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Effect of family structure on urban areas modal split by using the life cycle concept

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ABSTRACT

The modal split model is one of the steps of the classical four-step travel demand planning. Predictive, descriptive, and prescriptive modal split models are essential to make a balance between travel demand and supply. To calibrate these models, it is necessary to detect and employ influential independent variables that are related to characteristics of travel modes, individual and family attributes, zones land use, etc. In previous studies, researchers used the household size, the number of children, and the number of employees as independent variables to show the role of family structure on the modal split. These variables cannot discriminate between different families with different structures. This paper uses the life cycle concept to categorize families based on their structures, and the effectiveness of these new variables on modal split models is examined. For this purpose, five types of family structures are considered that differences between them are based on the age of the family's children. The Multinomial Logit model is used for mode choice modeling for different trip aims. The mode choice model has been calibrated using the origin-destination data of Qazvin-Iran. Results show the critical role of life cycle dummies in the mode choice models compared to household size, for work, educational, personal, and social- recreational trip aims. Life cycle variables are more active on the work trips mode choice model by estimating 14 significant coefficients, in a 90 percent level of significance. The number of life cycle significant coefficients is decreased to 3 for the shopping trips model.

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INTRODUCTION

A considerable increase in urban trips, especially those with personal vehicles, is one of the main factors that cause traffic congestion, and related problems such as air pollution, noise pollution, energy loss, and safety decrease (Batur *et al.*, 2019). On the other hand, the welfare of humans is increasing along with the improvement of lives quality, and for this reason, increasing the use of personal vehicles is expectable (Gilhooly and Low, 2005; Vijayalakshmi and Raj, 2019). Due to this high volume of vehicles, the urban structure will be changed as well as the streets and roads must be widened (Edrisi and Askari, 2019). The development of infrastructures is one of the tasks which are used for solving traffic congestion. Still, in

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most cases, this is not a logical instruction or solution for solving this problem. Additionally, the high costs of construction and limitation of resources lead to finding a better solution (Provotorov *et al.,* 2018). Therefore, more efficient and right policies and plans, as well as infrastructure development, can respond to the future demand for transportation (Wijaya and Imran, 2019). One of the most significant results of the transportation planning process is to determine the modal share. There are various models with different concepts and data for determining modal share (Mitra, 2013; Ton *et al.,* 2019; Calastri *et al.,* 2019; Shen *et al.,* 2020). The main goal of mode choice models is to discriminate the share of modes among the traffic flow. The first application of these models was dual selection among the personal vehicle and public transport (Train and McFadden, 1978). With the development of mode choice models, determining the share of each mode was generalized after the step of trip distribution (Vrtic *et al.,* 2007). These models are called as trip interchange models (Othayoth and Katti, 2017). The common ones are Probit (Van Can, 2013), Logit (Liang *et al.,* 2018), nested logit (Ma *et al.,* 2020), and mixed logit (Guo *et al.,* 2020). There are other models for determining the share of modes before the trip distribution step. These models are called trip end (for example, product models) (Blainey, 2010). Determining the influential factors in choosing each mode is one of the essential parts of modeling. In the current study paper, the role of factors related to the family structure is studied. The independent variables associated with the individual attributes are used in many studies (Johansson *et al.,* 2006). Other critical independent variables in the mode choice models are related to the family structure (Chang *et al.,* 2014; Kuo *et al.,* 2012; Boellis *et al.,* 2016). Several studies consider some variables such as the number of family members and children to study the effect of family structure on the mode choice (Rubin *et al.,* 2014; Mehdizadeh *et al.,* 2018). For instance, Li *et al*., (2014) consider some variables such as the number of employed members and the number of children as independent variables in order to capture the effect of the family structure in the mode choice models. In another study, Yun *et al*., (2014) for studying the impact of family structure on mode choice use household size and the number of children as independent variables. The most crucial point is the inability of these variables to distinguish between families with the same attributes but different structures. In Yun et al.'s study, a family with four members, including two children, ages more than 18 years, and the other family consists of two children, age of children are less than 7 years, were considered have the same structure. The structure of these two families is different, as well as their transportation decisions. How to define the effect of family structure on transportation decisions is considered in some studies (Kitamura and Kostyniuk, 1986; Kitamura, 2009; Huntsinger and Rouphali, 2012; Susilo *et al.,* 2019). In this paper, the idea which was proposed by Rasaizadi and Kermanshah (2018) was used to capture the effect of family structure on the modal split.

