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Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

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World Conference on Transport Research - WCTR 2019 Mumbai 26-31 May 2019

Interrelationships between Mode Choice and Trip-chain Choice decisions in the context of Developing Countries

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Abstract

Mumbai is one of the major cities in India, where the traffic volume is constantly being increased because of urbanization trend and changes in the socio-economic status of the society. These conditions not only influence commuter's travel behaviour but also making it too complex. Mode choice and trip-chain choice are the two critical factors influencing this complex travel behaviour. In practice, different activity-based models are using different relationship patterns due to lack of consensus and proper empirical evidence. A few studies focus on the directionality of the trip-chain and mode choice decisions. Hence, this study investigates the hierarchical relationship between these two choice decisions including the influences of socio-demographic characteristics on them. This study uses Structural Equation Models for capturing this multidirectional relationship. This study uses a 15-day activity-travel data and activity-travel information obtained from the survey for defining the choice set. Two separate models are estimated for weekdays and weekends. From the model results, it was observed that the mode choice precedes trip-chain choice during weekdays and mode choice and trip-chain choice decisions are simultaneous during weekends. A number of socioeconomic characteristics also play major roles in influencing the relationships. The model results presented in this study are based on the individual level observations. Hence, for future research, it is necessary to incorporate household interactions and to study the relationship between these choices at the household level.

Keywords: Travel behaviour; Mode choice; Trip-chain choice; Structural equation model (SEM); Developing countries

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1. Introduction

Travel behavior of individuals plays a very significant role in travel demand management and transport planning. Travel behavior patterns and their interaction have many applications in the analysis of transportation policies. Past studies and various survey results show that the travel patterns of people are turning very complex day by day because of individual's desire for activity fulfillment with least amount of travel possible (Hensher and Reyes, 2000; McGuckin et al., 2005). People's desire of minimizing travel time may lead to the tendency of linking single trip of various activities in a single journey rather than making a number of unlinked trips for each of the activities separately. Further, they choose different modes to complete these interconnected trips in the form of trip-chains.

Traveler's behavior with respect to these choices (mode choice and trip-chain choice) is very crucial for effective planning of future transport networks, policy testing and analysis of existing transportation systems. Particularly in populous countries like India, switching between different modes in the trip making of a traveler due to the availability of multiple modes and also switching between the routes due to the complexity involved in a particular trip is very common. Therefore, the relation between trip-chaining behavior and mode choice behavior plays a very significant role in travel demand management. Trip-chaining and mode choice decisions are two very important travel behavior patterns. The hierarchical relationship of mode choice and trip-chain has important applications in developing activity-based travel demand modelling. Though this relationship is the fundamental building block in the activity based travel demand modelling, due to lack of empirical evidence and consensus, different activity based models assumed different relationship patterns in practice (Miller and Roorda, 2003; Arentze and Timmerman, 2004; Bhat et al, 2004; Pendyala et.al., 2005). Practically, the assumed hierarchy of modeling trip-chain and mode choice has influenced over predictive capacity and policy sensitivity of these activity-based models (Roorda et al., 2008).

Till now, a limited number of studies focus on investigating the relationship between mode choice and trip-chain choice and most of these models assumed that these decisions are being made simultaneously or some predefined order. Strathman et al. (1994) made an early attempt to understand the relationship between mode choice and trip-chaining. In this study, they assumed mode choice as an exogenous variable to trip-chaining decisions. Similarly, Bhat (1997) and Bhat and Singh (2000) simultaneously modelled the mode choice and stop making behaviour of individuals. Most of these studies assumed that mode choice and trip-chain choices are correlated and the results from these studies proved the same. However, none of these studies explained the hierarchy between mode choice and trip-chain choice decisions. Very few studies focus on the directionality of the relationship by testing the hypothesis of hierarchy. Strathman and Dueker (1995) developed a Nested Logit (NL) model to examine the relationship between mode choice and trip-chain choice and they found that trip-chain precedes mode choice. Krygsman et al. (2004) investigated the interdependencies between mode choice and activity choice. The results from the study reveal that mode choice is significantly influenced by the activities and activities are less influenced by the mode choice. Ye et al. (2007) examined the relationship between mode choice and trip-chaining patterns using the recursive simultaneous bi-variate probit model. They found that trip-chain precedes mode choice for non-work, and either trip-chain precedes or decisions are simultaneous for work tours. Jianchuan (2013) proposed a mixed binary multinomial choice modelling framework to the exploration of the relationship between mode choice and trip-chaining behavior and examined the interdependencies between mode choice and trip-chain choice. He compared the two interrelationships of mode to chain and chain to mode and from the results, it was observed that trip-chaining choice drives the mode choice.

Structural equation modeling (SEM) approach is adopted for the investigation of the relationship between mode choice and trip-chain choice decisions. Some of the earlier studies reported in the literature have already proved that structural equation modelling is flexible than other approaches for analysing the interactions or relationships between travel and activity decisions of individuals (Golob, 2003; Yang et al., 2010; Xu et al., 2010). Islam and Habib (2012) investigated the hierarchical relationship between mode choice and trip-chain choice decisions including the influence of socioeconomic characteristics on them. They attempted two different models for work and non-work trip-chains. From the study, it was concluded that trip-chain and mode choice decisions are simultaneous in case of work tours on weekdays and weekends. For non-work tours, in weekdays mode choice decisions precede trip-chain decisions and in weekends trip-chain decisions precede mode choice decisions. Sakano and Benjamin (2008) developed a structural equations model to examine the individual's decision about activities and modes on a workday. The results show that if the trip makers have accessibility to different travel modes, the mode choice decisions become a significant predictor of non-work activities.

