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Modal shift behavior of car users to light rail transit, some evidence from the field

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ABSTRACT: Growing population and car dependency in developing countries have led to congestion that adversely affects the environment, travel time, trip cost, accidents, and public transportation reliability. Through implementation of travel demand management (TDM) policies, governments and policymakers aim to reduce private vehicle dependency and encourage people to use public transportation. Light rail transit is an important part of an attractive public transport. Rail transportation systems, though offer many potential benefits, are a major financial challenge for governments because of the high capital and operation costs. Therefore, passenger behavior must be determined before a new system is introduced. Using a stated preference (SP) questionnaire, private car users' behavior in Tehran's universities has been investigated to determine the explanatory factors affecting the modal shift to urban light rail transit (LRT). A binary logit model estimation results showed that men are less likely than women to shift toward LRT because they rely more on their private cars. It was the provision of free on-street parking at destinations and the frequency of using private cars on a weekly basis that had the most negative effect on LRT modal shift, demonstrating the critical role that implementation of TDM policies could play. Moreover, reduction in travel time by LRT has the most positive impact on modal shift toward LRT among private car users. As an interesting finding, marginal effect values indicate that a 10% reduction in travel time (0.32) has a greater impact than the possibility of sitting 50% of the travel time (0.25) on the likelihood of modal shift to LRT. Furthermore, the probability of modal shift to LRT will be reduced by 0.12 units for each unit increase in car ownership. In addition, owning a driver's license was also negatively correlated with LRT modal shift and decreased the likelihood by 0.27. This research will facilitate the decision-making and planning for future transportation systems to increase LRT's utility for potential users.

KEYWORDS: Binary Logit Model, Light Rail Transit, Modal Shift, Stated Preference, Travel Behavior.

INTRODUCTION

Transportation is enabling the spatial accessibility and plays a crucial role in maintaining communication and social interaction in cities. Besides the benefits of transportation, with increasing population as well as car ownership and dependency in metropolitan areas, the adverse effects of congestion on various aspects of cities are increasing every day and the reliability of public transportation is also reduced (Abbasi et al., 2021). To reduce car usage and relieve traffic congestion, many cities around the world implemented public transit priority in order to increase transit ridership. However, differences between the characteristics of various transportation systems, including capital investment, accessibility, mobility, and environmental impacts, have made it challenging for decision makers to choose the appropriate system. The development of sustainable rail transportation systems has attracted the attention of many developed and developing countries to reduce the negative effects of transportation (Christodoulou et al., 2019; Abbasi & Hadji Hosseinlou, 2022). In comparison to bus systems, light rail systems attract between 30 and 40% of their patronage from former car trips. Bus systems attract less than 5% of trips from cars, less than the variability of traffic (Lewis Lesley 2008). Therefore, Light Rail systems can play an important role of modal shift in urban areas. However, initial capital and operation costs of rail systems are major challenges for transportation organizations. Capital losses will result if the demand for these systems is not accurately assessed. On the other hand, the introduction of a new system can affect society in various dimensions, from the travel mode choice and traffic flow to economic growth and environmental impact. Therefore, it is essential to investigate passengers' behavior before introducing a new system (Yashiro & Kato, 2019).

Rapid population growth, urban sprawl, and urban trips have necessitated proper planning for intercity public transportation systems (Abbasi et al., 2020). Among the public transportation systems, Bus Rapid Transit (BRT) and subway systems, in recent years, they have not been able to meet the urban trip's demand properly. Compare to BRT system, Light Rail Transit (LRT) has many potential benefits such as higher passenger capacity, safety, more travel comfort, fuel economy and reliable time table; compare to metro, LRT needs lower capital infrastructure and operational costs, a better view due to not passing underground and better accessibility to stations (Hensher et al., 2019). Forecasting urban rail patronage and developing effective rail policies require an accurate understanding of factors which influence rail transit choice among urban travelers. Therefore, we have designed a stated preference (SP) questionnaire to determine and quantify the most influential explanatory factors of modal shift to LRT using binary logit, as a discrete choice model. We aimed to respond to questions such as what are the factors affecting the modal shift behavior of car travelers. Among the contributions of this research, it can be mentioned that: 1) we have identified variables affecting the modal shift to LRT in the metropolis of Tehran due to the lack of a study in this context; 2) we have considered the effect of attitudes on modal shift to LRT; and 3) proposing a modal shift model unlike

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previous studies which only focused on the mode choice of respondents.