In this study, life cycle dummy variables are defined as follows:

- Life cycle 1 (LC1): The age of the oldest child is less than 6 years;
- Life cycle 2 (LC2): The age of the oldest child is between 6 and 12 years;
- Life cycle 3 (LC3): The age of the oldest child is between 12 and 18 years;
- Life cycle 4 (LC4): The age of the youngest child is under 18 years, and the age of one of the children [at least one child] is more than 18 years; and
- Life cycle 5 (LC5): Other families.

LC1, LC2, and LC3 only depend on the age of the oldest child. Usually, the trips of children under 6 years old are completely dependent on family trips. Children between 6 and 12 years old that are students of elementary school need to have educational trips with the family escort. Children between 12 and 18 years old that are students of high school can have their independent educational trips. LC4 includes families that have at least one child who can drive a car and at least one young child under 18 years old. Other families are placed in LC5. Kermanshah (1997), in another study, used these variables in order to study the effect of family structure on the trip generation model. In the current study, the impact of these variables on the mode choice models is investigated, for different trip aims, separately. Trip aims include work, educational, shopping, personal and recreational trips. The estimated coefficients of these variables are compared, and the statistical significance of them is examined. According to

the author's knowledge, it is the first time that the life cycle concept is used for modal split by using the multinomial logit model. The remainder of the paper is as follows. In the next section, the proposed model is introduced. After that, the data description is provided. Results and interpretations are presented in the result and discussion section. In the final section, the conclusion is presented. The current study has been carried out in Tehran, Iran, in 2019.

MATERIALS AND METHODS

Methodology

The multinomial logit model is used for modeling the mode choice. Assume that "*q*" is the index of a person, "*i*" is the index of each mode, and "h_{qi}" is the utility of "*i*" mode for the individual "*q*" (Eq. 1) (Ben-Akiva *et al.,* 1985). Therefore:

$$h_{qi} = \beta x_{qi} + \varepsilon_{qi} \quad (1)$$

In which; x_{qi} is the vector of independent variables, *β* is the coefficient vector that must be estimated, and ε_{qi} is the error term of the utility function. Assume that ε_{qi} follows the iid extreme value, with location parameter equal to 0 and scale parameter equal to 1. Based on the utility theory, "*q*" chooses the mode "*i*" in a case as its utility is more than other ones. In other words, it can be said that the utility of "*i*" is more than the maximum utility of other modes for individual "*q*". This term can be written as Eq. 2:

$$h_{qi} > \max_{j \neq i} h_{qj} \quad (2)$$

r_{qi} is a dummy variable that is equal to 1 and 0. It is equal to 1, if the mode "*i*" is chosen by "*q*"; otherwise, it is equal to 0. Also, v_{qi} is defined as Eq. 3:

$$v_{qi} = \{\max_{j \neq i} h_{qj}\} - \varepsilon_{qi} \quad (3)$$

By combining Eq. 1 and Eq. 2:

$$\beta x_{qi} + \varepsilon_{qi} > \max_{j \neq i} h_{qj} \quad (4)$$

The Eq. 4 is rewritten as follows:

$$\beta x_{qi} > \max_{j \neq i} h_{qj} - \varepsilon_{qi} \quad (5)$$

And by subsisting v_{qi} from Eq. 3 into Eq. 5:

$$\beta x_{qi} > v_{qi} \quad (6)$$

So, $r_{qi} = 1$ if and only if $\beta x_{qi} > v_{qi}$.