Based on the reported literature in the previous sections, researchers have arrived at different conclusions of interrelationships between trip-chain and mode choice decisions. Most of these have focused on cities in developed countries, but some recent studies have been reported in the context of developing countries (Kabir et al., 2017; Yang et al., 2015). However, the socioeconomic characteristics, land use and built environment, the combination of multiple mode choices and activity choices in one travel in India are entirely different from any other country, till now no study is reported towards observing these relationships when it comes to Indian scenario. Hence, the objective of this study is to investigate the interdependencies between these two choices, i.e. trip-chain and mode choice on weekdays and weekends. The findings of this study will provide useful insights into the trip-chain typology, mode choice typology and the hierarchy of trip-chain and mode choice. The remainder of this paper is organized as follows. The next section provides the brief introduction about SEM and the methodology adopted in this study. Then, the data collection and administration techniques are explained. Further, trip-chain typology and mode choice combinations considered in the study is described. Then, model specification and development is explained. Finally, conclusions and directions for further research are discussed in the last section.

2. Methodology

The methodology adopted in this study can be divided into two parts. First one is classifying the choice set for the commuter modes and trip-chains. And the second one is investigating the relationship between mode choice decisions and trip-chain choice decisions of individuals by using a structural equation modelling approach. Structural equation modelling has become very popular in the behavioural research in recent years because of its capability of analyzing complex causal relationships among a large number of exogenous and latent variables.

The purpose of SEM is to investigate the relationship between one or more Independent (Exogenous) variables or dependent (Endogenous) variables. Independent variables are usually considered as causal variables as they predict or cause the dependent variables. Therefore, Structural Equation Modelling is also known as Causal Modelling. In general, SEM has two components: the structural model and the measurement model.

The structural equation indicates the relationship between latent variables and exogenous variables.

$$\boldsymbol{\eta} = \boldsymbol{\beta}.\boldsymbol{\eta} + \Gamma.\mathbf{X} + \varsigma$$

Measurement equation indicates the relationship between endogenous variables and the underlying latent variables.

$$\boldsymbol{Y} = \Lambda.\boldsymbol{\eta} + \varepsilon$$

Where, β (a_{11}, a_{12}, a_{13}.............a_{1n} and a_{21}, a_{22}, ...,a_{2k}) are the estimates of the exogenous variables

η (b_{12}, b_{21}) are the estimates of the latent variables

X indicates exogenous variables and Y indicates Endogenous variables

Γ indicates the coefficients of X variables in the structural relationship

Λ (c_{11}, c_{12},.............,c_{1n} and c_{21}, c_{22},.............,c_{2k}) are the estimates of the observed or the endogenous variables.

ς (E1, E2) are the coefficients of the direct relationship between trip-chain choice and mode choice utility ε (e_1, e_2, e_3, ………….e_{16}) are the error coefficients of trip-chain choice as a function of trip-chain choice utility and mode choice as a function of mode choice utility

Estimation of SEM parameters is normally based on covariance analysis, where the difference between the sample covariance matrix and the model implied covariance is minimized (Bollen, 1989). Figure 1 show the modified framework of the SEM path diagram which was developed for this study. Trip-chain choice utility and mode choice utility are the two assumed latent variables in the model. Now, the sequential and simultaneous relationships are verified by evaluating the statistical significance of b_{12} and b_{21}. In order to investigate the relationship between trip-chain choice and mode choice, the following four hypotheses are tested: trip-chain choice and mode choice decisions are two independent decisions, trip-chain choice precedes mode choice, mode choice precedes trip-chain choice, mode choice and trip-chain choice decisions are simultaneous decisions.

3. Data collection and analysis

Analyzing and capturing the complex relationships between mode choice and trip-chain choice requires detailed and quality data. By selecting Mumbai Metropolitan Region (MMR) as a study area, a fifteen-day activity-travel survey conducted by the one of the authors' (Subbarao, 2013) is used as a primary source of data in this study. For reaching different categories of people, the survey instrument was prepared in different languages including regional languages, viz., English, Hindi, Marathi, Gujarati, and Telugu. A geographically stratified random sampling method was adopted for the data collection by considering zonal information, income level, type of residence etc. as a sampling frame. Drop-off and Pick-up (DAP) method of survey administration was adopted for the study in view of the requirement of quality data, though many advanced survey administration technologies are available like GPS, web- based surveys. The survey collected detailed activity and travel information of 350 households with a response rate of 36 percent. The survey data contains three sets of information i.e. household, personal and activity data. These data files consist of information related to household characteristics, person characteristics and all travel and activity related information which includes in-home and out of home activities.

3.1 Trip-chain typology

Every trip-chain starts at home location and ends at the same point with one or more intermediate activities. Trip-chains are broadly classified as simple, complex and open chains. Simple chains are the simplest form of trip-chains that contain two trips and one activity in-between. Complex chains include all trip-chains with at least two activities. Open chains are those in which information on starting or closing trip is missing. A trip-chain typology is proposed in this study based on the earlier research and the data obtained from the activity-travel survey (Strathman and Dueker, 1995; Primerano et. al., 2008; Valiquette and Morency, 2010; Subbarao and Krishnarao, 2013). A detailed explanation of the trip-chain typology used in the study is presented in Table 1.

