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Trip Chaining Behavior in Developing Countries: A Study of Mumbai Metropolitan Region, India

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Abstract

Trip making behavior of people is becoming complex day by day due to their modern and hectic life style. This exhibits that a better understanding of trip chain decision making is necessary to transportation researchers and policy makers. Hence, this paper explores trip chaining behavior of Mumbai Metropolitan Region (MMR) residents using the activity-travel survey conducted by the authors in 2011. This paper proposes a typology of trip chains based on the structure of trips and activity purpose. Further, this study develops an empirical framework to examine the effect of household and individual socioeconomic characteristics, and travel choices on individual trip chain making behavior. In addition to the descriptive analysis, a nested logit model is proposed for further understanding of the concept. Model estimation results shows that, the identified variables have significant explanatory power in the decisions relating to the trip chain choice. This study provides promising insights on trip chaining behavior of the people in developing countries and it also extends the need to incorporate trip chaining behavior in existing travel demand forecasting models.

Key words: Activity-travel behavior - Trip chain - Developing countries - Nested logit model.

1. Introduction

Over the past few decades, increase in the complexity of travel and improvement in the technical and mathematical abilities lead researchers to work on more efficient behavioral models by updating conventional trip based models. Thus activity based travel demand models have now become the focus of model development. The major

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advantages of activity based travel demand analysis over the trip based models are better understanding of travelers' responses to transportation policies and an explicit analysis of complex travel patterns such as trip-chaining behavior. As people's activities are becoming more complex day by day and involves interaction between household members, individuals are searching for the opportunities to minimize the amount of travel required for activity fulfillment (Hensher and Reyes, 2000; McGuckin, et al., 2005; Ye, et al., 2007). Trip chaining is one of the ways of conducting more number of activities with less travel. Adler and Ben-Akiva (1979) explained the necessity of considering trip chaining behavior in travel demand forecasting model.

Trip chain is a succession of various trip segments. McGuckin and Murakami (1999) defined that a trip chain is a series of trips between two anchor points, home and work. Several authors have conducted studies on daily behaviours for typical days and proposed various definitions of a trip chain in travel behavior research (McGuckin and Murakami,1999; Valiquette and Morency, 2010; Srinivasan, 2000, Holzapfel, 1986). But these literatures fail to conclude a commonly accepted definition of trip chain. Primerano et. al. (2008) presented a good summary of the various commonly used definitions of trip chain in travel behavior research. In their study, the term trip chain was used to refer to a sequence of trips which start and finish at home with several trips in between to various other places. Earlier studies defined various trip chain typologies and the same were used in the research field. Strathman and Dueker (1995) derived two main groups of trip chains, namely simple and complex. A trip chain that involves two activities with a single destination was defined as a simple chain, whereas the one with different activities at different places including final destination was defined as a complex chain. The same typology was also used in Hensher and Reyes (2000) to determine the effect of trip chaining behaviour on the choice of travelling by public transport in Sydney.

The analysis of trip chaining activity is important for better understanding of peoples' travel behavior and transportation policy sensitivity analysis (Strathman and Dueker, 1995; Ye et al., 2007; Lee et al., 2007). A significant amount of research work has been done on travellers' trip chaining (also called as stop making) behavior (Adler

and Ben-Akiva, 1979; Golob, 2000; Ye et al., 2007; Ye, 2010; Islam, 2010; Shiftan, 1998; Kumar and Levinson, 1995; Lee and McNally, 2006; McGuckin et.al., 2005; Primerano et al., 2008; Chu, 2003). These works exposed that household and individual socio-demographic characteristics make clear impact on trip chaining behavior. Kumar and Levinson (1995) analyzed the home interview survey by relating trip chaining with demographic and travel characteristics. They observed that women are more prone to conduct other activities associated with work trips as compared to men. Strathman and Dueker (1995) investigated trip chain formations across age, gender, household structure, trip purpose, travel time, urban area, income and mode. They found that changing household structure encouraged peak period non-work travel, which intensifies congestion. Various other studies showed the impact of socio-demographic characteristics on trip chaining behavior (Yang et al, 2007; Wallace et al., 2000; Lee et al., 2007; Strathman et al, 1994; Golob, 1986). Trip chaining research has more recently focused on specific population segments like gender differences (McGuckin and Murakami, 1999; Handy, 1996; Ye et al., 2007), age differences (Golob and Hensher, 2007; Schmocker, 2010), and workers and non-workers (Bhat, 1997; Wegmann and Jang, 1998; Bhat, 1999; Bhat and Singh, 2000; Kuppam and Pendyala, 2001, Chu, 2003, Chu, 2004). These studies examine the trip chaining complexity of individuals using discrete choice models.

For further understanding of the trip chaining complexity of individuals, different modeling approaches have been followed by the researchers during the past few decades. Wallace et al. (2000), Wegmann and Jang (1998), Goulias and Kitamura(1989) and Yang et al. (2007) used the statistical modeling approaches to study the effect of household socio-demographic statistics on trip chaining behavior. In this process, they have proposed different regression models to understand the effects. Discrete choice models are often applied to dealing with the concepts of this nature. Adler and Ben-Akiva (1979), Strathman et al. (1994), Hensher and Reyes (2000) and Dissanayake and Morikawa (2002) studied about the trip chaining and proposed various discrete choice (multinomial and nested logt) models to investigate the role of household structure and travel characteristics to undertake the trip chains of various degrees of complexity. Further, Ye et.al. (2007) and Islam (2010) investigated the relationship between mode

choice and complexity of trip chaining patterns. In this process they have studied about the hierarchical relationship between trip chaining and mode choice. Some researchers have adopted advanced modeling frameworks including simultaneous doubly-censored tobit model (Lee et al., 2007) and recursive simultaneous bi-variate probit model (Ye et al., 2007) for studying the effect of socio-demographic characteristics on trip chaining behavior.

Based on the previous studies, researchers have arrived at different conclusions of trip chaining behavior from different geographic contexts. A plenty of studies have focused on cities in developed countries, but minimal research has been produced in the context of developing countries (Dissanayake and Morikawa, 2001, 2002; Yang et al., 2007, Yun et al, 2011) and of is absolutely zero when it comes to Indian scenario. However, the characteristics of land use and built environment, household and individual characteristics, travel attributes, modal switching and multiple activities in one travel and activity-travel patterns in India are entirely different from any other country. Therefore, the findings of this paper will provide useful insights into trip chaining behavior study in the cities in developing countries and contribute to a comparison of trip chain choice making behavior of individuals between India and other countries. In this study, an individual traveler's activity chaining behavior is formulated as a utility maximization problem.