Based on Eq. 3, v_{qi} has resulted from the differentiation of the utility of the other alternatives and the error term of that mode. As both of them follows the iid extreme value, the random variable of v_{qi}, follows the logistic distribution. The marginal distribution of v_{qi} is shown in Eq. 7 as follows:

$$F_i(\beta x_{qi}) = \Pr(v_{qi} < \beta x_{qi}) = \frac{\exp(\beta x_{qi})}{\sum_j \exp(\beta x_{qj})}, j = 1,2,\dots,J \quad (7)$$

In which, "*J*" is the number of multinomial logit alternatives.

Assume that 1[0] is a function that its value is changed based on the number of integers and non-integers, one for the integers and zero for the non-integers. In such a case, M_{qik} is defined as Eq. 8.

$$M_{qik} = 1[r_{qi} = 1] \quad (8)$$

If the person "*q*" chooses mode "*i*", M_{qik} for that person equals one, and for the other "i_s" equals 0 [1].

The likelihood function of this model is as Eq. 9.

$$\log L = \sum_{q=1}^{Q} (\sum_{i=1}^{!} M_{qik} \log [\text{prob}(r_{qi} = 1)]) \quad (9)$$

By maximizing this function, the coefficients of this model can be estimated. R-studio programming is used in order to maximize this function. Numerical methods, including SANN, Nelder-Mead, and BFGS, are used for optimizing the likelihood function (Seyedabrishami and Izadi, 2019).

Data

The used data was collected in the survey of origin-destination trips for Qazvin, a city in Iran in 2010. The number of observations is 8891. The raw data needs data preparation. The age of travelers is continuous in raw data. This paper defines four dummy variables for the age of travelers to explore the effect of each age bracket separately. Also, the job of travelers in raw data is nominal. By defining four dummy variables, job variables become quantitative. Table 1 shows the defined independent variables of this data. The choice set for mode choice model includes personal vehicle, taxi, bus, motorcycle, and other modes.

Fig. 1 shows the location of Qazvin in Iran. The transportation network of this city is divided into 14

Table 1: Variable definition

Characteristics	Variable	Definition
Age	AGE 6-18	1= if the age is between 6 to 18, 0= otherwise
	AGE 19-30	1= if the age is between 19 to 30, 0= otherwise
	AGE 31-41	1= if the age is between 31 to 41, 0= otherwise
	AGE>41	1= if the age is more than 41, 0= otherwise
Sex	SEX	1= if sex is male, 0= otherwise
Job	ADM.JOB	1= if the job is administrative, 0= otherwise
	SERV.JOB	1= if the job is a service job, 0= otherwise
	EDU.JOB	1= if the job is educational, 0= otherwise
	OTHER	1= if the job is another job, 0= otherwise
Driving license	DL	1= if the person has a driving license, 0= otherwise
Number of vehicles	NVEH	Number of vehicles
Household size	HHSZ	Number of family members
Life cycle	LC1	1= if the family placed in life cycle 1, 0= otherwise
	LC2	1= if the family placed in life cycle 2, 0= otherwise
	LC3	1= if the family placed in life cycle 3, 0= otherwise
	LC4	1= if the family placed in life cycle 4, 0= otherwise
	LC5	1= if the family placed in life cycle 5, 0= otherwise