Table 1. Typology of trip-chain patterns

Trip-chain type	Sequence	Percentage
Simple chain (work/study)	H - W/S – H	39.65
Simple chain (non-work/study)	H - M/L – H	48.32
Complex chain (work/study)	H - W/S(1) - W/S(2) - W/S(N) – H	2.49
Complex chain (non-work)	H - M/L(1) - M/L(2) – M/L(N) – H	2.21
Complex to work/study	H - [- M/L -] - W/S – H	0.73
Complex from work/study	H - W/S - [- M/L -] – H	4.32
Complex at work/study	H - W/S - [- M/L -] - W/S – H	1.05
Multiple complex chains	H–[- M/L-]-W/S- [- M/L-]-W/S–[- M/L-]-	1.23

[H= Home, W/S = Work or Study, M/L = Maintenance or Leisure]

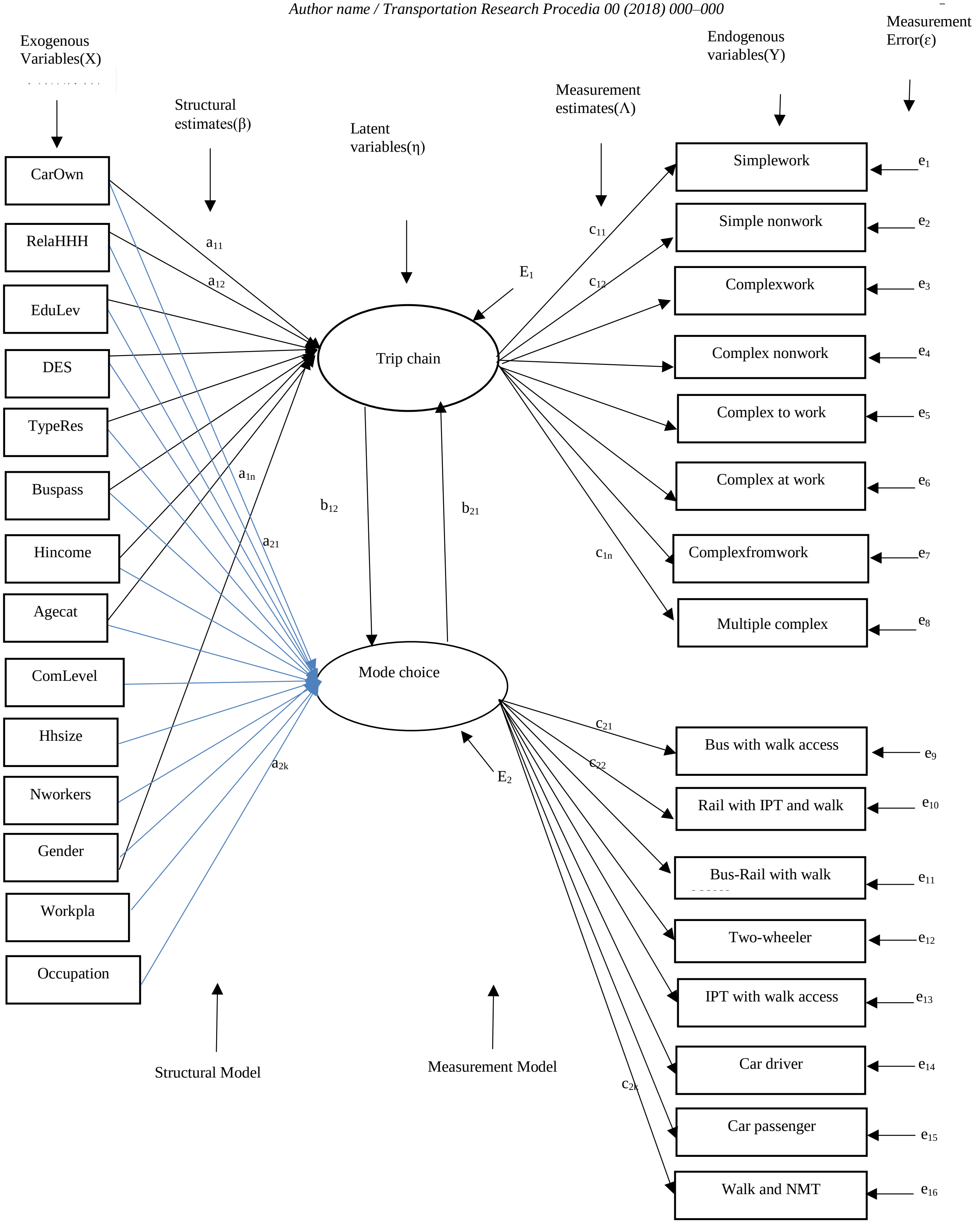

Fig. 1 Modified framework of the SEM path diagram

3.2 Mode choice combinations

Travelers are using different modes for pursuing their activities that are distributed in time and space. In developing countries like India, Individuals switch between different modes for fulfilling their activities or travel distributed over space. Transit mode choices are not only limited to bus, rail, etc., but also to the various access mode combinations, including transfer modes. Consequently, the range of transit modal choices and combinations can be huge, particularly the cities in developing countries like India. In such cases, travellers give hierarchy to some specific modes based on their socio-economic characteristics, type of travel and available modal options. Keeping in view all these aspects, the study proposes various mode choice combinations by prioritizing one specific mode from the data obtained for the study area.