This paper is structured as follows: After the introduction, section 2 reviews the previous studies on this field and Section 3 introduces the methodological approach and data. Section 4 provides a critical discussion of the main findings and provide some implications for policy and practice. Finally, the conclusions along with suggestions for further studies are outlined in Section 5.

LITERATURE REVIEW

In this section, a review of the previous studies on the factors affecting travel mode choice and modal shift based on socioeconomic and travel-related characteristics is presented.

Among the travel-related characteristics, reliable travel time has a significant effect on increasing the likelihood of choosing transit (Schramm et al., 2010; Van Loon et al., 2011; Weng et al., 2018). On-time schedule has a positive significant impact on transit choice (Outwater et al., 2011; Zhang et al., 2008) while Ahern and Tapley (2008) concluded that travel time with high reliability has no significant impact on travel mode choice. Moreover, other features of public transportation system such as travel costs, in-vehicle time, waiting time, egress and departure times, number of transfers and the possibility of seating affect the choice of people (Alberini, 2019; Hensher & Rose, 2007; Mattson et al., 2010). Ben-Akiva and Morikawa (2002) found that different components of travel time including arrival time, waiting time, in-vehicle time and departure time have a significant effect on people's choices. Furthermore, they showed that travelers prefer comfortable travel modes which have services such as heating and air conditioning. Outwater et al. (2011) pointed out the negative effect of transfer on mode choice. Mayo and Taboada (2019) identified the factors influencing the choice of public transportation in Philippines and ranked these factors based on socioeconomic characteristics and trip purpose using AHP. The results indicated the high importance of safety, accessibility, travel costs, convenience and environmental issues. Ranjbari et al. (2017) examined the factors affecting the demand for the future intercity transportation system in the United States using internet-based SP questionnaire. They used multinomial logit, nested logit and mixed logit models and found reliable public transportation system with appropriate headway and safety have the potential to attract a large number of passengers. According to the results of Bierlaire et al. (2001), the presence of unoccupied seats would increase the utility of transit.

Besides travel-related characteristics, it was found that individual characteristics and attitudes significantly affect travel mode choice. Variables such as age, gender, car ownership and income are often considered as influential variables on people's choices (Chatterjee, 2011; Mackett & Sutcliffe, 2003; Popuri et al., 2011; Macioszek et al., 2022). In some studies, it has been observed that individual attitudes are also influential in people's decision making (Domarchi et al., 2008; Murray et al., 2010). For example, some studies concluded that people with a negative attitude towards public transportation and a positive attitude towards using private cars are less inclined to use public transportation. Mattson et al. (2010) found that people with low experience in using public transportation were more likely to choose it. Pan (2015) incorporated the effect of social interaction on travel mode choice and found that the travel behavior of respondents, especially mode choice is not independent of others. Cochran (2020) assess the effect of transportation-related social interaction on travel behavior and health of people with disabilities. He has concluded that travel is more likely to occur among people who feel socially connected while traveling or have a high level of transportation self-efficacy.

In the city of Bergen, Norway, the effect of launching LRT on the travel behavior was examined using SP questionnaire (Engebretsen et al., 2017). They aimed to identify the factors influencing the public transport share between four scenarios including launching LRT, a new bus network with lower headway, increasing road tolls and changing the city structure. The results showed an increase in public transportation usage in areas equipped with LRT. The travel mode choice and willingness to use LRT as a new mode has been studied using SP survey in Indonesia (Bando et al., 2015). Using latent class and ordered logit models, they found that high-income men were more likely to shift toward LRT while Qin et al (2017) and Idris (2013) found that female are more likely to shift to LRT in China and Toronto, respectively. In Toronto, Canada, the effect of public transportation system characteristics on the modal shift of home-based trips was examined using revealed and stated preference data (Idris et al., 2014). They found that travel time and travel cost are less important compared to number of transfers and crowdness. In Mumbai, India, the effect of quantitative and qualitative characteristics of trip on the attractiveness of intercity trains was evaluated using SP data and it was found that service headway, travel time and in-vehicle crowdness level affect travel choice (Basu & Hunt, 2012).