In this paper, activity-travel data collected by the authors was used to provide insights into the trip chaining behavior of individuals and the extent to which trip chain can be chosen by the travelers to make their activity fulfillment in developing countries. Keeping track of these issues in mind, rest of the paper is organized as follows. Section 2 presents the methodology and section 3 introduces the study area as well as the process by which the data set need for model estimation has been prepared. Section 4 consists of a brief analysis of socio-economic characteristics in the study area, followed by trip chaining theory and analysis in Section 5. Section 6 and 7 describe the model specification and estimation results respectively. Section 8 concludes the paper by highlighting some of the results found from the model.

2. Methodology

The aim of this research is to explore trip chaining behavior in Mumbai Metropolitan Region (MMR), India. To investigate trip chaining behavior, an analysis of the activity-travel survey conducted by the author was undertaken. The methodology proposed in this study can be divided into three steps. They are preparation of data base, analysis of trip chains and development of trip chain choice model. The first step involves identification of trip chains, determination of the number of trips per trip chain, identification of the primary activity and typology of trip chains. The second step is to analyze the trip chains based on their number, duration, length, trip purpose, mode choice and identifying the interactions between trip chaining and other individual and travel characteristics. The third step is to develop trip chain choice model.

The methodology adopted for the model development is presented below. Discrete choice process can be easily explained by random utility theory (Domenich and McFadden, 1975). For this study, a hierarchical logit (or nested logit) modeling structure is used for the development of a trip chain choice model by using identified trip chain choices as alternatives. The Nested logit (NL) model is a generalization of simple Multinomial logit model (MNL) and it characterizes a partial relaxation of the Independence of Irrelevant Alternatives (IIA) property of the MNL model. At the same time, it is computationally straightforward and fast compared to the other advanced models due to the existence of a closed-form expression for the likelihood function. A nested logit model is appropriate when the subsets of alternatives which are similar are grouped in hierarchies or nests and the IIA property of the MNL model holds within each nest, not in general for alternatives in different nests.

The NL model can be calibrated by using any standard logit estimation software. Proceeding from the bottom up to top of the hierarchical structure, a MNL model like equation (1) is estimated for each hierarchy. (Ortuzar, 1983)

$$P_{ji} = \frac{e^{\beta' z_{ji}}}{\sum_{l=1}^{j} e^{\beta' z_{li}}} \quad \text{---------- (1)}$$

Where, P_{ji} is the probability that individual *i* chooses alternative *j*

$\beta^{'}$ is a vector of all estimable coefficients for alternative *j*

Z_{ji} is a vector of all explanatory variables for individual *i*

The results allows us to compute the values of the expected maximum utility (EMU) of every nest from equation (2)

$$EMU = \ln \sum_l e^{\beta' z_{ji}} \text{ ---------- (2)}$$

This EMU value then enters as an independent variable along with the vector z of attributes which are common to all members of the nest into the higher level of hierarchy.

Therefore, the composite utility of the nest is:

$$V_j = \varphi EMU + \sum \alpha z \text{ ---------- (3)}$$

Where, φ and α are parameters to be estimated

z are the attributes common to all members of the nest.

The process is repeated until the highest level of the hierarchy is reached, which will yield the marginal probabilities of the options specified at that level. The lower levels of the hierarchies will yield the conditional probabilities of the choices considered. The probability of choosing an alternative is obtained by multiplying the appropriate marginal and conditional probabilities corresponding to each of the nests. The following section describes the details of the study area and data collection for the analysis.

3. Study area and data collection

Analyzing and capturing the travel behavior and trip chaining patterns requires detailed and quality data due to complexity in finding the relationships between the timing and location of activities and interactions within households. Mumbai Metropolitan Region (MMR), in which the financial capital of India, Mumbai, is located, is the study area for this analysis. Mumbai Metropolitan Region is one of the fastest growing metropolitan regions and an economic power house of the country. There is no other metropolitan area in the world with such a large and diverse

socioeconomic environment as MMR. As per the Census 2011, the total population of the MMR region is 21.3 million (Census, 2011) and approximately sixty percent of the MMR population is residing in Greater Mumbai (GM), the mother city of the region. The population density of MMR is around 4900 persons per square kilometer as compared to the figure of 20500 for Greater Mumbai. The work participation rate is anticipated to reach about 45% by the year 2031 (from 37% in 2005) which equates to a doubling of the 2005 level of employment.

The MMR with its geographical spread of 4350 square kilometre comprises of 7 municipal corporations and 13 municipal councils and is linked with the core activity centre, GM, through suburban railway system and large network of roads. As per Transform (2008) study, built up land in MMR was measured as 574.76 square kilometres, which is about 13.65% of the total area of the region. Nearly, half of the region has agricultural and open land (50.11%), while more than one fourth of the region has forest and plantations (27.94%). Remaining land has coastal wetlands (6.65%) and water bodies (1.65%).

The transportation system of Mumbai Metropolitan Region is dominated mainly by the public transportation mode. Public transport systems in Mumbai include the suburban railway, buses and intermediate public transport (IPT) modes like taxis and auto rickshaws. About 78% of the trips (53.3% of trips by suburban rail and 24.8% by bus) are carried by public transport modes and remaining trips by the private vehicles (car and two wheelers) and IPT modes (Transform, 2008). Figure 1 shows the land use characteristics of the study area. The activity based data pertaining to this study area was collected by using an appropriately designed survey instrument by the author.

