MODELING FACTORS AFFECTING SUBWAY UTILIZATION USING TRANSIT-ORIENTED DEVELOPMENT (CASE STUDY: TEHRAN CITY)

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ABSTRACT

Transit-Oriented Development (TOD) is a sustainable urban development planning approach and also an important concept to achieve appropriate coordination between transportation and land use. TOD's basic idea is to develop the city around efficient public transport stations, diverse and mixed-use residential and commercial units with relatively high concentrations, and pedestrian-based environments. High share of private cars, and hence high gas consumption and air pollution in metropolises, explains the need for planning sustainable cities and investigating such urban development strategies as the TOD.

This research aims to identify and quantify the TOD indicators for which the subway stations have been considered as the TOD area center. Modeling results show the meaningfulness of such variables as the waiting time, habit of subway use, walking/private car access to subway stations, and housewifery/entrepreneurship of lodgers and those without private cars. A comparison of models based on the goodness of fit and percent correct estimation indicates the superiority of the dual logit model with dependent variable (using subway once a week, using subway more than once a week).

Keywords: *Transit-Oriented Development (TOD), Indicator, Subway, Accessibility, Discrete Selection Models*.

1. Introduction

In recent years, such concepts as stability, liveliness, and sustainable development have drawn the researchers' attention and different strategies and tools have been presented, in specifically the urban transport planning, to achieve them [12]. The sustainable development aims to create an urban environment wherein the economic development and social justice are promoted and, in the meantime, the destructive effects on the environment are reduced [16]. Accordingly, transit-oriented development (TOD) and smart growth have been verified as two powerful tools to support stability in various dimensions [1,3,4]. Today, many cities are experiencing such problems as traffic congestion, air/noise pollution, accidents, improper/unequal access to transportation facilities and services, unreasonable public transportation, congestion, urban dispersion, and social segregation due to lack of necessary coordination between the land use design and transport policies [8,11].TOD is a planning approach for sustainable urban development and a key concept to achieve an appropriate coordination between transportation and land use. Various dimensions and interpretations of the TOD concept have made its planning a difficult task [13].

TOD was first raised in the late 1980's by an American architect, Peter Calthorpe, and became part of the Urban Design Planning with the publication of his book, "New Cities of America", in 1993. Many such American cities as San Francisco and Atlanta accepted its planning principles at the very beginning and then Copenhagen, Stockholm, and Zurich in Europe became interested. Recently, many Asian countries including South Korea, Hong Kong, Taiwan, Japan and Singapore make use of this concept in their programming [5,6,7,14]. To limit urban dispersion and reduce using private cars, Pert, Australia, and Calgary, Canada, have based their urban development on the public transport services as a strategy to achieve sustainable development [9]. TOD is focused on a land use pattern in a quarter to half a mile from the public transport station, and the corridors are provided service by a public transportation system (Fig. 1). It puts emphasis on increased mobility, walkability, connection, urban form, and mixed application in a higher-density area than one located more than half a mile away [10].

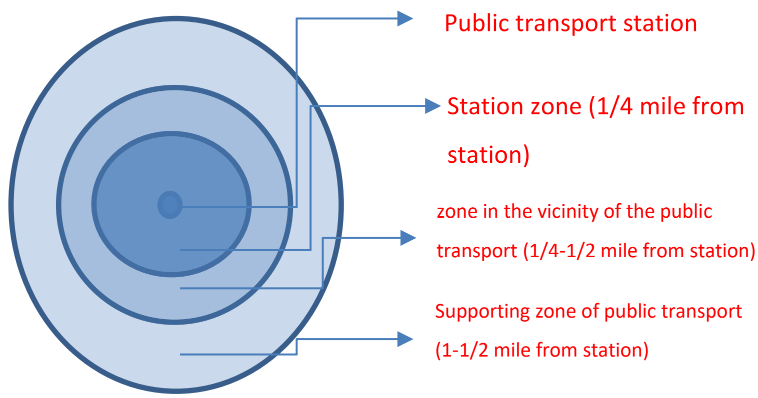

Fig. 1- A pattern of the TOD definition [10].

According to the earlier definitions, TOD key features are:
1- Mixed application around the public transport station (access to outer area is through public transport and within the area is on foot or by bike).
2- High density of residential buildings close to the public transport station is such that it supports the public transport performance and establishment of commercial units in that location.
3- The road network and pedestrian/bicycle routes are such that they support high utilization of the public transport as well as access within the area by non-motorized methods.