This was achieved by adopting a hierarchical structure between the modes based on their relative efficiency and function. Total available modes in the study area, Mumbai Metropolitan Region (MMR) are identified as suburban rail, bus, auto rickshaw, taxi, two-wheelers (TW), car, walk and non-motorized transport (WNMT). From these alternatives, both auto rickshaw and taxi are considered as a single mode, IPT (Intermediate Public Transport) based on their similar properties. Car alternative is divided as Car-Driver (CarD) and Car-Passenger (CarP). Hence, the considered modes are Rail, Bus, IPT, TW, CarD, CarP and WNMT. Transform (2008) study identified that public transport services are dominating the transport picture in MMR and suburban railway is the most used public transport mode, carrying more than 50 percent of all person trips and about 70 percent of the total public transport patronage. Hence public transport has been given the top priority in identifying mode choice combinations. Public transport systems in Mumbai include the Suburban Railway and Buses. If the trip involves, both the suburban railway and bus, both modes have been given the equal priority and remaining modes act as a feeder service to the public transport system. Next priority given in the hierarchical structure is to private transport systems (car and two-wheeler) due to their flexibility and door to door service. Though these vehicles run with low capacity, in developing countries like India, people use private vehicles as a status symbol in their community. Next prioritized mode of transport is IPT which includes auto rickshaws and taxis. These are the least efficient type of transport due to its use of large road space and extensive parking requirement. Though these modes run with low capacity, high flexibility and personal door to door service attract the travellers. In this hierarchical structure, the last priority is given to walk and non-motorized transport. These modes act as transfer modes between public and private transport modes. Based on the above discussion, the order of prioritization is considered as Rail-Bus-CarD-CarP-TW-IPT-WNMT, with Rail as the high prioritized mode. Following the above prioritization rules, a hierarchical structure is developed for identifying the primary mode of a trip maker and subsequently, the mode choice combination.

Based on the total available modes in the study area and the prioritization rules discussed in the previous section, forty combinations of mode choices observed from the data set. Eight types of mode choices were identified by aggregating several combinations of modes, namely, Rail with IPT and walk access (Rail), Bus with IPT and walk access (Bus), Bus-Rail with IPT and walk access (BR), Car-Driver with IPT and walk access (CarD), Car-Passenger with IPT and walk access (CarP), Two-wheeler with IPT and walk access (TW), IPT (Auto rickshaw (Auto) and Taxi) with walk access and Walk and Non-motorized transport (WNMT).

3.3 Interdependencies between Mode choice and Trip-chain

In recent studies, it is extensively accepted that there is some relation exists between mode choice and trip-chaining patterns of travelers. The directivity of this relation between mode choice and trip-chain patterns is not easily understandable. One may first decide to make a particular trip-chain pattern based on his/her personal and household need and then choose a mode that is convenient for making the selected trip-chain. On the other hand, one may first choose a mode based on the availability and then based on the flexibility and convenience offered by that mode, he/she may plan their chain of trips. Thus, it is useful to empirically test the hierarchy regarding the decision of trip-chain formation and mode choice. The hierarchical relationship between the trip-chain and mode choice has an important connection also for the providers of public transport who are interested in attracting travelers. If mode choice decisions are taken prior to trip-chain choice decisions, then public transport service providers have a greater chance to attract travelers by improving service quality, frequency, accessibility, safety, security, and comfort. On the other hand, if trip-chain choice decisions are taken prior to mode choice decisions, then the public transport industry has a greater challenge to attract riders.

Table 2 and 3 show the percent proportion of trips made by the individuals in weekday and weekend respectively. In the analysis, it was observed that for making simple trip-chains (H-W-H), nearly 40 percent of people are using walk mode on weekdays, whereas it is becoming more than 50 percent during weekends, perhaps due to short distance trips during weekends. For making complex work chains (H-W-W-W-H), more percent of people are using public transport on a weekday, but on weekend nearly equal proportion of peoples are using public transport and their private vehicles. The difference might be due to individuals need to reach their workplace on time during weekdays, hence they prefer to use private vehicles. When making the complex non-work trip-chains (H-M/L-M/L-M/L-H), it was observed that more percent of trips were made by using public and para-transit system on a weekday and in a contrasting way, more percent of trips were made by using private vehicles during weekends.

Table 2. Percent proportion of trips made by using different mode choices vs trip-chain choices during weekdays

Mode choice / Trip-chain choice	Percent proportion of trips								
	Bus	Rail	Bus-Rail	TW	IPT	Car D	Car P	WNMT	Total
H-W-H	22.08	12.42	4.47	8.98	5.80	3.26	3.88	39.12	100.00
H -M/L-H	6.49	4.05	1.04	7.96	4.34	4.51	2.32	69.28	100.00
H-W_1-W_2-W_n-H	10.57	17.22	0.20	0.78	4.50	21.33	22.90	22.50	100.00
H-M/L_1-M/L_2-M/L_n-H	11.58	5.41	1.16	3.09	20.85	3.86	3.86	50.19	100.00
H-M/L-W-H	17.05	13.07	6.82	10.51	4.26	8.24	2.56	37.50	100.00
H-W-M/L-W-H	5.52	2.88	0.48	18.47	4.80	6.95	2.88	58.03	100.00
H-W-M/L-H	22.81	10.95	3.99	2.39	7.18	17.45	3.19	32.04	100.00
H-M/L-W-M/L-W-M/L-H	8.10	4.76	0.00	13.81	7.62	23.81	4.76	37.14	100.00

Table 3. Percent proportion of trips made by using different mode choices vs trip-chain choices during weekends