Following a standardized procedure for question formulation and pertaining to the data needs of an activity based model development, a new survey instrument called activity-travel diary was designed. The survey instrument was designed in such a way that it can overcome the limitations of traditional travel diaries like lack of time use concept and their inability to represent interaction between household members. The

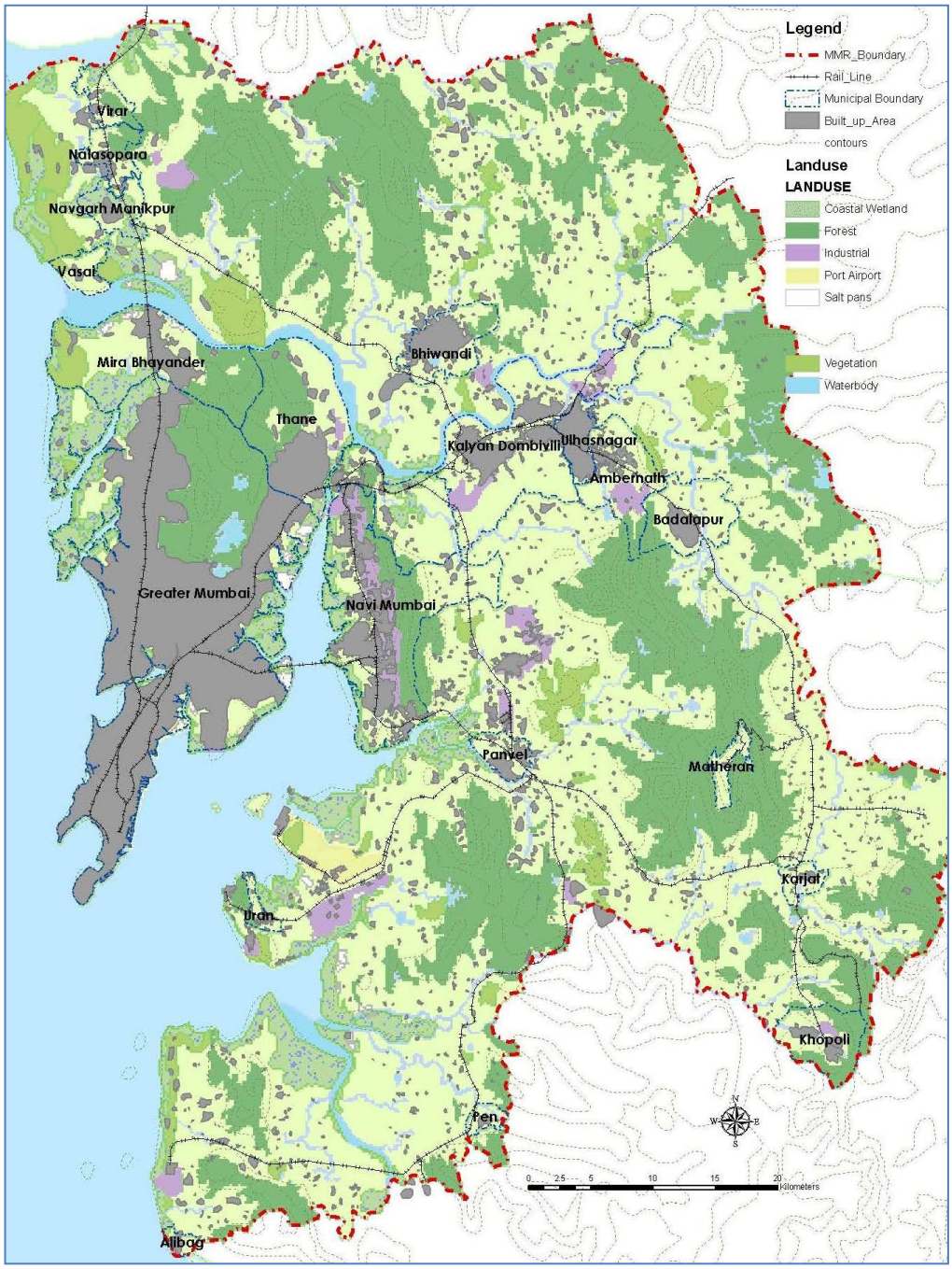


Figure 1: Study area
Source: Transform, 2008

questionnaire included in this instrument was reviewed by academic experts to check its suitability to developing countries like India. Though the survey booklet is in three languages, viz., English, Hindi (Indian national language) and Marathi (regional language), respondents reported the data 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 sampling frame. Though many advanced methods are available, the use of paper-based diaries in developing countries allowed us to reaching some categories of people who do not have Internet access or are not comfortable with computers. In view of the requirement of the data and based on experts opinion, drop-off and pick-up (DAP) method of survey administration was adopted for the study. As a preliminary step a pilot survey was conducted to evaluate the performance of the designed survey instrument and the respondent's reaction to the survey process. The main survey was carried out for a sample size of 350 households with a net response rate of 36 percent. In addition to the diary, each respondent was provided with the questionnaire about their household and personal characteristics. To capture complex interactions and to observe even the activities which are occasionally carried out by the individuals, a continuous 15 day activity-travel survey is proposed for this study. Both in-home and out-of-home activities were collected in this survey. Households with children over the age of 5 years are considered for the survey. The data set used in this study is the first of its kind which carries 15 days travel diary data set that included all trip purposes and transport modes. Each activity pursued by individuals was described by start time, end time, description of activity, activity location, mode of travel, travel time, travel cost, waiting time, accompanied household members and comfort level in using public transport.

4. Socio-economic characteristics

This section provides a descriptive analysis of socio-economic characteristics of household and individuals obtained from the sample. The work force ratio was found to be 42.8 percent compared to 38.4 percent in Transform (2008) study and 39.7 percent in Census (2011). In Gender composition, male-female ratio was found to be 1.13 against 1.12 in Transform (2008) and 1.2 in Census (2011). This comparison suggests that the sample-population distortion is minimal in the study. Vehicle ownership (car and two-wheeler) data shows that 39 percent of households have no vehicle, 36 percent of them have one vehicle and rest of the sample has more than one vehicle at their home. This analysis clearly demonstrates the level of dependency on public transport in the study area. More than 60 percent of the households fall into middle class, who fall in the

monthly income range of Rs.20000 to Rs.50000. More than 40 percent of the respondents do not have a minimum education level of secondary school education, and nearly 45 percent of respondents have pursued graduation and above. These statistics clearly shows that there are significant variations in income level and education level in the study area. Table 1 shows some selected descriptive statistics which represents socio-economic characteristics of the sample.