METHODOLOGY

Choice experimental design

Due to the lack of LRT in Tehran, an SP questionnaire has been designed and administered as the experimental design tool. There are two reasons for adopting SP survey: first, collecting RP data is expensive (in terms of both money and time), and second, Tehran has no LRT. SP data represent choices made by respondents under hypothetical conditions in which personal constraints are not considered limitations during the decision-making process. This is particularly true when respondents do not treat the SP task seriously (Zheng et al., 2016). The SP questionnaire designed for this purpose consisted of three main sections (after stating the survey objectives and anonymity of responses): 1- respondents were asked to consider their last trip by private car and mention their trip characteristics (such as departure time, total travel time, number of accompanying people, parking type, parking cost, possibility of using public transportation), and alternative mode if it is not possible to use private car; 2- SP scenarios which address respondents' preference about their modal shift to LRT according to three three-level attributes (including travel time, travel cost and sitting time in LRT); 3-socioeconomic characteristics such as gender, age, marital

Scenario	Changes in fare	Changes in travel time	Sitting time in LRT	Would you shift to LRT?	
S1	+20%	-10%	50% of travel time	☐Yes	☐No
S2	0%	-20%	20% of travel time	☐Yes	☐No
S3	-20%	0%	0% of travel time	☐Yes	☐No

Table 1. An example of stated preference scenarios for modal shift to LRT

status, income level, car ownership, household size, and frequency of using private car in a week. For the SP scenarios, the most suitable factor combinations were determined by an orthogonal design method (Table 1). Respondents were also asked to declare the importance of various factors on LRT choice along with the appropriateness level of these factors in current travel modes using a 5-point Likert scale.

Data

Considering the survey procedure, a face-to-face interview with respondents was conducted to gather the necessary research data from May to June 2014. In terms of sampling method, a cluster sampling was used for the survey and questionnaires were used to sample car users in Tehran universities. Before the main survey, 10 questionnaires were filled out as a pre-test to check the clearness of the questionnaire. As a result, some questions were removed or revised due to different perceptions. Descriptive analysis of socioeconomic characteristics (Table 2) shows that male respondents account for 66% of data which is due to higher car ownership level of men compare with women. The average age of respondents is 25.7 years old and the majority of individuals (82%) are single. Concerning the household size and income level, the average values are 4.26 and 1.68, respectively.

Binary logit model

The basic assumption of discrete choice models is that the individual is faced with a set of alternatives, and his or her preference for each alternative can be expressed by a criterion of utility or attractiveness. This utility is a function of the characteristics of the alternative as well as the characteristics of the decision maker (Eq. 1).

$$(1)\quad U_{ni} = V_{ni} + \varepsilon_{ni},$$

where V_{ni} is defined as the deterministic (representative) utility of alternative i for decision-maker n and ε_{ni} is the unobserved and probabilistic utility term of alternative i for decision-maker n. Assuming Gumble distribution for the error terms which are independently and identically distributed for, the binary logit closed-form, which indicates probability that decision maker n chooses alternative i (Eq. 2) (Train, 2009).

$$(2)\quad P_{ni} = \frac{e^{V_{ni}}}{\sum_{m \in C_n} e^{V_{nm}}},$$

We used the t-statistics for the chcecking the significance of the explanatory factors with a given confidence level (90, 95 and 99%). Also, likelihood ratio test with chi-square distribution (Eq. 3) have been used to investigate the statistical significance of the proposed models in different stages of modeling (Guo et al., 2018).