Mode choice / Trip-chain choice	Percent proportion of trips								
	Bus	Rail	Bus-Rail	TW	IPT	Car D	Car P	WNMT	Total
H-W-H	20.12	9.71	2.89	7.17	4.28	1.62	1.62	52.60	100.00
H -M/L-H	3.91	2.16	0.11	13.20	6.69	7.57	5.01	61.35	100.00
H-W_1-W_2-W_n-H	16.39	19.67	0.00	0.00	13.11	16.39	11.48	22.95	100.00
H-M/L_1-M/L_2-M/L_n-H	5.69	10.70	0.67	10.03	14.38	27.42	15.05	16.05	100.00
H-M/L-W-H	2.78	11.11	2.78	22.22	8.33	41.67	5.56	5.56	100.00
H-W-M/L-W-H	0.00	0.00	0.00	25.00	0.00	0.00	0.00	75.00	100.00
H-W-M/L-H	37.50	7.35	0.00	4.41	8.82	8.82	5.88	27.21	100.00
H-M/L-W-M/L-W-M/L-H	4.76	4.76	0.00	38.10	28.57	0.00	4.76	19.05	100.00

4. Model specification and development

By considering trip-chain choice utility and mode choice utility as two latent variables in the model, a variety of exogenous variables are identified by considering the previous theoretical and empirical works and also by taking into account the conditions in developing countries. The variables included in the model are household size (HHSize), Number of workers in the household (NWork), Car Ownership (CarOwn), Gender, Relationship with household head (RelaHHH), Description of the activity (work, maintenance, leisure) (Des), Occupation level (Occu), Type of workplace (TofWork), Type of residence (TofRes), Bus pass (BusPass), Household Income (HHInc), Age, Comfort level for using public transport (ComLel)

Dataset is prepared in SPSS format which is imported into the LISREL software. Based on the dataset, path diagrams are drawn using LISREL and the corresponding correlation factors and t-stat values can be read from the output file. All the possible correlations between the trip-chain and mode choices are investigated by testing the four hypotheses using different combinations of exogenous variables. The final model is obtained by systematic testing of these hypotheses. The endogenous variables of the model remain the same for all the hypotheses testing, but the exogenous variables are selected by trial basis to get a stable and only the statistically significant variables. However, some variables with t-statistics less than the critical value are also reported here. It is presumed that these variables would be statistically significant for a larger dataset. It is difficult to rely on only one goodness-of-fit index by considering the complexity of SEM structure. Hence, in this study, two goodness-of-fit indices are considered like Root Mean Squared Error of Approximation (RMSEA) and Standardized Root Mean Squared Residual (SRMR). The recommended value of RMSEA is below 0.1, which indicates a good fit and the values below 0.5 indicate a very good fit (Steiger, 1990). Further, the recommended value of SRMR less than 0.1 indicates a good fit of data in SEM models (Vandenberg and Lance, 2000)

4.1 Model results from weekday patterns

In order to investigate the relationship between trip-chain choice and mode choice in weekdays, initially, it is assumed that there is no direct relationship between trip-chain choice and mode choice utilities other than error correlation. In this case, it is found that the error terms of trip-chain utility and mode choice utility are correlated with a high statistical significance. So, in the next step, by connecting the path from mode choice to trip-chain directly, it is found that the path connecting from mode choice to trip-chain has the coefficient of 0.0424 (t-statistic value is 5.52) and the path connecting from trip-chain choice to mode choice is insignificant. The model result can be interpreted in a way that individuals are likely to make mode choice decisions first and then make the activity related trip-chain utility decisions. The goodness-of-fit measures of the final model are found to be reasonable with RMSEA value of 0.011 and SRMR value of 0.0132.

From the model results, it is also clear that many exogenous variables are influencing mode choice and trip-chain choice decisions. Hence, it is necessary to explain the effects of exogenous variables on mode choice and trip-chain choice decisions in weekday. Table 2 shows the estimates of coefficients of exogenous variables on decision variables during weekdays. The table reveals that the households with more number of workers are prone to select their mode first and then decide on trip-chain choice. The individuals with car ownership are always deciding their mode first, perhaps due to the availability of mode. Further, the education level of individuals' increases, the probability of choosing complex trip-chains are decreasing, perhaps due to proper planning in making their activities. Individuals who are residing in their own houses are making more number of simple chains and making more percentage of trips by walk. The reason might be due to an increase in maintenance and leisure related activities at home. With the age, individuals are planning their activities or trip-chains first and choosing their mode later. As income increases, individuals are more likely to plan their activities using their private mode. It is obvious that higher household income reduces the tendency to use public transport and IPT. Further, household income has minimal impact on choosing trip-chains during weekdays. This infers that most of the individuals travel patterns are fixed in the study area during weekdays.

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Table 2. Estimates of the coefficients of exogenous variables on decision variables in weekdays