Table 1: Descriptive statistics from the sample data

Household characteristics	**Mean**	**Std Dev**
Household size	3.64	1.23
Gender		
Males per household	1.94	0.85
Females per household	1.7	0.89
No. of workers	1.56	0.77
Children age <5 years	0.3	0.48
Vehicle ownership (No. of vehicles per household)	0.921	0.891
Passenger cars per household	0.365	0.531
Two wheelers per household	0.524	0.654
Bicycles per household	0.024	0.153
Others (Taxis, Rickshaws etc.)	0.008	0.089
Licensed drivers per household	1.06	0.855

5. Trip chaining theory and analysis

Every trip chain starts at home location and ends at the same point with one or more intermediate activities. If these activities include mandatory activities like work/study, they are considered as primary activity; otherwise, the activity which takes longest duration is called as the primary activity. All other activities conducted in between the home and the primary activity are considered as secondary activities. Thus, a trip chain can have home, primary activity and one or more secondary activities. The data set used

for analysis and model development is extracted from the activity-travel survey explained in the previous sections. Total number of trip chains identified in 15 days is 7642. In the total trip chains, 58.32% of chains were formed by the male activities and 41.67% of chains were formed by the female activities. In this paper, trip chains are broadly classified as simple, complex and open chains. Simple chains are the simplest form of trip chains that contains 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. Trip chaining information is extracted based on the above classification. The conditions used to determine and construct the trip chains are every trip chain will start and end on the same day, a trip chain's end point is the start point of the next chain except the last chain segment, and modal switching is not a separate activity. In this study, more than eighty percent of the trip chains are comprised of simple chains (home-destination-home). Of all the trip chains, 11.5% of the trip chains are considered as complex. Open chains are highly uncommon, due to missing or incomplete observations. Indeed, 0.6% of the trip chains are open chains in the data. Table 2 presents the sample share of trip chains based on the purpose. The trip chains including work or study as primary activity are classified as work chains and others are non-work chains. From the table, nearly half of the trip chains are observed as work-based. About 80 percent of these work chains were simple journeys to and from places of work/study, which is less than the comparable split (96 % simple) for non-work journeys. This indicates that travelers are more willing to do simple non-work journeys compared to work journeys. The most notable thing is the proportion of shopping and social/recreational journeys is on par with the proportion of work and study related journeys in MMR.

Table 2: Sample share of purpose based trip chains

Type of chain	Purpose of trip chain		
	Work	Non-work	Total
Simple	39.65	48.33	87.97
Complex	9.25	2.21	11.46
Open	0.35	0.21	0.56
Total	49.25	50.75	100

For the subsequent analysis, a refinement in the previous classification has been performed based on their trip purpose. A trip chain typology is proposed in this study based on the earlier research (Strathman and Dueker, 1995; Primerano et. al., 2008; Valiquette and Morency, 2010) and the data obtained from activity-travel survey. In the typology, simple chains are further classified as simple work chains (one work or study related activity in between home ends) and simple non-work chains (one activity other than work or study in between home ends). Complex chains are classified as complex work chain (more than one work or study related activities in between home ends), complex non-work chain (more than one activity other than work or study in between home ends), complex to work/study (complex work chain with one or more maintenance or leisure activities before the work/study), complex from work/study (complex work chain with one or more maintenance or leisure activities after work/study activities), complex to and from work/study (complex work chain with one or more maintenance or leisure activities before and after the work/study activities), complex at work/study (complex work chain with one or more maintenance or leisure activities in between work/study activities), complex at and from work/study (complex work chain with one or more maintenance or leisure activities in between and after the work/study activities), complex to, from and at work/study (complex work chain with one or more maintenance or leisure activities before, after and in between the work/study activities) and open chains (incomplete trip or information). Table 3 shows the typology of proposed trip chain patterns and their share in the sample.

Further, the analysis provides insights on the relation between socio-demographic variables and trip chaining patterns. The purpose of this analysis is to capture the effect of socio-demographic variables on people's trip chaining behavior and generating a basis for upcoming model development. Average number of trips observed per trip chain is 2.17. Overall, the difference between weekday and weekend trip chains is less: 2.19 for weekday and 2.09 for weekend. Moreover, the average number of trip chains observed per person per day is 1.47 (1.59 by men and 1.33 by women). These observations are showing the variations in study area in terms of making trip chains per day. Table 4 presents the percent number of trip chains made by male and female in weekday and weekend based on purpose of trip chain.

Table 3: Typology of proposed 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/study)	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 to and from work/study	H - [- M/L -] - W/S - [- M/L -] - H	0.21
Complex at work/study	H - W/S - [- M/L -] - W/S - H	1.05
Complex at and from work/study	H - W/S - [- M/L -] - W/S - [- M/L -] - H	0.38
Complex to, from and at work/study	H - [- M/L -] - W/S - [- M/L -] - W/S – [- M/L -] - H	0.08
Open chains	H – W/M/S – …..	0.56

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

Table 4: Sample share of trip chains based on gender and purpose

Purpose of trip chain	Percentage of trip chains			
	Male		Female	
	Weekday	Weekend	Weekday	Weekend
Simple Work	51.71	22.90	38.77	18.77
Simple Non-work	34.66	67.13	49.20	72.59
Complex work	12.30	4.53	9.72	2.63
Complex Non-work	0.74	4.12	2.18	5.38
Open	0.59	1.32	0.13	0.63

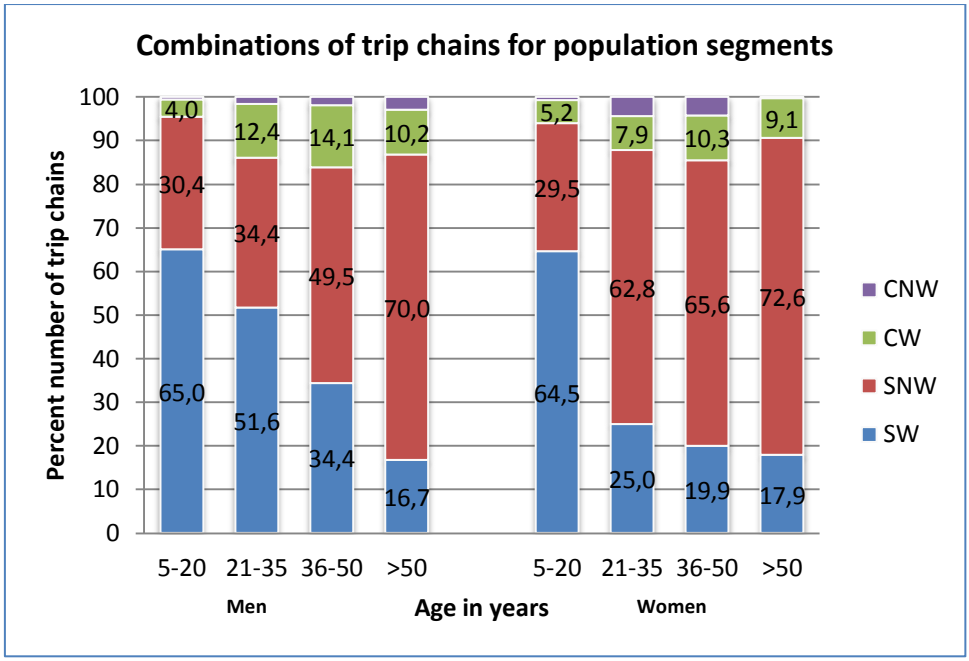
From Table 4, it is observed that 44.03% of men and 33.45% of women choose the simple work-related trip-chaining pattern. Male travelers are making more number of trip chains compared to female travelers except for complex non-work chains. This entails that women are keen to make number of trips when they went out on non-work purpose. Male travelers are making more number of simple work chains compared to women in both weekday and weekend. Women are tending to make more number of complex non-work chains compared to men. This signifies the role of women in conducting non-work trips for personal or family-related activities along with work related activities in study area. Table 5 presents the statistics related to the impact of age and gender on trip chain behavior of individuals. Average number of trip chains per day increases with age, from 1.63 for the 5-20 years old to 1.65 for more than 50 years old for men and decreases with age, from 1.68 for the 5-20 years old to 0.86 for more than 50 years old for women. This infers that men are becoming active in trip chain making with age compared to the women of same age. While women below 35 years are making more percent of trip chains than men, and this infers that women having age less than 35 years are more active than men in trip chain making.