$$(3)\quad -2\left[LL(0) - LL(\beta)\right] > X^2_{N,1-\alpha},$$

where, α represents the significance level and N is the number of parameters that are estimated by applying constraints in the model. Likelihood ratio index (Eq. 4 and 5) is also used to check the proposed model's goodness of fit.

$$(4)\quad \rho_0^2 = 1 - \frac{LL(\beta)}{LL(0)},$$

$$(5)\quad \rho_C^2 = 1 - \frac{LL(\beta)}{LL(C)},$$

where, ρ_0^2 presents the improvment in loglikelihood function value at convergence (LL(β)) compare to loglikelihood function value at zero (LL(0)). Further, ρ_C^2 presents the improvment

Variables	Categories	Minimum	Maximum	Mean	Standard deviation
Gender	0: Female 1: Male	0	1	0.658	0.481
Age	≤ 22 23-27 (28-34) ≥ 35	21	39	25.760	3.106
Marital Status	0: Married 1: Single	0	1	0.820	0.393
Driving license	0: Not owning 1: Owning	0	1	0.890	0.311
Number of driving license in household	1 2 3+	1	4	2.95	0.837
Parking at destination	1: Free on-street 2: Paid	1	2	1.13	0.343
Household Size	1 2 3 4 5+	2	7	4.26	1.369
Income level	1: Low 2: Medium 3: High	1	3	1.68	0.775

Table 2. Descriptive statistics analysis of the research sample

in loglikelihood function value at convergence (LL(β)) compare to loglikelihood function value at constant-only (LL(C)) (Train, 2009; Abbasi et al., 2022).

Findings and Estimation Results

According to the responses, 43.86% of car travelers are willing to shift to LRT. According to Fig. 1, in scenarios 1 and 2, the travel time has a significant effect on the willingness to shift to LRT. While in scenario 3, where it is not possible to sit on LRT, about 90% of respondents are not willing to shift to LRT due to the high level of comfort in private car despite a 20% reduction in travel costs.

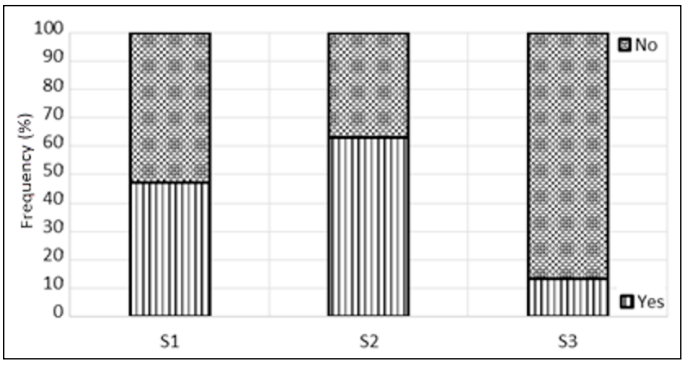

Figure 1: Willingness of personal car users to shift to LRT in different proposed scenarios

