TeMA

Journal of
Land Use, Mobility and Environment

The Special Issue the Tema Journal of Land Use, Mobility and Environment, collects the proceedings of the Joint workshop, which is to be held by Center for Technology of Society (ZTG) of Technische Universität Berlin (TUB) and Road, Housing and Urban Development Research Center (BHRC) in Tehran on Feb. 29, 2016, under the title "Transit-Oriented Development (TOD) in Iran: Challenges and Solutions".

TeMA Journal of Land Use, Mobility and Environment offers papers with a unified approach to planning and mobility. TeMA has also received the Sparc Europe Seal of Open Access Journals released by Scholarly Publishing and Academic Resources Coalition (SPARC Europe) and the Directory of Open Access Journals (DOAJ).

TRANSIT- ORIENTED DEVELOPMENT IN IRAN
CHALLENGES AND SOLUTIONS

SPECIAL ISSUE 2016

ISSN 1970-9889
University of Naples Federico II

TeMA

Journal of
Land Use, Mobility and Environment

Special Issue (2016)

TRANSIT-ORIENTED DEVELOPMENT IN IRAN

CHALLENGES AND SOLUTIONS

Published by
Laboratory of Land Use Mobility and Environment
DICEA - Department of Civil, Architectural and Environmental Engineering
University of Naples "Federico II"

TeMA is realized by CAB - Center for Libraries at “Federico II” University of Naples using Open Journal System

Editor-in-chief: Rocco Papa
print ISSN 1970-9889 | on line ISSN 1970-9870
Lycence: Cancelleria del Tribunale di Napoli, n° 6 of 29/01/2008

Editorial correspondence
Laboratory of Land Use Mobility and Environment
DICEA - Department of Civil, Architectural and Environmental Engineering
University of Naples "Federico II"
Piazzale Tecchio, 80
80125 Naples
web: www.tema.unina.it
e-mail: redazione.tema@unina.it

TeMA. Journal of Land Use, Mobility and Environment offers researches, applications and contributions with a unified approach to planning and mobility and publishes original inter-disciplinary papers on the interaction of transport, land use and environment. Domains include: engineering, planning, modeling, behavior, economics, geography, regional science, sociology, architecture and design, network science and complex systems.

The Italian *National Agency for the Evaluation of Universities and Research Institutes* (ANVUR) classified TeMA as scientific journal in the Area 08. TeMA has also received the *Sparc Europe Seal* for Open Access Journals released by *Scholarly Publishing and Academic Resources Coalition* (SPARC Europe) and the *Directory of Open Access Journals* (DOAJ). TeMA is published under a Creative Commons Attribution 3.0 License and is blind peer reviewed at least by two referees selected among high-profile scientists. TeMA has been published since 2007 and is indexed in the main bibliographical databases and it is present in the catalogues of hundreds of academic and research libraries worldwide.

TeMA
Journal of
Land Use, Mobility and Environment

Special Issue (2016)

TRANSIT-ORIENTED DEVELOPMENT IN IRAN
CHALLENGES AND SOLUTIONS

Contents

TeMA

Journal of
Land Use, Mobility and Environment

TeMA TOD in Iran: Challenges and Solutions | SPECIAL ISSUE | 77-94
print ISSN 1970-9889, e- ISSN 1970-9870
DOI: 10.6092/1970-9870/3947

review paper received 19th June 2016, accepted 29th Semptember 2016

Transit-Oriented Development in Iran: Challenges and Solutions

Road, Housing and Urban Development Research Center (BHRC)
Tehran, 29 February 2016

How to cite item in APA format:
Soltani, A., Shariati, S., Amini, A. (2016). Modelling the shifts in activity centres along the subway stations. The case study of metropolitan Tehran. *Tema. Journal of Land Use, Mobility and Environment*, 77-94. doi:http://dx.doi.org/10.6092/1970-9870/3947

MODELLING THE SHIFTS IN ACTIVITY CENTRES ALONG THE SUBWAY STATIONS

THE CASE STUDY OF METROPOLITAN TEHRAN

ALI SOLTANI[a], SAMANE SHARIATI[b] , ALI AMINI[b]

[a]Associate professor, Urban Planning Department, Shiraz University, Shiraz, Iran
e-mail: soltani@shirazu.ac.ir
corresponding author

[b] Urban planner, Shiraz Municipality, Shiraz, Iran
e-mail: samane.shariati@gmail.com

ABSTRACT

Activity centers are areas of strong development of a particular activity, such as residence, employment or services. Understanding the subway system impacts on the type, combination, distribution and the development of basic activities in such centers plays an important role in managing development opportunities created along the Tehran subway lines. The multi criteria and fuzzy nature of evaluating the development of activity centers makes the issue so complex that it cannot be addressed with conventional logical systems. One of the most important methods of multi criteria evaluation is Fuzzy Inference System. Fuzzy inference system is a popular computing framework based on the concepts of Fuzzy Sets Theory, which is capable of accommodating inherent uncertainty in the multi-criteria evaluation process. This paper analyses shifts in activity centers along two lines of the Tehran subway system based on three major criteria by designing a comprehensive fuzzy inference system. The data for the present study were collected through documentary analysis, questionnaires and semi-structured interviews. The result revealed that the level of the subway system influence on the pattern and process of the development of activities varied with the location, physical environment and entity of each station. Furthermore, empirical findings indicated that the subway line might weaken residential activities while attracting employment and service activities to the city center. Specifically, residential estates have moved away from the city center to the suburbs whereas employment and service activities have expanded from the existing central business district (CBD). The results can be applied to suggest planning policies aimed at improving the effects of public transit on property development and land use change in a developing country.