Table 5: Sample share of trip chains based on age and gender

Age in Years	Percentage of trip chains			
	Male		Female	
	Weekday	Weekend	Weekday	Weekend
5-20	26.17	24.53	33.92	28.70
21-35	22.84	23.78	28.12	26.73
36-50	25.31	25.05	21.68	26.08
Above 50	25.68	26.64	16.28	18.49
Total	100	100	100	100

Figure 2 summarizes the distribution of daily behavior according to various combinations of trip chains for population segments. From the Figure, it is observed that, men having age between 36 to 50 years are making more number of trip chains when compared to other ages and women having age between 21 to 35 years are making more number of trip chains when compared to other ages. These values signify the role

of age in making trip chains in study area. Individuals with age between 21 to 35 years are not showing any interest in making complex non-work related trip chains, perhaps due to their hectic work or study related schedule. The most notable observation is that average number of simple work chains per day decreases with age from 65 percent (5-20 years) to 17 percent (above 50 years) for both men and women.



[SW = Simple work, SNW = Simple non-work, CW = Complex work, CNW = Complex non-work]

Figure 2: Distribution of trip chains for various population segments

Average duration of trip chains is estimated using the total out-of-home time, which can be estimated accurately from the activity-travel survey. The overall average trip chain duration is 4.51 hours. Average duration of trip chains observed for the age groups 5-20 years, 21-35 years, 36-50 years and above 50 years are 4.16, 4.98, 4.60 and 3.68 hours respectively. As predicted, weekday trip chain durations are longer than weekend trip chain durations for all categories and people with age group of 21 to 35 years are making long duration trip chains. Table 6 presents the variations in average trip chain durations with gender and trip chain purpose. Key observation from the table is that women are making long duration trip chains than men in weekends. In addition, they are making long duration complex work chains too. This infers that women are perfectly chaining their work trips along with non-work related activities and spending adequate time on these activities.

Figure 3 shows the variations in percent number of trip chains with age and duration. From the figure, it can be observed that people aged between 36-50 years are making more number of trip chains with all durations compared to 21-35 years old people. This infers that middle aged people are more active in making all types of chains. People with an age group of 5-20 years old are making nearly 90 percent of their trip chains with duration of less than 8 hours, and it infers that most of the people in this age group are students and most of their trips are self constrained to education related activities. Individuals are making more than half of their trip chains with duration of less than 4 hours irrespective of their age group. This observation entails that all the people are doing short duration trip chains more frequently in the study area. As expected, people having age more than 50 years old are keen to make short duration trip chains.

Table 6: Variations in average trip chain duration with gender and purpose of chain

Trip chain purpose	Average trip chain duration in hours					
	Male			Female		
	Weekday	Weekend	Average	Weekday	Weekend	Average
Simple Work	7.13	5.70	6.75	6.59	4.50	6.03
Simple Non-work	1.56	2.16	1.72	1.38	1.96	1.54
Complex Work	8.75	5.32	7.83	9.62	7.64	9.09
Complex Non-work	4.16	5.51	4.52	2.01	5.41	2.92
Average	**5.40**	**4.67**	**5.21**	**4.90**	**4.88**	**4.89**

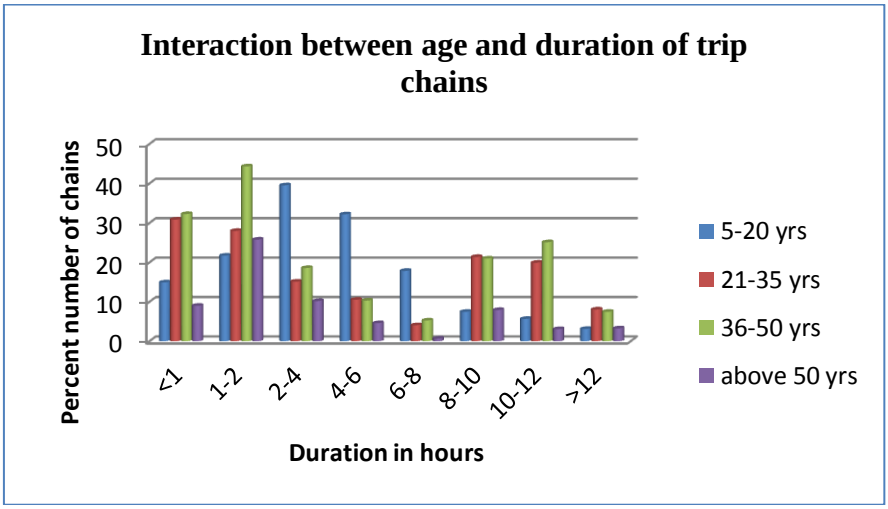


Figure 3: Variation in percent number of trip chains with age and duration

Table 7 presents the sample distribution of percent trip chains of male and female in relation with mode choice. This analysis has been done by considering the modes Rail, Bus, Car, Two Wheeler (TW), Intermediate Public Transport (IPT), Walk and Non-Motorized Transport (WNMT). It has been observed that men preferred to use private transport when making complex trip chains. For simple non-work related trip chains, more percent of men and women prefer non-motorized transport modes. Women prefer public transport for making more percent of trips when compared with men. All the travelers are choosing IPT modes for making complex non-work related trip chains and this mode is used most by women compared to men. Next section describes about the specification and estimation of the model.