	Coefficients of exogenous variables													
Endogenous variables	**HHSize**	**Nwork**	**CarOwn**	**Gender**	**RelaHHH**	**EduLel**	**Des**	**Occu**	**TofWork**	**TofRes**	**BusPass**	**HHInc**	**Age**	**ComLel**
H-W-H	**-0.004**	*0.0004*	*0.004*	**0.0002**	*0.005*	**0.006**	**-0.003**	**0.003**	*0.0002*	**0.009**	**-0.008**	*-0.002*	*0.0003*	**-0.009**
H -M/L-H	**-0.004**	*0.0004*	*0.004*	**0.0002**	*0.005*	**0.007**	**-0.003**	**0.003**	*0.0002*	**0.009**	**-0.008**	*-0.002*	*0.0003*	**-0.009**
H-W$_1$-W$_2$-W$_n$-H	**-0.004**	*0.0003*	*0.004*	**0.0002**	*0.004*	**0.006**	**-0.003**	**0.003**	*0.0001*	**0.008**	**-0.007**	*-0.002*	*0.0003*	**-0.008**
H-M/L$_1$-M/L$_2$-M/L$_n$-H	**-0.004**	*0.0003*	*0.004*	**0.0002**	*0.004*	**0.006**	**-0.003**	**0.003**	*0.0001*	**0.008**	**-0.007**	*-0.002*	*0.0003*	**-0.008**
H-M/L-W-H	**-0.004**	*0.0003*	*0.004*	**0.0002**	*0.004*	**0.005**	**-0.003**	**0.003**	*0.0001*	**0.007**	**-0.007**	*-0.002*	*0.0003*	**-0.008**
H-W-M/L-W-H	**-0.004**	*0.0003*	*0.004*	**0.0002**	*0.004*	**0.006**	**-0.003**	**0.003**	*0.0001*	**0.008**	**-0.007**	*-0.002*	*0.0003*	**-0.008**
H-W-M/L-H	**-0.004**	*0.0003*	*0.004*	**0.0002**	*0.004*	**0.006**	**-0.003**	**0.003**	*0.0002*	**0.008**	**-0.007**	*-0.002*	*0.0003*	**-0.009**
H-M/L-W-M/L-W-M/L-H	**-0.004**	*0.0003*	*0.004*	**0.0002**	*0.004*	**0.005**	**-0.003**	**0.003**	*0.0001*	**0.007**	**-0.007**	*-0.002*	*0.0003*	**-0.008**
Bus + Access modes	*-0.002*	**0.009**	**-0.012**	**0.005**	*0.003*	**0.012**	**-0.005**	**0.005**	**0.001**	**0.014**	**-0.034**	**0.019**	*0.0002*	**0.034**
Rail + Access modes	*-0.002*	**0.009**	**-0.012**	**0.005**	*0.003*	**0.012**	**-0.005**	**0.005**	**0.001**	**0.014**	**-0.034**	**0.019**	*0.0002*	**0.034**
Bus-Rail + Access modes	*-0.002*	**0.008**	**-0.011**	**0.005**	*0.003*	**0.011**	**-0.004**	**0.005**	**0.0005**	**0.013**	**-0.031**	**0.018**	*0.0002*	**0.031**
TW + Access modes	*-0.002*	**0.009**	**-0.013**	**0.005**	*0.003*	**0.012**	**-0.005**	**0.005**	**0.001**	**0.014**	**-0.034**	**0.020**	*0.0002*	**0.035**
IPT + Access modes	*-0.002*	**0.008**	**-0.011**	**0.005**	*0.003*	**0.011**	**-0.004**	**0.005**	**0.0005**	**0.013**	**-0.031**	**0.017**	*0.0002*	**0.031**
CarD + Access modes	*-0.002*	**0.009**	**-0.013**	**0.005**	*0.003*	**0.012**	**-0.005**	**0.006**	**0.001**	**0.015**	**-0.035**	**0.020**	*0.0002*	**0.035**
CarP + Access modes	*-0.002*	**0.008**	**-0.012**	**0.005**	*0.003*	**0.011**	**-0.005**	**0.005**	**0.0005**	**0.014**	**-0.033**	**0.019**	*0.0002*	**0.033**
WNMT + Access modes	*-0.002*	**0.009**	**-0.013**	**0.005**	*0.003*	**0.012**	**-0.005**	**0.005**	**0.001**	**0.015**	**-0.035**	**0.020**	*0.0002*	**0.035**

Note: Bold Numbers indicate t-statistic ≥1.64 and Italic Numbers indicate t-statistic < 1.64

Table 3. Estimates of the coefficients of exogenous variables on decision variables in weekends

	Coefficients of exogenous variables											
Endogenous variables	**HHSize**	**VehOwn**	**Gender**	**RelaHHH**	**EduLel**	**Des**	**Occu**	**TofWork**	**TofRes**	**BusPass**	**HHInc**	**CarLic**
H-W-H	**-0.001**	*-0.004*	**0.014**	**0.008**	**0.012**	**-0.011**	**0.001**	--	**0.029**	**-0.001**	*-0.004*	**0.010**
H -M/L-H	**-0.001**	*-0.005*	**0.017**	**0.010**	**0.015**	**-0.013**	**0.001**	--	**0.035**	**-0.002**	*-0.005*	**0.012**
H-W_1-W_2-W_n-H	**-0.001**	*-0.004*	**0.013**	**0.008**	**0.011**	**-0.010**	**0.001**	--	**0.026**	**-0.001**	*-0.003*	**0.009**
H-M/L_1-M/L_2-M/L_n-H	**-0.001**	*-0.005*	**0.015**	**0.009**	**0.013**	**-0.011**	**0.001**	--	**0.031**	**-0.001**	*-0.004*	**0.011**
H-M/L-W-H	**-0.001**	*-0.004*	**0.013**	**0.008**	**0.011**	**-0.010**	**0.001**	--	**0.027**	**-0.001**	*-0.004*	**0.009**
H-W-M/L-W-H	**-0.001**	*-0.004*	**0.014**	**0.008**	**0.012**	**-0.011**	**0.001**	--	**0.029**	**-0.001**	*-0.004*	**0.010**
H-W-M/L-H	**-0.001**	*-0.004*	**0.013**	**0.008**	**0.011**	**-0.010**	**0.001**	--	**0.027**	**-0.001**	*-0.004*	**0.009**
H-M/L-W-M/L-W-M/L-H	**-0.001**	*-0.004*	**0.012**	**0.007**	**0.010**	**-0.009**	**0.001**	--	**0.025**	**-0.001**	*-0.003*	**0.009**
Bus + Access modes	**-0.005**	*0.006*	**-0.002**	**-0.001**	**0.009**	**-0.009**	**0.004**	**0.0005**	**0.015**	**-0.006**	**0.008**	**-0.002**
Rail + Access modes	**-0.004**	*0.006*	**-0.002**	**-0.001**	**0.009**	**-0.009**	**0.004**	**0.0004**	**0.015**	**-0.006**	**0.008**	**-0.002**
Bus-Rail + Access modes	**-0.004**	*0.005*	**-0.002**	**-0.001**	**0.008**	**-0.008**	**0.004**	**0.0004**	**0.013**	**-0.006**	**0.007**	**-0.001**
TW + Access modes	**-0.005**	*0.006*	**-0.002**	**-0.001**	**0.010**	**-0.009**	**0.004**	**0.0005**	**0.016**	**-0.007**	**0.009**	**-0.002**
IPT + Access modes	**-0.004**	*0.006*	**-0.002**	**-0.001**	**0.009**	**-0.009**	**0.004**	**0.0004**	**0.014**	**-0.006**	**0.008**	**-0.002**
CarD + Access modes	**-0.005**	*0.006*	**-0.003**	**-0.002**	**0.010**	**-0.010**	**0.004**	**0.0005**	**0.016**	**-0.007**	**0.009**	**-0.002**
CarP + Access modes	**-0.005**	*0.006*	**-0.002**	**-0.001**	**0.010**	**-0.009**	**0.004**	**0.0005**	**0.015**	**-0.006**	**0.008**	**-0.002**
WNMT + Access modes	**-0.005**	*0.006*	**-0.003**	**-0.001**	**0.010**	**-0.009**	**0.004**	**0.0005**	**0.016**	**-0.007**	**0.009**	**-0.002**

