afternoon periods (21.43%). Tours for eating out are mostly during the a.m. peak period (55.32%) and tours for serving passengers are during a.m. pre-peak (29.23%), a.m. peak (24.62) and p.m. peak period (27.69%). The discretionary activities such as visiting others are undertaken during a.m. peak (50 %).

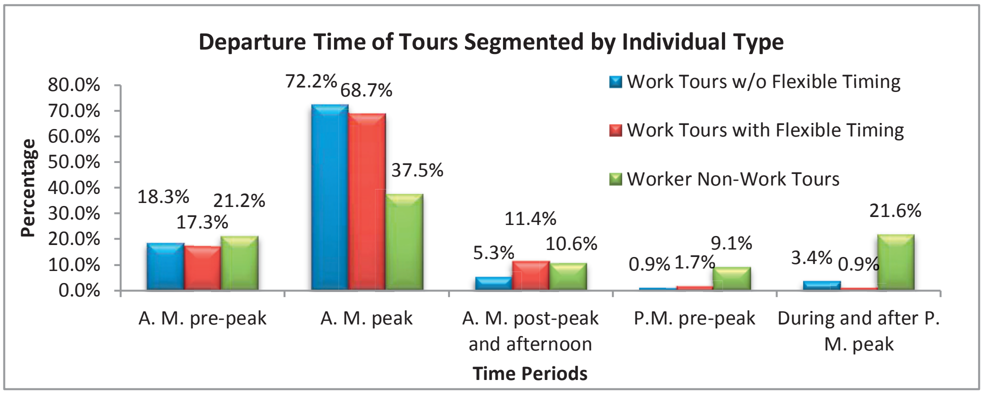

Fig 2 Departure Time of Tours Segmented by Individual Type

4. Methodology

The dependent variable used in the analysis, namely departure time interval chosen for each tour is discrete in nature and has five alternatives. Due to the discrete and nominal nature of the dependent variable, Multinomial Logit Model (MNL) was used for modeling. The MNL model is based on the principle of utility maximization which assumes that the individuals choose that alternative that maximizes his/ her utility. According to this principle, an individual 'i', chooses an alternative „m. from among the set of alternatives, if and only if the utility of alternative 'm' is greater than or equal to the utility of all the other alternatives in the choice set. The departure times of different observation are treated as mutually independent, since about 85 % of individuals in the sample undertook only one tour in a day.

The utility of an alternative is assumed to be made up of two components: the deterministic component and the random component. The deterministic component is assumed to be a function of the characteristics of the individual (X_i), household (X_h), intra-household interaction (X_{hi}), accessibility (X_{acc}), activity (X_{act}) and transportation system and supply characteristics (X_t). In the case of Multinomial Logit model (MNL), the random component is assumed to follow Gumbel distribution (Independent and Identically Distributed (0, $\pi^2/6\mu^2$)). This form represents the effect of unobserved attributes on the choice process. The utility of an alternative can thus be expressed as:

$$U_{im} = V_{im}(X_i, X_h, X_{hi}, X_{acc}, Xact, X_t) + \varepsilon_{im} \quad \forall \text{ i, and m} \tag{1}$$

The probability of choosing an alternative (m) from a set of „M. alternatives can be expressed as follows for the MNL model,

$$P(m) = \frac{\exp(V_m)}{\sum_{k=1}^{m} \exp(V_k)} \quad \forall\ k \neq m \tag{2}$$

The deterministic component is assumed to follow a linear-in-parameters specification.

$$V_m = \beta_0 + \beta_1 X_1 + \ldots + \beta_k X_k$$

where, β_0, β_1, β_k, are the coefficients and X_1, X_k are the independent variables. The coefficients are then estimated using Maximum Likelihood Estimation technique using SST software in this study. The resulting coefficients are consistent, asymptotically unbiased and asymptotically efficient (Train, 2009).