Table 7: Sample distribution of percent trip chains based on gender and mode choice

Mode choice	Percent number of trip chains							
	Male				Female			
	SW	SNW	CW	CNW	SW	SNW	CW	CNW
Rail	19.24	2.32	20.33	9.46	17.95	2.62	32.69	9.47
Bus	24.31	4.95	22.18	20.27	25.21	4.62	34.23	6.32
Car	5.78	9.65	27.10	28.38	8.09	5.64	22.31	17.89
TW	11.62	12.33	13.14	10.81	3.16	6.50	0.38	3.16
IPT	4.20	4.95	3.70	28.38	5.58	6.56	8.85	28.42
WNMT	34.85	65.79	13.55	2.70	40.00	74.06	1.54	34.74
Total	100	100	100	100	100	100	100	100

[SW=Simple Work, SNW=Simple Non Work, CW=Complex Work, CNW=Complex Non Work]

6. Model specification

The possible inclusion of choice variables for model specification are based on previous theoretical and empirical work on trip chaining models and experts opinions by taking in to account the conditions in developing countries. Types of variables included in the model are household socio-demographics, individual characteristics, employment characteristics, and activity participation and system characteristics. The household socio-demographic characteristics included in the model are household size, children of age less than five years, number of workers, vehicle ownership, car ownership, two

wheeler ownership, bicycle ownership, household income, type of ownership and type of residence. The individual characteristics and employment variables considered in the model are age, gender, occupation, education level, license holding to drive, travel pass, description of individuals, individuals of age less than 30 years and individuals of age more than 50 years. The activity participation variables considered are type of trip chain, number of trips per trip chain, duration of trip chain, type of primary activity, type of day, time of day, accompanied members in the activity and primary mode of the trip chain. The final model specification was developed through a systematic process of adding sets of different variables to the trip chaining model and eliminating statistically insignificant variables. Also, variables were combined when their effects on the model were not statistically different. Table 8 provides a list of variables used in the model and their descriptions.

Table 8: Description of Explanatory Variables

Variable	Definition
Household characteristics	
HHSize	Household Size
Nwork	Number of worker in the Household
VehOwn	Vehicle Ownership
CarOwn	Car Ownership (1 if yes, 0 otherwise)
TWOwn	TW Ownership (1 if yes, 0 otherwise)
BicOwn	Bicycle Ownership (1 if yes, 0 otherwise)
Less5Yrs	Children age less than 5 yrs in the Household (1 if yes, 0 otherwise)
HHInc	Household Income in Rupees per month (1 if less than 10000, 2 if 10001-20000, 3 if 20001-30000, 4 if 30001-50000, 5 if 50001-75000, 6 if 75001-100000, 7 if more than 100000)
TypeRes	Type of residence (1 if apartment/flat, 2 if independent house, 3 if chawl, 4 if slum)
TypeOwn	Type of ownership (1 if owned, 2 if rented, 3 if government quarters, 4 if employer provided)

(Table 8 continued)

Variable	Definition
Person Characteristics	
Age	Age of Individual
Gender	Gender (1 if male, 2 if female)
Occupation	Occupation Level (1 if employed in executive, 2 if employed in managerial, 3 if employed in supervisory, 4 if employed in clerical, 5 if employed in attendant, 6 if employed in part time, 7 if self employed, 8 if employed in daily wages, 8 if student, 9 if seeking employment, 10 if home maker, 11 if retired with pension, 12 if retired without pension
Edulevel	Education level (0 if illiterate, 1 if primary, 2 if secondary, 3 if higher secondary, 4 if graduation, 5 if post graduation and above)
TraPass	Travel Pass (1 if yes, 0 otherwise)
LicStatus	Driving License status (0 if no license, 1 if auto/car/jeep/van, 2 if two wheeler, 3 if both car and tw, 4 if heavy vehicle)
Des	Description of Individual (1 if worker, 2 if non-worker, 3 if student)
Agele30yrs	Individual having age less than 30 years (1 if yes, 0 otherwise)
Agemor50yrs	Individual having age more than 50 years (1 if yes, 0 otherwise)
Travel Characteristics	
TyofChain	Type of trip chain (1 if simple, 2 if complex)
Ntrips	Number of tirps per trip chain
Duration	Duration of trip chain in minutes
TypeofAct	Primary activity (1 if work related, 2 if maintenance related, 3 if leisure activity
TypeofDay	Type of day (1 if weekday, 2 if weekend)
TimeofDay	Starting time of trip chain in 24 hour format (1 if 2-7, 2 if 7-11, 3 if 11-16, 4 if 16-21, 5 if 21-2)
AccMem	Accompanied members in the trip chain (1 if yes, 0 otherwise)
Mode	Primary mode of trip chain (1 if walk, 2 if bicycle, 3 if taxi, 4 if auto rickshaw, 5 if two wheeler, 6 if car-driver, 7 if car-passenger, 8 if Bus(Govt. transport), 9 if Bus(company provided), 10 if rail

7. Model Estimation

Keeping in view the trip chain typology, identified trip chain choices in the study area are simple work (SW), simple non-work (SNW), complex work (CW), complex non-work (CNW), complex to work (CTW), complex at work (CAW), complex from work (CFW), complex at and from work (CAFW), complex to and from work (CTFW),

complex to, from and at work (CTFAW) and open chains. From these choices, most complex chains like CAFW, CTFW and CTFAW are aggregated and named as multiple complex chains (MCC) for modeling purpose. Open chains are very few in number and missing data about these chains leads to the exclusion of same from the analysis. The Revealed Preference (RP) information of around 7319 valid individual observations are considered after making necessary corrections and logical checks in the 15 days activity-travel survey data for this study. The split-up of the observations are as follows: SW is 39.88 percent, SNW is 48.6 percent, CW is 2.5 percent, CNW is 2.22, CTW is 0.73 percent, CAW is 1.06 percent, CFW is 4.34 and MCC is 0.67 percent.