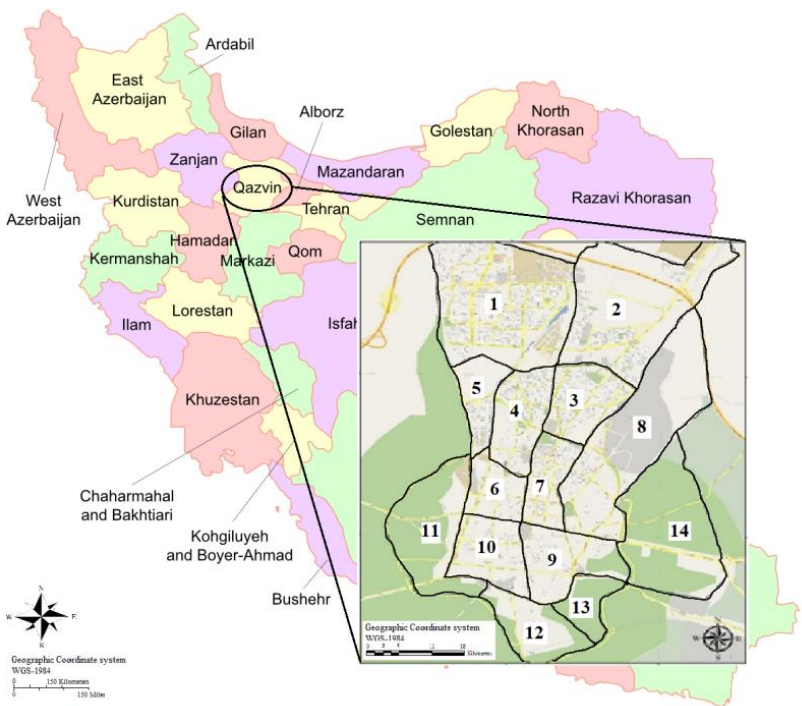

Fig. 1: Location of Qazvin in Iran and its traffic analysis zones

traffic analysis zones. The centroid of each zone is a representative point for all links and nodes of that zone. The origin and destination of trips and location of travelers home are determined based on these 14 traffic analysis zones.

RESULTS AND DISCUSSION

Mode choice models are calibrated for different trip purposes. Work and educational trips include mandatory trips to work and school (also university), respectively. The destination for shopping trips is

shopping centers or stores. Personal trips are related to their aims, such as visiting offices and doctors. Social-recreational trips include trips for visiting friends and family or trips to the parks, etc. to have recreation. Each trip purpose has a different pattern of the modal split, so to depict the effect of family structure on them, it is vital to calibrate separate models based on trip aims. Table 2 shows the mode choice model results for work trips.

For work trips, all life cycle variables and household size are estimated significantly and have a useful role in the mode choice model. LC5 is considered as base variable, and other life cycle variables are estimated related to the base variable. Bus and taxi are a preferable option for individuals that placed in LC5 and motorcycle, and others have more utility for LC1 families. Increasing household size decreases the probability of choosing a personal vehicle. People between 6-30 years old have less tendency to want personal vehicles regarding positive estimated coefficients for the other four modes. For individuals between 31- 40, motorcycle and taxi are a preferable mode and bus has less utility for these persons compared to a personal vehicle and other. The probability of choosing a motorcycle and other is high for men, while bus and taxi have more choosing probability for women. Bus, taxi, and motorcycle are more appropriate modes for individuals with ADM. jobs and SERV.jobs. Other modes have the highest utility for SERV.jobs and the least utility for EDU.jobs. Also, EDU.jobs have more tendency to choose bus for their work trips. Having a driving license increases the probability of selecting personal vehicles. Table 3 shows the mode choice model results for educational trips.

It can be seen from Table 3 that for educational trips, LC4 can discriminate the taxi from the personal vehicle by its significant coefficient, but for household size, taxi, and personal vehicles considered as base alternatives. It means that families that placed in LC4 have more tendency to choose a taxi rather than families in other families. This result shows the importance of life cycle variables when families can select a taxi for their educational trips. Bus, motorcycle, and other are preferable options for individuals in large families. Bus, motorcycle, and others have the least utility for individuals in LC2, LC3, and LC1, respectively. Also, other coefficients are interpretable. Individuals between 6 to 30 years old have more tendency to use a bus, taxi, and other modes. Taxi has the most utility for individuals between 31-41 years old, and for these individuals, other modes have the least utility. Individuals over 41 years old have less tendency to use taxis and motorcycles. Bus and motorcycle are preferable modes for men rather than women. The probability