5. Modeling results and interpretation

This section has been divided into two sub-sections. The first deals with the models for the departure time for work tours followed by a sub-section discussing the modeling results for the non-work tour of workers.

5.1. Departure Time Model for Work Tours

As discussed in the previous section, departure time is modeled as a function of various characteristics such as individual, household, activity characteristics and transportation system and supply characteristics. The significant variables are discussed below.

Individual characteristics such as gender, employment type and industry have a significant influence on the departure time of work tours. Young circles (between 16 and 25 old) are more likely to pursue work tours in the a.m. pre-peak and a.m. post peak & afternoon periods. Males are more likely to start tours during a.m. pre-peak. From the exploratory analysis, it was observed that the distance to work-place was higher for men and this may explain why men start tends to start early to work. Individuals working in public sector are less likely to start during the a.m. post-peak & afternoon period, which may be due to the fixed work start times in the public sector. Those pursuing business tend to start later in the morning perhaps due to the fact that they are more likely to attract customers in the afternoon and evening hours. The low income workers were found to make more tours in the a.m. post peak and afternoon period than others. The respondents in the sample in this category were employed as technicians, mechanics, plumbers, salesmen and may not have a fixed work start time. They may also have the flexibility to start late for work.

Employees with access to vehicles might start a little later in comparison with those without access to vehicle, as they do not encounter transfer delays. Individuals who do not drive to work (those who rely on public transport system) will have to take into consideration the waiting time and also the fluctuations in the arrival time of the buses/ trains. This makes it necessary for them to start a little earlier in comparison with those who drive to work.

Further, the role of household characteristics in deciding the departure time of a worker for his work tour was investigated. Individuals belonging to nuclear and large families are more likely to start during the a.m. post peak & afternoon period (between 10.30 a.m. and 3.30 p.m.) than a.m. peak period. This could be because, individuals from these households may have to perform some of the activities such as serving passengers or some maintenance shopping before starting to work-place. It was also observed that individuals from nuclear families and large families do not undertake work tours during p.m. peak period and may prefer to spend time with other family members at home during these periods.

Related to work characteristics, the variables tested included the duration of work and whether the individual had flexible working hours. As expected, individuals who had flexible working hours found greater utility in undertaking tours during the a.m. post peak & afternoon period and evening period. The work time flexibility could be used to perform non-mandatory activities and may also be aimed at avoiding congestion. However, even individuals with flexible working times did not prefer to undertake work tours in the p.m. peak period.

The role of transportation system and supply characteristics was analysed. The analysis revealed that when the congestion in the neighborhood was low or medium, individuals found more utility in carrying out work tours during the a.m. peak period compared to a.m. post peak & afternoon. It was observed from the exploratory analysis, that when the congestion levels are high, individuals tend to perform more work tours during the a.m. post peak & afternoon period, probably to avoid travelling during the congested time intervals, suggesting same potential for peak spreading and departure time to alleviate congestion.

Table 1 Results of the Departure Time Model for Work Tours

Variable	Coefficient	T-Stat
Constant		
Constant-AM pre-peak	-1.81	-7.2
Constant-AM post-peak and Afternoon period	-2.79	-6.18
Constant-P.M. pre-peak period	-4.01	-13.17
Constant-During and After PM Peak	-2.25	-5.46
Individual Level Characteristics		
Male; AM pre-peak 1-True	0.59	2.29
Business; AM post-peak and Afternoon period 1-True	0.82	2.45
Low-income worker; AM post-peak and Afternoon period 1-True	0.7	2.33
Public Sector; AM post-peak and Afternoon period 1-True	-1.19	-2.23
Has access to vehicle; AM peak 1-True	-0.57	-2.13
Household Level Characteristics		
Nuclear Family; AM post-peak and Afternoon period 1-True	0.51	1.26
Nuclear Family; During and After PM Peak 1-True	-0.96	-1.85
Large Family; AM post-peak and Afternoon period 1-True	0.74	1.68
Large Family; During and After PM Peak 1-True	-1.35	-1.93
Work-related Characteristics		
Flexible Work Time; AM post-peak and Afternoon period 1-True	0.62	2.27
Flexible Work Time; During and After PM Peak 1-True	-1.25	-2.2
Distance to Work-place; Pre AM peak 1-True	0.03	2.73
Mode Characteristics		
Used Two-wheeler for commuting to work; Pre AM Peak 1-True	-0.7	-3.65
Used Bus to commute to work; AM post-peak and Afternoon period 1-True	-1.02	-1.89
Transportation System and Supply Characteristics		
Road Congestion is Medium; AM post-peak and Afternoon period 1-True	-0.81	-1.79