2. Discrete selection models

The inefficiency of linear models for many socioeconomic applications that have a discrete selection nature has led researchers to use discrete selection models capable of modeling the man's selection behavior [15].
Because of their behavioral nature, and the fact that they consider utility as a random variable, selection models are strong modeling tools with high ability to model man's selection behavior. Discrete selection models can either be ordinal or non-ordinal [2].
Discrete selection models are the most general theoretical framework or paradigm for creation. Assuming the Gumbel distribution for random component Ɛ, its difference has a logistic distribution; in this case, the selection probability function will result in the logit model (dual or multiple) which is the simplest and most practical discrete selection model. Here, the probability that person q will select option j is as follows:

$$\boldsymbol{P_{jq}} = \frac{\mathbf{exp}(\boldsymbol{\beta V_{jq}})}{\sum_{A_i \in A(q)} \mathbf{exp}(\boldsymbol{\beta V_{iq}})}$$

In this equation, the utility function is defined linearly with respect to features, and β is the standard deviation of the Gumbel distribution found as follows:

$$\beta = \frac{\pi}{\sigma\sqrt{6}}$$

Model processing is meant to find the coefficients of the descriptive variables of the utility function, that is, to determine the importance rate of each variable. Since the relationship between utility and descriptive variables is linear, the interpretation of the processed coefficients is similar to that of the linear trend-oriented model. Among several methods that find coefficients, the common "maximum likelihood estimation" is one wherein L(β) (product of the selection probability of each option) is defined as follows:

$$\mathrm{L}(\beta) = \prod_{q=1}^{Q} \prod_{j=1}^{N} (\mathbf{P_{jq}})^{y_{jq}}$$

where N is the number of observations in the intended sample, P_{jq} is the probability that option j is selected by person q, and $y_{jq}$is 1 if person q selects option j and 0, otherwise.
Coefficients are so estimated in this method that the occurrence probability of simultaneous observations is maximized. To simplify mathematical computations in analyses, use is usually made of the L(β) logarithm.

$$\mathrm{LL}(\beta) = \ln \mathrm{L}(\beta) = \sum_{q=1}^{Q} \sum_{j=1}^{N} \boldsymbol{y_{jq}} \, \mathbf{ln}(\boldsymbol{p_{jq}})$$

Now, to maximize the value of the LL (β) function, its partial derivatives are put equal to zero for each coefficient [15].

3. Data analysis

In this research, subway stations are the TOD center and the final questionnaire has 6 sections:

a- Features of travelling by subway: This section asks about the number of subway trips during the week (as a dependent variable and in ordinal scale), trip purpose, and travel time.

b- Subway operational specifications: This section asks, on Likert's quintuple scale, about the subway supply characteristics and their importance for passengers in using the subway.

c- Social, economic, cultural, and environmental characteristics: This section asks, on Likert's quintuple scale, about the demand characteristics and people's attitudes and their importance in using the subway.

d- Policy making: This section, with preference type questions, asks, on Likert's quintuple scale, about the effects of policies that increase the subway use.

e- Access to the subway station: This section asks about the station name nearest to the place of residence, the station access method, and importance of the factors affecting walking considering the TOD principles as regards promoting walking in the TOD area.

f- Personal/household specifications:

This section asks about the passenger's age, gender, marital status, housing situation, income status, private car ownership, education, and number of household members.

Next, results found from the multi-variate logit modeling of the factors affecting the rate of subway use based on the field survey data and 450 designed questionnaires distributed at some Tehran subway stations and bus terminals are discussed.

4. Processing results of the multi-variate logit model

To make the multi-variate logit model based on the rate of the subway use (dependent variable), frequencies of once or twice, 3 or 4 times, and 5 or more than 5 times subway use a week have been considered as the first, second, and third choices, respectively. Fig. 2 shows how the selected options have been separated and Table 1 shows the processing results of the multi-variate logit model.

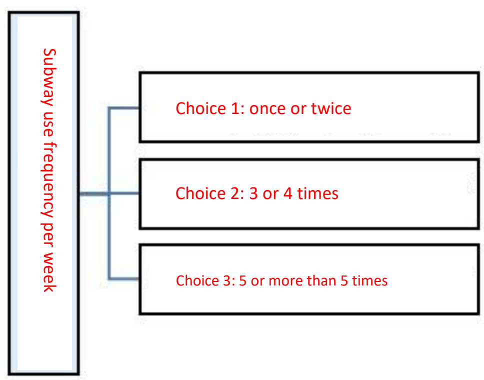

Fig. 2- How options have been separated to make the multi-variate logit model

Table 1- Processing results of the multi-variate logit model, dependent variable (subway use frequency per week) *

Symbol	Variable definition	Coefficient in choice 1	Coefficient in choice 2	Meaningfulness in choice 1	Meaningfulness in choice 2
CONSTANT	Constant value	1/22	-	0/008	-
CONDITI4	Virtual variable of entrepreneurship	1/61	-	0/018	-
AGE1	Virtual variable of age (14-19 years)	1/33	1/03	0/000	0/007
WAITTIME	Importance of waiting time	-0/32	-0/15	0/001	0/014
GENDER	Gender	-0/741	-0/749	0/003	0/001
MARITALS	Marital status	0/76	-	0/002	-
HOUSING	Housing status	-0/48	-	0/037	-

IINDEPEN	Income status	-	0/46	-	0/041
NOCARS	Virtual variable of lacking private car	-	0/41	-	0/064
	LL(0)			-440	
	LL(C)			-433	
	LL(β)			-403	
	ρ_0^2			0/08	
	ρ_c^2			0/07	
	Percent correct			0/50	

* Option 1 (once or twice subway use per week), option 2 (3 or 4 times subway use per week), option 3 (with 0 utility) (more than 4 times subway use per week)

- The coefficient of entrepreneurship variable in the utility function of option 1 (once or twice subway use per week) is 1.61 with positive sign; hence, the probability of choosing this option is more than other options for this group of passengers.