Table 2: Mode choice results for work trips

Variables	Personal Vehicle	Bus	Taxi	Motorcycle	Other
constant	--	2.94(***)	2.79(***)	-2.20(***)	-2.14(***)
Individual characteristics					
AGE 6-18	--	0.61(***)	0.89(***)	0.66(***)	0.30(*)
AGE 19-30	--	0.44(***)	0.81(***)	0.70(***)	0.13(*)
AGE 31-41	--	-0.08(*)	0.24(***)	0.32(***)	--
AGE>41	--	--	--	--	--
Sex	--	-0.428(***)	-0.51(***)	2.18(***)	0.49(**)
ADM.JOB	--	1.05(***)	0.77(***)	0.44(***)	--
SERV.JOB	--	0.31(***)	0.55(***)	0.81(***)	0.78(***)
EDU.JOB	--	0.28(**)	--	--	-0.86(**)
OTHER	--	--	--	--	-
DL	--	-2.46(***)	-2.11(***)	-2.38(***)	-1.04(***)
Family characteristics					
NVEH	--	-2.33(***)	2.02(***)	-0.09(*)	-0.98(***)
HHSZ	--	0.19(***)	0.12(***)	0.11(***)	0.27(***)
LC1	--	-0.65(***)	-0.66(***)	0.23(**)	0.83(***)
LC2	--	-0.53(***)	-0.60(***)	-0.20(**)	0.53(***)
LC3	--	-0.26(**)	-0.38(***)	-0.32(***)	0.26(***)
LC4	--	-0.17(**)	-0.28(***)	--	--
LC5	--	--	--	--	--

Stars show level of significance (***99%, **95% and* 90%)

Table 3: Mode choice results for educational trips

Variables	Personal Vehicle	Bus	Taxi	Motorcycle	Other
constant	--	1.28(***)	2.19(***)	-2.97(***)	-13.91(***)
Individual characteristics					
AGE 6-18	--	1.54(***)	0.48(*)	--	11.84(***)
AGE 19-30	--	2.10(***)	0.46(*)	--	11.20(***)
AGE 31-41	--	1.54(***)	--	--	-5.41 (***)
AGE>41	--	--	-0.74(*)	-1.03(***)	--
Sex	--	2.15(***)	--	2.18(***)	--
ADM.JOB	--	--	--	0.44(***)	-8.03 (***)
SERV.JOB	--	-0.76(**)	-1.67(***)	0.81(***)	--
EDU.JOB	--	--	--	-	--
OTHER	--	--	--	-	--
DL	--	-1.48(***)	-1.21(***)	-2.38(***)	-1.30(**)
Family characteristics					
NVEH	--	-0.93(***)	-0.68(***)	-0.09(*)	-0.51(**)
HHSZ	--	0.05 (***)	--	0.11(***)	0.22(**)
LC1	--	-1.19(***)	--	0.23(**)	-44.12(**)
LC2	--	-1.40(***)	--	-0.20(**)	0.42 (*)
LC3	--	-0.37(***)	--	-0.32(***)	--
LC4	--	--	0.21(***)	--	--
LC5	--	--	--	--	--