The mode chosen for a tour plays an important role in deciding the departure time of an individual. An individual choosing the personal vehicle as the mode of travel need not start early for work as compared to an individual who uses public transport as his mode of travel. This difference may be explained by the consideration of time required for transfers, waiting time and also the reliability of the arrival time of buses by a bus user. The indicator variable for the choice of two-wheeler as a mode has a negative coefficient. This indicates that, the individual has a negative utility in starting to work in the a.m. pre-peak period. However the indicator variable for bus as a mode has a positive but insignificant coefficient, suggesting that the individual may have a greater utility in starting early to work. The coefficient obtained for an individual using bus to commute to work during a.m. post-peak & afternoon period was negative, but is statistically insignificant.

Table.2 Summary of Results in the Departure Time Model for Work Tours

Performance Measures	
Number of observations	859
Initial likelihood	-1382.5
Likelihood at convergence	-734.5
ρ^2	0.469
Percent correctly predicted	70.547

The model fit is assessed by the Log Likelihood ratio, which is 1-the ratio of the likelihood at convergence to the initial likelihood. A log-likelihood ratio between 0.2 and 0.4 is considered to be reasonable. In the current analysis, the initial likelihood was found to be equal to -1382.5 and the final likelihood was found to be equal to 734.5. The log-likelihood ratio for the departure time models for workers was 0.47 indicating satisfactory performance.

5.2. 5.2. Departure Time Model for Non-Work *Tours of Workers*

The non-mandatory tours by the workers may have very different characteristics than mandatory tours. The difference is likely in two respects, the purpose for undertaking the tour is different and the factors that influence the tour making are different. In the case of the mandatory tour, the starting time for work is determined by work start time. The non-mandatory tours could be scheduled based on the residual time left after the mandatory tours are performed. The result from the analysis of departure time of non-work tours of workers is given in Table 3.

Distance to the work-place and the work duration are some of the key variables that determine an individual's preferred time for participation in non-work activities. In the model for departure times, the effect of both these variables is significant. As the distance to the work-place increases, individuals may tend to leave early to the work-place and perform non-mandatory activities during the off-peak periods. The effects of the variable were significant for the p.m. peak period. The individual may have to find time for performing the non-mandatory activities either before the work tour or after returning from work. When the work duration increases, the individual may undertake these activities during the pre-a.m. peak period or in the p.m. peak period. Positive coefficients were obtained for both these time periods, though only the coefficient for the a.m. peak period turned out to be statistically significant. It is possible that some of the opportunities to perform non-mandatory activities might be unavailable after they return from work.

Vehicle availability is defined as the difference between the number of vehicles and the number of adults in the household. Some of the non-mandatory activities may be pursued by the individual during his commute to work as vehicle is available for his travel.

A worker tends to undertake activities such as shopping during the a.m. pre-peak and p.m. peak periods. Hence, coefficients for the tours with "shopping" as the purpose are positive for these two time intervals. Tours involving pick-up and drop-off activities are less likely during p.m. peak and post p.m. peak due to institutional timings.

Individual from peri and semi-urban areas however were less likely to undertake non-work tours during p.m. peak or p.m. post peak periods. In comparison to individuals from urban areas it is plausible, individuals from peri and semi-urban areas might not have the same access to facilities and transportation systems. The quality and frequency of service and opportunities for activities such as shopping or transportation system may be lower at these intervals. In addition to this, most of these facilities may not be available in the late hours.