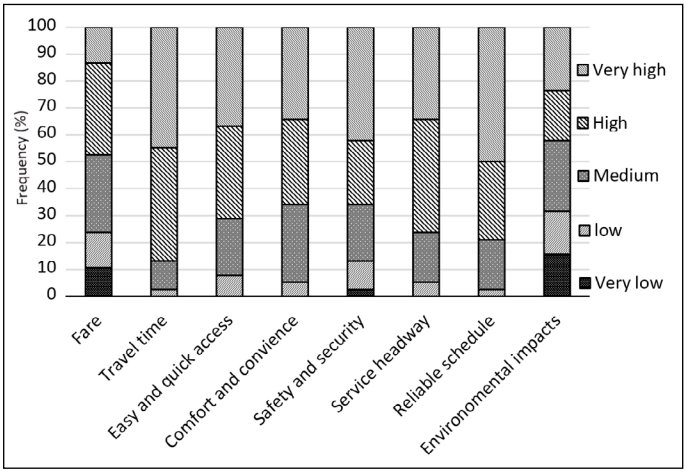

Figure 2: Importance of various factors in LRT choice

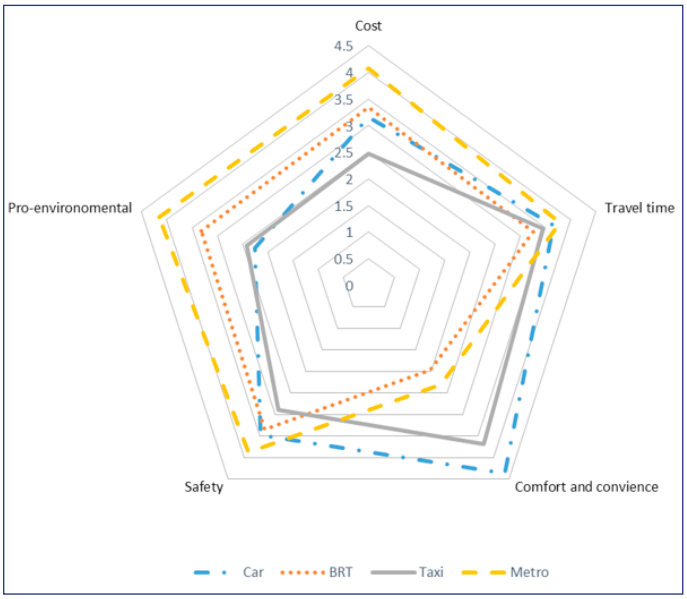

Figure 3: Appropriateness level of different travel modes in terms of various factors

Five point Likert scale (1= very low to 5= very high) was used to examine the importance of different attitudinal factors in LRT choice including fare, travel time, easy and quick access, comfort and convenience, safety and security, service headway, reliable schedule and environmental effects. According to the results of statistical analysis of attitude characteristics (Figure 2), travel time, quick and easy access, reliable schedule, service headway and safety and security are the most important and fare and environmental effects are less important in LRT choice, respectively. Further, the appropriateness of various factors in different travel modes were also asked using five-point Likert scale (1= very inappropriate to 5= very appropriate). According to responses, it can be found that the comfort and convenience of private car is much more than other modes, while the degree of compatibility of this mode with the environment has the lowest value. One of the interesting findings is that apart from comfort and convenience, the subway is the most appropriate travel mode, but due to the high dependence on private cars and the lack of subway network integration, respondents are more willing to use private cars.

Moreover, a binary logit model has been proposed to identify the strongest explanatory factors in modal shift to LRT among car travelers. After estimating a large number of binary logit models, the best fit model was presented in Table 3. It is worth noting that the Nlogit5.0 was used for the models' estimation. As shown in the Table 3, ρ^2 and ρ_c^2 values are 0.549 and 0.544, respectively, indicating the appropriateness of model estimation result (Hensher, 2005). In addition, the expected sign of variables and their significance level indicate the validity of proposed model. We used the t-statistics for the checking the significance of all the explanatory variables of the model with a given confidence level. In this context, all of the explanatory variables are significant at a confidence level of more than 90%.

Variable	Coefficient	t-statistics	Marginal effect
Constant	7.28**	2.01	
a 20% reduction in LRT travel time	5.47***	4.10	0.43
Possibility of sitting 50% of the travel time	2.57***	3.05	0.25
No possibility of sitting	-2.26**	-2.37	-0.22
Owning a car	-1.17*	-1.78	-0.12
Safety Importance in mode choice	-0.92**	-2.06	-0.09
a 10% reduction in LRT travel time	4.06***	3.63	0.32
Owning Driving license	-3.21***	-3.56	-0.27
Male	-2.58**	-2.87	-0.08
Frequency of using private car in a week	-4.23*	-1.71	-0.34
On street parking	-3.43***	-3.31	-0.34
Perception of Car's comfort	-0.86**	-1.96	-0.08
Perception of Metro's environment friendliness	-1.06***	-2.93	-0.10
Perception of taxi's safety	-0.97**	-2.51	-0.09
Departure time (12-15)	-3.58**	-2.28	-0.32
Model statistics			
Number of observations			114
ρ_0^2			0.5496
ρ_c^2			0.5447

Note: ***, **, * are significant at 1%, 5%, and 10%, respectively.