Table 4: Mode choice results for shopping trips

Variables	Personal Vehicle	Bus	Taxi	Motorcycle	Other
constant	--	1.11(*)	1.01(*)	-1.49(*)	-19.18(***)
Individual characteristics					
AGE 6-18	--	2.37(**)	2.45(**)	2.50(*)	2.01(*)
AGE 19-30	--	1.87(***)	2.22(***)	1.97(***)	2.75(***)
AGE 31-41	--	0.87(*)	1.09(***)	1.05(*)	1.16 (*)
AGE>41	--	--	--	--	-
Sex	--	--	--	--	16.86 (***)
ADM.JOB	--	1.76(***)	1.29(**)	2.16(**)	0.96 (*)
SERV.JOB	--	--	0.80(**)	2.32(***)	--
EDU.JOB	--	--	--	--	--
OTHER	--	--	--	--	--
DL	--	-3.14(***)	-3.32(***)	-3.07(***)	-1.17(**)
Family characteristics					
NVEH	--	-2.30(***)	-2.22(***)	-0.88(**)	-1.14(**)
HHSZ	--	0.34(***)	0.40(***)	0.29(***)	0.51(***)
LC1	--	--	--	--	--
LC2	--	--	--	--	--
LC3	--	--	-0.55(*)	--	--
LC4	--	--	--	-1.24(**)	-1.49(**)
LC5	--	--	--	--	--

of choosing a motorcycle is higher for ADM.job and SERV.job compared to EDU.job and OTHER. Individuals with ADM.job have less tendency to use other modes. The probability of choosing the bus and taxi is decreased when individuals have SERV.jobs. Peoples that have the driving license are more likely to choose personal vehicles regarding estimated coefficients for the other four modes. Table 4 shows the mode choice model results for shopping trips.

For shopping trips, household size depicts the family structure better than life cycle variables. This variable appears in all non-base alternatives utilities, but life cycles do not appear in bus utility. Individuals in large families prefer to use a bus, taxi, motorcycle

Table 5: Mode choice results for personal trips

Variables	Personal Vehicle	Bus	Taxi	Motorcycle	Other
constant	--	2.36(***)	2.91(***)	3.47(***)	-2.29(***)
Individual characteristics					
AGE 6-18	--	1.45(***)	--	-1.49(***)	--
AGE 19-30	--	1.14(***)	--	1.80(***)	--
AGE 31-41	--	--	--	--	--
AGE>41	--	--	-0.64(**)	--	--
Sex	--	--	--	6.41(***)	1.78 (**)
ADM.JOB	--	-1.30(***)	--	--	2.28(***)
SERV.JOB	--	--	--	2.26(***)	2.19(***)
EDU.JOB	--	--	0.59(**)	--	--
OTHER	--	--	--	-2.68(***)	--
DL	--	-2.80(***)	-2.57(***)	-2.64(***)	-2.53(***)
Family characteristics					
NVEH	--	-2.01(**)	-1.02(***)	--	--
HHSZ	--	0.11(***)	--	--	--
LC1	--	-0.64(***)	--	--	--
LC2	--	--	-1.11(**)	--	-1.84(**)
LC3	--	--	-0.50(**)	--	--
LC4	--	--	--	--	-0.81(**)
LC5	--	--	--	1.56(**)	--

Table 6: Mode choice results for social-recreational trips

Variables	Personal Vehicle	Bus	Taxi	Motorcycle	Other
constant	--	3.93(***)	1.44(***)	-9.10(***)	-1.60(***)
Individual characteristics					
AGE 6-18	--	--	--	--	--
AGE 19-30	--	--	--	0.72(*)	-2.00(**)
AGE 31-41	--	0.72(*)	0.54(*)	--	-1.09(*)
AGE>41	--	--	--	--	--
Sex	--	--	--	4.41(***)	1.68(***)
ADM.JOB	--	-2.31(***)	--	4.56(***)	-1.59(*)
SERV.JOB	--	-4.06(***)	--	--	-1.19(*)
EDU.JOB	--	--	2.02(**)	--	-0.98(*)
OTHER	--	-0.84(*)	--	--	--
DL	--	-1.79(***)	-1.62(***)	--	--
Family characteristics					
NVEH	--	-1.69(***)	-1.41(***)	--	--
HHSZ	--	--	0.19(*)	--	--
LC1	--	--	--	--	2.25(***)
LC2	--	--	--	-2.98(***)	-1.93 (**)
LC3	--	-0.75(**)	-1.57(***)	--	--
LC4	--	--	-1.05(**)	--	--
LC5	--	--	--	--	1.18 (*)