Table.3 Results of Departure Time Models for Non-Mandatory Tours of Workers

Variable		Coefficient	T-Stat
Constant-A.M. pre-peak period		-1.74	-4.01
Constant-A.M. post peak and afternoon period		-0.87	-2.25
Constant-P.M. pre-peak period		-1.57	-5.33
Constant-P.M. peak and post p.m. peak period		-0.24	-0.7
Work Characteristics			
Distance to Work-place; During and after p.m. peak		0.1	3.09
Work duration is high; A.M. pre-peak	1- True	0.0017	2.32
Household Level Characteristics			
Vehicle Availability; A.M. post-peak and afternoon period	1- True	-0.4	-1.39
Tour Characteristics			
Shopping tour; A.M. pre-peak	1- True	1.13	2.75
Shopping tour; During and after P.M. peak	1- True	0.55	1.2
Tour to serve passengers; During and after P.M. peak	1- True	-1.29	-2.07
Accessibility Characteristics			
Peri-urban area; During and after P.M. peak	1- True	-1.09	-2.22
Semi-urban area; During and after P.M. peak	1- True	-1.22	-2.35

In the current analysis, the initial likelihood was found to be equal to -280.04 and the final likelihood was found to be equal to -236.62. The log-likelihood ratio for the departure time models for workers was 0.16. Thus the fit is significantly lesser than for work tours, given the discharge rate of such tours.

Table.4 Summary of Results for Departure Time Models for Non-Mandatory Tours by Workers

Performance Measures	
Number of observations	174
Initial likelihood	-280.04
Likelihood at convergence	-236.62
ρ^2	0.16
Percent correctly predicted	47.701

6. Summary and conclusions

The exploratory analysis reveals that workers with flexible working hours are more likely to perform tours than individuals with fixed work timings in the a.m. post peak & afternoon period. P.M. peak and post p.m. peak periods are preferred for non-work tours by individuals with flexible working hours.

Congestion was found to influence the travel making of a worker. In the event of high congestion, the worker was observed to find a greater utility in travelling during the time periods with lower congestion. Thus, a worker was more likely to perform work tours in the a.m. post-peak and afternoon period, in the event of high congestion.

When segmented based on the relation status (head, spouse, child, others), it was observed that the individuals from all segments tend to depart during am peak for most of their tours, possibly due to institutional timing. A significant fraction of tours pursued by head, child and others were also during the a.m. pre-peak. However, tour frequency of spouse spans in the other three time periods. Tours during a.m. pre-peak and a.m. peak were mostly for mandatory activities. In the remaining time periods, a significant percentage of tours are undertaken for maintenance activities.

Regardless of the distance to the work-place, individuals preferred to start during the a.m. peak period, as work start time is mostly during this period. The timing of maintenance tours, however, is affected by the work distance. Workers were more likely to perform these tours after returning from work (during p.m. peak). Work duration plays a significant role in deciding the timing of the non-work tours. Individuals were more likely to perform these tours during the pre am peak period perhaps due to the unavailability of time after return from work.

The departure time models developed in the study can be used for arriving at short-term demand management measures. This study models the departure time choice of workers. The tours by non-workers also need to be modeled to clearly understand the travel pattern. Further, the interdependence of tours undertaken by the same individual is not considered. This would be an interesting direction for further study. The study also does not account for the intra-household interactions which might influence departure times significantly. Considering them could make these models more behavioral. Considering smaller time windows for modeling could help in analyzing departure time at a microscopic level.

Acknowledgements

This work is supported in part by the Centre of Excellence in Urban Transport at IIT Madras, funded by the Ministry of Urban Development, Government of India.
This support is gratefully acknowledged. We also are thankful to the reviewers for their constructive comments and suggestions.

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