- The coefficient of 14-19 years age range variable has become meaningful at values 1.33 and 1.03 in the utility functions of options 1 and 2 (once or twice and 3 or 4 times subway use per week), respectively; hence, for this group of passengers, the higher utility is related to option 2.

- The "importance of waiting time inside the station" variable has become meaningful at values - 0.32 and - 0.15 in the utility functions of options 1 and 2 (once or twice and 3 or 4 times subway use per week), respectively; hence, an increase in this variable reduces the probability of the subway use in option 2.

- The gender variable has become meaningful with a negative sign in the utility functions of options 1 and 2 (once or twice and 3 or 4 times subway use per week), respectively meaning a lower probability for men to choose option 2.

- The "marital status" variable has become meaningful with a positive sign in the utility function of option 1 (once or twice subway use per week); therefore, married people are more likely to choose this option.

- The "housing status" variable has become meaningful with a negative sign in the utility function of option 1 (once or twice subway use per week); therefore, tenants are less likely to choose option 1 compared to option 3 (more than 4 times subway use per week).

- The "income status" variable has become meaningful with a positive sign in the utility function of option 2 (3 or 4 times subway use per week); hence, passengers with no independent income are more likely to choose option 2 compared to other options.

- The "lacking a private car" virtual variable has become meaningful with a positive sign in option 2 (3 or 4 times subway use per week); therefore, this group of passengers are more likely to choose option 2 compared to other options.

5. Calculation results of the "walking access indicator"

The ARCGIS Software calculation results of the walking access indicator (ideal and real) of the 10 selected subway stations at 400, 500 and 600 m radius thresholds show that:

1. An increase in the access radius threshold reduces the real access indicator (except for Sadeghiyeh, Shahid Beheshti, and Tehran Pars Stations); the highest reduction is for Imam Khomeini Station.

2. Despite the highest number of passengers per day, Sadeghiyeh Station has the lowest ideal and real access at all three radius thresholds. Intersection of subway lines 2 and 5 at this station, especially line 5 - Karaj passengers, affects the high passenger rate at this station.

3. With the highest ideal and real access indicator at all three radius thresholds, Sar Sabz Station (located at only 1 line) has the highest number of daily passengers among all subway stations.

4. Based on the indicated indicators, Sadeghiyeh, Shahid Beheshti, and Imam Khomeini Stations have lower external access; however, their locations (being at subway lines intersections and having more internal network access) have affected their number of passengers.

6. Conclusions and suggestions for future studies

This research has used the multi-variate logit approach to model the factors that affect the rate of the subway use. Some of the results, considering the variables' values and signs in the processed models, are as follows:

- An increase in the "importance of passengers' waiting time inside the station" variable increases the subway use during the week; hence, reducing the headway time and planning a regular scheduling of the trains' arrivals and departures will increase the subway use.
- The habit of using the subway is directly related to the amount of using the subway.

- The walking/private car access to the subway station is directly/inversely related to the frequency of the subway use per week.
- Housewifery is inversely related to the frequency of the subway use per week.
- Entrepreneurship is inversely related to the subway use more than once a week; this group's subway use per week is less than that of other groups because their income is relatively high and they often own a private car.
- Tenants and no independent income people tend to use the subway more than twice a week because it is cheap and they can afford the price.

To model the factors affecting walking, use was made of the dual and multi-variate logit models; the former with dependent variables (walking/vehicle access to the subway station) and the latter with dependent variable (desired time for walking). The variables were both socioeconomic and explanatory (sidewalks' safety and walking path slope/view/furniture) in the Likert's quintuple scale. Walking models are not mentioned because the explanatory variables' fitness was inappropriate and they did not become meaningful.
The following topics are suggested for future research:

- Including such variables as the passenger resident's distance from the nearest subway station, number of line changes in travelling by subway, and distance between the last station and the passenger's destination in the questionnaire and examining these factors in the rate of the subway use.
- Quantifying land use indicators (density, variety, and mixing applications) and income tax around subway stations.
- Investigating the factors affecting non-motorized access to public transport stations from both the supply and demand dimensions.
- Investigating the factors that can increase the capabilities of the areas around subway stations to promote the non-motorized transportation modes.

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