compared to a personal vehicle. Taxi, motorcycle, and others have the least choosing probability for individuals in LC3, LC4, and LC4, respectively. All individuals, except individuals over 41 years, have more tendency to use a bus, taxi, motorcycle, and others rather than a personal vehicle. The probability of choosing other modes is high for men compared to women. The personal vehicle has the least utility for individuals with ADM.jobs, and bus and motorcycle are preferable modes for individuals with SERV. jobs. The probability of choosing a personal vehicle is increased when individuals have a driving license. Table 5 shows the mode choice model results for personal trips.

Mode choice model results for personal trips show the critical role of life cycle variables in utility functions. Still, household size cannot consider the effect of family structure on the taxi, motorcycle, and other modes. Individuals in large families are more likely to choose a bus for their trips. Bus, taxi, and others have the least utility for individuals in LC1, LC2, and LC2, respectively. Individuals in LC5 have more tendency to choose the motorcycle. Individuals between 6 to 30 years old have more tendency toward using a bus. The motorcycle is an attractive mode for individuals between 10 to 30 years old, but this mode has a less attractive option for individuals between 6 to 18 years old. Selecting of taxi negatively affected for individuals over 41 years old. The probability of choosing a motorcycle and other is increased for men compared to women. Bus, motorcycle, and other are preferred options for EDU, SERV, and ADM jobs. Having a driving license has a significant positive effect on choosing a personal vehicle. Table 6 shows the mode choice model results for social-recreational trips.

Similar to personal trips, for social-recreational trips, life cycle variables appear in all utility functions by high statistically significant, but household size only appears in taxi utility. Individuals in large families prefer to use a taxi for their social-recreational trips. Bus, taxi, motorcycle, and others have a less choosing probability for individuals in LC3, LC3, LC2, and LC2, respectively. Bus and taxi are the preferred options for individuals between 31 to 41 years old. Individuals between 19- 31 have more tendency to use a motorcycle for their social-recreational trips. Also, other has less utility for persons between 19 to 41 years old. Motorcycle and others are attractive options for men. Persons with EDU.jobs have more tendency to use the bus. Taxi and motorcycle have the highest choosing probability for EDU.jobs and ADM.jobs, respectively. Individuals with OTHER jobs have more tendency to choose other modes for their social-recreational trips. Having a driving license decrease the probability of choosing a bus and taxi.

CONCLUSION

The most important question of this study was; how life cycle as the family structure affects the trip mode choice. Also, there are some variables, such as the number of family members, which shows the family structure. For work trips, the coefficients of all life cycle variables and the number of family members are estimated and were significant that indicates the mutual effect of these variables for the description of the family structure on mode choice. For the shopping trips, the number of family members is considered in the utility of all modes. However, variables of the life cycle are limited to the utility of two modes. For such trips, the number of family members has an effective role in describing the family structure. For the educational, personal, social, and recreational trips, variables of the life cycle are considered in all alternatives, but, for each aim, the number of family members did not emerge in the utility of two options. This point shows the role of life cycle variables in the description of the family structure. In general, it can be said that the use of life cycle variables is essential for studying the effect of family structure on the modeling of transportation decisions.

AUTHOR CONTRIBUTIONS

A. Rasaizadi commenced the process by conceptualizing and formulating the research idea, followed by data collection and cleaning. A. Rasaizadi and M. Askari calibrated multinomial logit models, reviewing the literature, and preparing the manuscript.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy has been completely observed by authors.

ABBREVIATIONS

LC	Life Cycle
IID	Independently and Identically distributed
ADM.JOB	Administrative job

SERV.JOB	Service job
EDU.JOB	Educational job
HHSZ	Household size
NVEH	Number of vehicles
SANN	Simulated Annealing Algorithm
BFGS	Broyden – Fletcher – Goldfarb – Shanno Algorithm

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