Note: Bold Numbers indicate t-statistic ≥1.64 and Italic Numbers indicate t-statistic < 1.64

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4.2 Model results from weekend patterns

Similar to the weekday model, the model is developed by assuming trip-chain choice and mode choice decisions are independent other than correlation. From the model, it has been observed that the error terms of trip-chain choice and mode choice utilities are correlated with a high statistical significance. In the next step, by connecting mode and trip-chain choice utility directly, it is found that the path connecting trip-chain choice to mode choice has the coefficient of 0.166 with a t-statistic of 3.63 and that the path connecting from mode choice to trip-chain has the coefficient of 0.217 with a t-statistic of 4.95. In these both the cases, paths are found to be statistically significant. This means that people are likely to make their trip-chain choice simultaneously with the corresponding mode choice. After making all the suitable co-variances between the variables, the goodness-of-fit measures of the final model are found to be reasonable with RMSEA value of 0.013 and SRMR value of 0.018.

Table 3 shows the estimation of coefficients of exogenous variables on decision variables during weekends. From the model results, it has been observed that household size has the negative impact on choosing private vehicles like the car and two-wheeler. It means if the household size increases, the probability of choosing public transport is increasing. Further, the impact of vehicle ownership on choosing trip-chain is minimal and it has a more positive impact on choosing a variety of modes, perhaps due to the availability of different modes. Another interesting observation is that car license status has a negative impact on choosing complex or multiple complex trip-chains. The reason might be due to the user's apathy towards making more number of trips. Gender is found to be having a significant impact on choosing trip-chains than mode choice. It has been observed that males prefer to make simple trip-chains on weekends. Further, it is also observed that education level increases, the proportion of simple trip-chains increases, perhaps due to highly educated individuals are making proper travel plans for completing their activities. Similar to the observation made in the weekday model, as income of the household increases, individuals are showing their disinterest towards making their activities using public transport and also observed that household income has minimal impact on choosing a trip-chain.

5. Conclusions and future directions

Modeling traveler's behavior and the investigation on hierarchical decisions of mode choice and trip-chain choice is very much necessary for the analysis of transportation systems. The study presented the results of models which are developed by using fifteen-day activity travel data for analyzing the relationship between mode choice and trip-chain choice decisions of individuals. For investigating these complex decisions, a trip-chain typology was defined by considering the activity travel data, which represents the socioeconomic characteristics and travel characteristics of the individuals in the study area and the opinions taken from the experts in the relevant field.

Further, it has been observed that individuals choose different modes for fulfilling their activities in developing countries like India. Hence, different mode choice combinations are proposed by adopting a hierarchical structure between various types of modes. Then, the study attempted to investigate the relationship between mode choice and trip-chain choice decisions by testing different hypotheses that trip-chain precedes mode choice, mode choice

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precedes trip-chain, mode choice and trip choice decisions are independent or simultaneous to each other. Further, it has been tested the consistency of the relationship obtained between weekdays and weekends and also investigated the impact of socioeconomic characteristics on trip-chain choice and mode choice decisions. For weekdays, it has been found that mode choice decisions precede trip-chain choice decisions and for weekends, it has been observed that mode choice decisions and trip-chain choice decisions are simultaneous.

The effect of socioeconomic characteristics on trip-chain choice and mode choice decisions are investigated and the results clearly show the impact of these characteristics on the trip-chain and mode choice decisions. It has been observed that the variables like household size, vehicle ownership, gender, education level, occupational level, type of residence, bus pass, and household income have a significant impact on mode choice and trip-chain choice irrespective of the type of day (weekday and weekend). It is also found that some variables have contrasting impacts on individual’s behavior during weekdays and weekends. It clearly shows the variation in the travel behavior of individuals in the study area.