A trip chain choice model system was developed as discrete choice model by assuming a hierarchy of the model components. The simultaneous estimation (full information maximum likelihood) method is used to estimate the developed NL model. It is assumed that the scale parameter for the bottom level of the nesting structure is unity, and the scale parameter for the upper level is estimated. In nested logit model, a two level hierarchical nested structure is proposed. The lower level consists of eight elemental alternatives (SW, SNW, CW, CNW, CTW, CAW, CFW and MCC) and the upper level consists of three composite alternatives (simple chains, complex chains, compound chains). This nesting thus creates set of conditional choices and set of marginal choices. Three conditional choices are observed in this model. (1) Simple work, Simple non-work are conditional on choosing Simple chains (2) Complex work, Complex non-work are conditional on choosing complex chains (3) Complex to work, Complex at work, Complex from work and Multiple complex chains are conditional on choosing compound chains. Figure 4 represents the tree diagram adopted for this study to recognize the potential linkages between choice sets. For every composite alternative in the model, there exists one unique inclusive value (IV) parameter as part of the tree structure. The parameter value of every IV variable must lie in the range of 0-1. To satisfy this condition, some of the IV parameters can be normalized or constrained to some fixed value. In developed model, IV parameter of composite alternative, complex chains is constrained to a fixed value of 0.9.

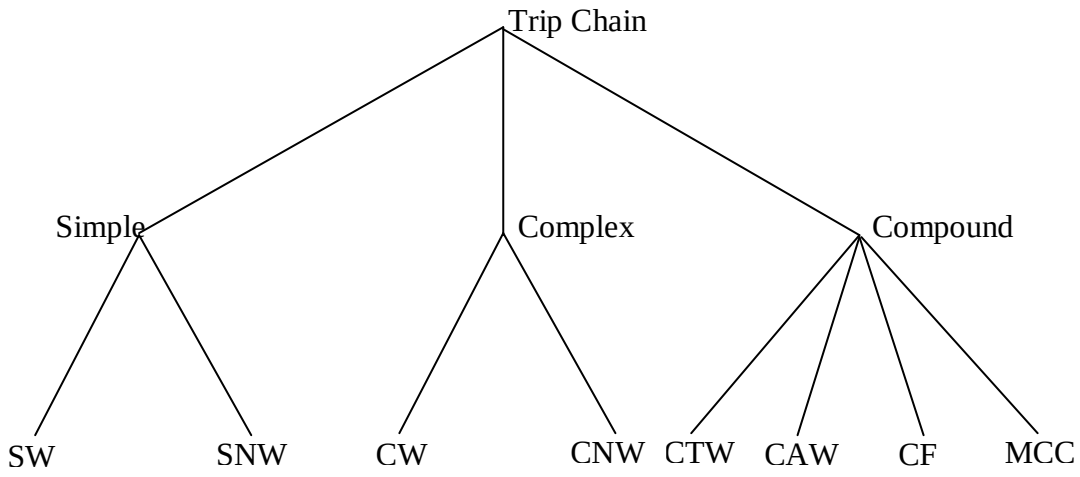


Figure 4: A nested structure to recognize the linkage between choice sets

Nested logit model is formulated with all identified household and socio-economic variables along with the alternative specific constants in defining the utility of different alternatives. Then attention was given to the use of alternative or choice specific variables in utility functions of alternatives. Significance of variables was checked and the non-significant variables were eliminated based on logical sign, t-statistic and likelihood ratio test. Factors considered in selecting the specification were overall goodness of fit measure i.e. logical sign, the significance of variables entered and ρ^2 statistic. The software NLOGIT is used to estimate the model parameters through maximum likelihood method. From the model, the log likelihood value observed with constants is -9222.7 and the log likelihood value at the convergence is -11996.7 with a rho squared value of 0.23, denoting that the model explains travel behavior adequately. All the parameters including IV parameters are observed to be statistically significant. The overall model fit is adequate and it is also observed that most of the variables share high t-statistic value which indicates the significance of these variables in the model. The parameter coefficients and goodness of fit statistics for the nested logit model are presented in Table 9.

Table 9: Parameter Estimates and Goodness of fit Statistics for Nested Logit Model

Variable (Specific to alternative)	**Parameter**	**t-statistic**
Alternative Specific constants		
Simple work chains (SW)	2.318	2.41
Simple non-work chains (SNW)	5.344	5.83
Complex work chains (CW)	-4.993	-8.43
Complex non-work chains (CNW)	-4.141	-7.50
Complex at work chains (CAW)	2.750	9.41
Complex from work chains (CFW)	-0.881	-2.42
Multiple complex chains (MCC)	-0.906	-2.17
Household characteristics		
Household income (SW)	0.110	4.03
Car ownership (SW)	-0.294	-3.06
Two wheeler ownership (SW)	-0.287	-3.77
Car ownership (CW)	1.171	7.43
Two wheeler ownership (CW)	-0.522	-3.45
Two wheeler ownership (CNW)	-0.324	-1.89
Vehicle ownership (CTW)	-0.316	-5.03
Household Income (CTW)	0.083	3.13
Car ownership (CFW)	0.296	2.18
Two wheeler ownership (CFW)	-0.456	-3.65
Children having age less than 5 years (CFW)	-0.478	-2.84
Person characteristics		
Description of individual (SW)	0.837	14.46
Gender (SW)	-0.527	-5.51
Individuals having age more than 50 years (SNW)	0.671	4.57
Licence status (SNW)	0.114	2.98
Gender (CW)	-0.725	-3.29
Travel pass (CW)	-0.540	-2.26
Gender (CNW)	0.603	2.80
Individuals having age less than 30 years (CNW)	-0.650	-2.61
Travel pass (CNW)	-0.907	-2.94
Description of individual (CTW)	0.504	7.04
Occupation level of individual (CTW)	0.054	3.63
Individuals having age less than 30 years (CTW)	0.184	1.81
Description of individual (CAW)	-0.169	-2.19
Gender (CAW)	0.350	3.42
Individuals having age more than 50 years (CAW)	0.677	3.96
Individuals having age more than 50 years (CFW)	0.616	2.93
Individuals having age more than 50 years (MCC)	-0.835	-1.89
Travel Pass (MCC)	-0.602	-2.19

(Table 9 continued)