Table 3: Binary logit model estimation results for modal shift to LRT

According to the proposed model, a positive and significant sign of a 20% reduction in LRT travel time (β = 5.47, p < 0.001) indicates an increase in the likelihood of modal shift to LRT among private car users, which is in line with Weng et al. (2018) findings. The estimated coefficient and marginal effect (ME) value indicate that a higher reduction in travel time is associated with a higher utility of LRT. The presence of unoccupied seats in transit plays an important role in increasing the convenience and use of these services (Bierlaire et al., 2001). The possibility of sitting in a LRT during the 50% of travel time (β = 2.57, p < 0.001) increase the likelihood of modal shift to LRT. Due to the high value of time (VOT) of private car users, a 20% reduction in travel time is more important and influential than the possibility of sitting during 50% of travel time (Ranjbari et al., 2017). The negative and significant sign of the variable of not being able to sit on LRT (β = -2.26, p < 0.05) indicates a lower likelihood of modal shift among respondents due to the lower level of comfort compare to private car. Also, owning a private car (β = -1.17, p < 0.1) and a driving license (β = -3.21, p < 0.001) decrease the likelihood of modal shift to LRT. Considering the ME of these two variables (-0.12 vs. -0.27), having a driving license has a more negative impact on this issue because respondents could use household car. In terms of gender, due to the higher level of income and more dependence on private cars among men (β = -2.58, p < 0.05), they are less inclined to shift to LRT than women. Due to less congestion during off-peak hours and discretionary nature of trips during these hours, if the departure time of a trip is in the range of 12 to 15 (β = -3.58, p < 0.05), the likelihood of modal shift will decrease. Among the factors that have the most negative impact on modal shift to LRT, the two variables including free on-street parking (β = -3.43, p < 0.001) and weekly frequency of using private car (β = -4.23, p < 0.1) have the most impact. According to the identical ME values of these variables (-0.34), they have a similar impact on the likelihood of modal shift to LRT among private car users. In terms of attitudinal factors, respondents' perception of private car comfort (β = -0.86, p < 0.05) reduces the willingness to shift to LRT. In other words, percepting higher level of comfort in a private car leads to lower inclination in modal shift from private car to LRT. Also, in accordance with Mayo and Taboada (2020) findings, as the importance of safety (β = -0.92, p < 0.05) increases among the travelers, they are less likely to shift to LRT.

CONCLUSIONS AND SUGGESTIONS

This research investigates the factors affecting the modal shift to light rail transit among private car users in Tehran universities using binary logit model. The significance of the attributes related to the different levels of stated preference questionnaire used in binary logit model indicates the importance of fare, travel time and the possibility of sitting in LRT. The estimation results state that a 20% reduction in travel time and the possibility of sitting 50% of the travel time have the most positive impact on increasing the likelihood of a modal shift to LRT, respectively. Therefore, policymakers are recommended to prioritize reducing LRT travel time by allocating dedicated routes to increase the attraction of LRT on educational trips. As an interesting finding, the possibility of sitting 50% of the travel time has a positive impact on probability of modal shift to LRT, but the impossibility of sitting has a twice negative impact on modal shift among private car travelers. Therefore, as a suggestion to policymakers, in designing a new rail system, passengers should be provided with suitable level of service through reliable scheduling at different times of day. Among the significant variables that reduce the likelihood of modal shift to LRT, free on-street parking and frequent use of private cars per week had the greatest impact, which highlight the importance of implementing travel demand management policies such as parking management and congestion pricing.

Although this research could significantly fill some research gaps and provide insightful findings to local authorities, our selected sample includes only educational trips of students in Tehran. Therefore, for further study, it is suggested to consider a more representative sample of Tehran residents.

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