Overall, the study provides promising insights on exploring the interrelationship between mode choice and trip-chain choice decisions of individuals. Further, the study demonstrates that assuming some arbitrary sequence of mode choice and trip-chain choice in activity based travel demand modeling is wrong. The models presented in the study are limited to the type of day and they can be extended to observe the difference in choice decisions of male and female, worker and non-workers as well. Further, the developed models are purely based on individual specific observations. Therefore, for future research, one can consider the household interactions and their impact on these choice decisions.

References

Hensher, D.A. and Reyes, A.J., 2000. Trip-chaining as a barrier to the propensity to use public transport. Transportation, 27 (4), 341-361.

McGuckin, N., Zmud, J., and Nakamoto, Y., 2005. Trip-chaining trends in the United States: understanding travel behavior for policy making. Transportation Research Record, 1917, 199-204.

Arentze, T. and Timmermans, H., 2004. A learning based transportation oriented simulation system. Transportation Research B, 38 (7), 613-633.

Miller, E.J. and Roorda, M.J., 2003. A prototype model of 24-h household activity scheduling for the Toronto Area. Transportation Research Record, 1831, 114-121.

Bhat, C.R., Guo, J.Y., Srinivasan, S. and Sivakumar, A., 2004. Comprehensive econometric microsimulator for daily activity-travel patterns. Transportation Research Record, 1894, 57-66.

Pendyala, R., Kitamura, R., Kikuchi, A., Yamamoto, T. and Fuji, S., 2005. Florida activity mobility simulator: overview and preliminary validation results. Transportation Research Record, 1921, 123-130.

Roorda, M.J., Miller, E.J., and Habib, K.M.N., 2008. Validation of TASHA: a 24-h activity scheduling microsimulation model. Transportation Research A, 42 (2), 360-375.

Strathman, J.G., Dueker, K.J., and Davis, J.S., 1994. Effects of household structure and selected travel characteristics on trip-chaining. Transportation, 21 (1), 23-45.

Bhat, C.R., 1997. Work travel mode choice and number of non-work commute stops. Transportation Research B, 31 (1), 41-54.

Bhat, C.R. and Singh, S.K., 2000. A comprehensive daily activity-travel generation model system for workers. Transportation Research A, 34 (1), 1-22.

Strathman, J.G. and Dueker, K.J. 1995. Understanding trip-chaining. Special Report on Trips and Vehicle Attributes, FHWA-PL-95-033, US Department of Transportation, Washington, DC.

Krygsman, S., Arentze., T. and Timmermans, H., 2004. Capturing interdependcies in tour mode and activity choice: A co-evolutionary logit modelling approach. 23rd Southern African Transport Conference (SATC 2004), 12-15 July, Conference planners, South Africa

Ye, X., Pendyala, R.M., and Giovanni, G., 2007. An exploration of the relationship between mode choice and complexity of trip-chaining patterns. Transportation Research B, 41 (1), 96-113.

Jianchuan, X., 2013. Research on the interdependencies between commute mode choice and trip-chaining behaviour. Proceedings of the 20th International conference on management science and engineering, July 17-19, China

Golob, T.F., 2003. Structural equation modeling for travel behavior research. Transportation Research B, 37 (1), 1-25

Yang, M., et al., 2010. Structural equation model to analyse sociodemographics, activity participation, and trip-chaining between household heads: survey of Shangyu, China. Transportation Research Record, 2157, 38-45.

Xu, C., et al., 2010. Using structural equation modeling to analyse travelers' acceptance intentions of travel information. Information Systems Journal, 5435, 1-17

Islam, M.T. and Habib, K.M.N., 2012. Unravelling the relationship between trip-chaining and mode choice: evidence from a multi-week travel diary. Transportation Planning and Technology, 35(4), 409-426

Sakano, R. and Benjamin, J.M., 2008. A structural equations analysis of revealed and stated travel mode and activity choices. Transportmetrica, 4(2)

Kabir, M.S., Mazumdar, R.J.R., Mitu, N.B. and Rahman, T., 2017. Trip-chaining and mode choice model for work trips: A structural equation model (SEM) approach. Batchelor of Science thesis, submitted to University of Asia Pacific, Bangladesh.

Yang, S., Wei Deng, Wu, D.X. and Gong, W., 2015. Analysis of interrelationship between trip-chain pattern and trip mode choice based on multinomial logistic model. Applied mechanics and materials,743, 407-412

Bollen, K.A., 1989. Structural equations with latent variables. Wiley, New York.

Subbarao, S.S.V., 2013. Activity based travel demand analysis for a mega city in a developing country. Ph.D. thesis, submitted Indian Institute of Technology Bombay, Mumbai.

Primerano, F., Taylor, M.A.P., Pitaksringkarn, L. and Tisato, P., 2008. Defining and understanding trip-chaining behaviour. Transportation, 35(1), 55-72.

Valiquette, F. and Morency, C., 2010. Trip-chaining and its impact on travel behaviour. Proceedings from the 12th World Conference on Transportation Research, Lisbon, Portugal.

Subbarao, S.S.V. and Krishnarao, K.V., 2013. Trip-chaining behaviour in developing countries: A study of Mumbai Metropolitan Region, India. European Transport, Institute for the Study of Transport within the European Economic Integration, 53, 1-7.

Transform. (2008). Comprehensive Transportation Study (CTS) for Mumbai Metropolitan Region. *Mumbai Metropolitan Region Development Authority (MMRDA)*, India.

Steiger, J.H., 1990. Structural model evaluation and modification: an interval estimation approach. Multivariate Behavioral Research, 25 (2), 173-180.

Vandenberg, R.J. and Lance, C.E., 2000. A review and synthesis of the measurement invariance literature: suggestions, practices, and recommendations for organizational research. Organizational Research Methods, 3 (1), 4-69.