Variable (Alternative)	Parameter	t-statistic
Travel characteristics		
Type of day (SW)	-1.254	-10.65
Duration of trip chain (SW)	0.002	4.34
Time of day (SW)	0.231	2.29
Duration of trip chain (SNW)	-0.008	-12.12
Primary mode of trip chain (SNW)	-0.062	-3.48
Accompanied members in trip chain (SNW)	0.113	2.12
Time of day (SNW)	0.271	2.58
Duration of trip chain (CW)	0.006	10.19
Primary mode of trip chain (CW)	0.106	2.63
Accompanied members in trip chain (CW)	-0.451	-2.86
Type of activity (CW)	0.418	3.12
Type of day (CNW)	1.068	4.67
Primary mode of trip chain (CNW)	0.147	4.52
Type of activity (CNW)	0.359	2.40
Type of day (CTW)	0.757	3.81
Duration of trip chain (CTW)	0.004	7.32
Starting time of trip chain (CTW)	0.254	4.00
Type of Day (CAW)	1.767	8.65
Duration of trip chain (CAW)	-0.005	-8.53
Accompanied members in trip chain (CAW)	0.130	2.30
Type of activity (CAW)	0.227	3.08
Starting time of trip chain (CAW)	0.215	3.00
Duration of trip chain (CFW)	0.006	8.80
Primary mode of trip chain (CFW)	0.112	3.94
Duration of trip chain (MCC)	0.002	2.27
Type of day (MCC)	1.622	5.73
Primary mode of trip chain (MCC)	0.097	2.57
Type of activity (MCC)	0.458	3.31
Travel Pass (MCC)	-0.602	-2.19
Inclusive value parameters		
Simple chains	0.320	6.46
Complex chains	0.9	(Fixed Parameter)
Compound chains	0.304	7.21
Log likelihood (at constants only)	**-9222.716**	
Log likelihood (at convergence)	**-11996.729**	
ρ2	**0.231**	

Note: 1. All the variables are alternative specific variables and choice to which a variable is alternate specific is shown in parenthesis.
2. Tabular t-statistic value at 95% confidence level is 1.96. All variables with t-statistic value > 1.96 are significant.

8. Results, Discussion and conclusions

Modeling traveler's behaviour with respect to trip chaining is crucial for analysis of existing transportation systems and policy testing and effective planning of future transport networks. This study examines the relation between socio-demographic characteristics and travel in relation to trip chaining. In order to conduct this analysis, this paper proposed a typology of trip chains based on the past research and collected data set. Further, this paper presents a rigorous analysis of the socio-demographic characteristics and its influence on trip chaining.

In this study it was found that, maximum trip chains are simple all over the survey period (15 days) and most of the trip chains are formed by male activities. A greater proportion of trip chains are undertaken during weekdays than weekends. All the travelers are using public transport for undertaking most of the simple work journeys, whereas women prefer public transport for complex work journeys too. More than half of all trip chains are made for non-work or personal travel and most of them are undertaken by private or non-motorized transport.

The aim of the analysis undertaken in this paper is to identify the relationships between trip chaining behavior of individual with various factors. The current analysis demonstrated that the primary activity, mode choice and individual characteristics like age, gender have significant impacts on all trip chains. The analysis recognized that decision making of trip chain choice undertaken across different age groups varies significantly. It was found that people in the age group of 36 to 50 years are making more number of trip chains when compared to other age groups and people in the age group of 21 to 35 years are not showing interest in making complex non-work related trip chains. People of age 50 and above are creating less work trip chains and more trip chaining is associated with maintenance and leisure activities. It is observed that men tend to make more percent of work related trip chains whereas women undertake more trip chains containing maintenance or leisure activities. This supports the notion of gender division of household in developing countries. The number of trip chains undertaken by households varies among household structure types and across days of the week. It was found that more percent of complex work chains are observed in

weekdays and more percent of complex non-work chains are observed in weekends. By observing the relation between age and duration of trip chains, it is found that people with all age groups prefer to choose short duration trip chains and women weekend trip chain duration is considerably higher than men weekend trip chain duration. Relation between trip chaining and mode choice reveals the fact that public transport is dominating private transport in the region when making simple chains and vice-versa in making complex chains.

Further, a trip chain choice model is formulated in this study for thorough understanding of the trip chaining behavior. In the model specification, all the estimated parameters have expected signs with plausible magnitudes and are found to be significant at 95 percent confidence level in the sense of explaining trip chaining behavior in developing countries. Alternative specific constants for most of the choices are estimated with reasonable significance. Moreover, significantly positive coefficients in alternatives SNW, CW, CNW describe household preferences for those trip chain choice combinations. In addition, all households with or without private vehicles are found to have a preference for the simple chains (Alternatives SW, SNW), as the alternative specific constant for these choices is positive with plausible magnitude and significance. In household characteristics, it was found that household income has positive effect on choosing any trip chain and car ownership has positive effect on choosing complex trip chains. In person characteristics, gender has clear negative effect on choosing work related chains and positive effect on choosing non-work related trip chains. This infers that more percent of non-work trip chains are conducted by females. In travel characteristics, it can be clearly observed that type of day is showing strong negative impact on choosing simple trip chains but positive impact on complex trip chains. It infers that people tend to choose complex (non-work) trip chains in weekends. The variable accompanied by household members (acchh) is introduced in the model and it significantly influences the choice between simple and complex chains in a travel activity.

The goodness of fit of the model is reasonable, and the data used in this model are found to be appropriate. Results from the model can be meaningfully interpreted for

household travel behavior in developing countries. The Log-likelihood ratio (LLR) test is conducted for nested logit model. The LLR value of developed model is substantially greater than the critical chi-square value with the respective degrees of freedom. The rho-squared value is found to be 0.231, which is fairly adequate.

Though the model results are satisfactory, the computational burden of performing many replications of the choices is an onerous task and also to achieve statistically representative outcome is non-trivial. Overall, the research effort provides promising insights on trip chaining behavior in developing world (especially for the cities like Mumbai Metropolitan Region). On the flip side, this model partially relaxes the assumption IIA property of the MNL model between error terms of the alternatives and also no test is available for discriminating among various tree structures. Hence, advanced models like random parameter logit or probit models can be tried for further improvement. For the purpose of policy evaluation and planning, trip chaining behavior needs to be appropriately incorporated into travel demand models. At the trip generation step, by creating transitional zones (for non-home based travel) between trip production and attraction phases where trip chain could be facilitated. This study is conducted as a part of activity based travel demand model in the context of developing countries. Future research, extended analysis to a large scale data will be useful for further identifying various factors in trip chaining behavior. Identifying the interactions between trip chaining behavior and mode choice will provide a good scope for further analysis. Finally, this study leads to development of a micro-simulation based prototype of activity based travel demand model.

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