KEYWORDS
Urban Development Pattern, Urban Transportation, Fuzzy Sets, Subway, Tehran

1 INTRODUCTION

The rapid growth of metropolitan Tehran coupled with an increase in urban population and their basic infrastructure requirements over the past few decades has created numerous problems, including the formation of satellite towns, urban sprawl and the emergence of single-use suburbs. For example, the implementation and development of a new public transportation system, the subway, with the increase in population and employment activities, the emergence of new functions around subway lines and stations, has brought many changes to the spatial structure of these areas. The concurrence of the above problems with the opening of subway system in the years 1991 to 2001 provided the conditions for the occurrence of new structural changes. The main reason is that the rail transport system often organizes major changes in cities as the first changes in various economic, functional and physical dimensions have often emerged in close proximity to rail transportation systems.

The influence of subway systems on urban development has been empirically investigated in numerous cities such as San Francisco (Cervero and Landis, 1997), Los Angeles (Fejarang, 1994), Miami (Gatzlaff and Smith, 1993), Naples (Risi and Cerrone, 2010), Milan (Pinto, 2010) and Thessaloniki (Macaluso et al., 2012). According to Risi and Cerrone (2010), analysis of the most important experiences points out, however, that where the interventions for transport infrastructures have been associated with urban transformations targeted to build, around the stations or inside the stations themselves, functional poles or at least opportunities of urban requalification there have been numerous results and a mitigation of negative impacts. For example, he points to the Line 6 *Mostra-Mergellina* route of the Naples subway which has led to an important process of requalification, affecting an important area of the *Fuorigrotta* district, one of the largest and most populous districts of Naples. Moreover, Pinto (2010) points to the Rail *"Passante"* as a transport infrastructure of Milan which has played a strategic role in the city's regeneration. Such regeneration is characterized by two important projects, one public and one private. The public intervention concerns the BEIC - European Library of Information and Culture, while the private action relates to the new district *"Porta Vittoria",* with mixed-use residences, offices, malls, hotels and cinemas. The importance of the redevelopment lies in the integration of city planning and the mobility system, in an area which hosts functions of a supra-municipal level, accessible from the urban region of Milan. However, the redevelopment project included only the railway areas and did not include the surrounding areas, whereas Pinto believes that it is also important to redevelop the surrounding areas, through a systematization of the various interventions. These investigations have mostly concluded that subway systems significantly influence population, employment, land use, activity distribution and property prices along subway lines. Effective development strategies can be designed based on the output of empirical research. Although the influence of subway systems in Tehran is expected to differ from other cities, it remains poorly understood because Tehran has experienced a subway system for only 14 years. Owing to a lack of empirical investigation of the influences of the Tehran subway system, the development strategies for subway corridors in Tehran have been based on incomplete information, creating a risk for the future development of the city. Understanding the shifts of activity distribution along subway lines can help direct subway corridor development.

One of the most important effects of the subway on the spatial structure of the city is the redistribution of basic and major activities and the displacement of activity centers and finally the process of their development along subway lines. A closer look at the characteristics of development suggest that we need a comprehensive framework when evaluating the degree or quality of development relating to activity centers, because imprecision and uncertainty appear to be a general characteristic of development. Due to this uncertainty and the multi criteria nature, development has no well-defined meaning. Therefore, the type of uncertainty regarding the evaluation of development essentially concerns the identity and meaning of development. In mathematical terms, this type of uncertainty is known as fuzzy uncertainty. According to

Klir and Folger (1988), fuzzy uncertainty relates to the events that have no well-defined, unambiguous meaning and multi-criteria nature. Fuzzy Set Theory (FST), with an expressive power that is far beyond classical set theory in terms of handling uncertainty, can be used to deal with ambiguity and also uncertainty in determining the degrees of development. Multi-valued logic related to fuzzy set theory enables intermediate evaluation between definitely developed and definitely undeveloped; i.e. fuzziness describes the degree to which the development (of green space) has occurred. Moreover (Kaur, 2012), fuzzy set theory is widely accepted to capture expert knowledge. It allows us to describe expertise in a more intuitive, more human-like manner and without thinking in terms of mathematical models. In this regard, Fuzzy Inference Systems are one of the most famous applications of fuzzy set theory and can cope with all the above-mentioned problems.

Therefore, in this study, a comprehensive fuzzy inference system is developed to evaluate and then to forecast the degree of activity center development based on multiple criteria in order to restructure the development processes of new centers, and make optimal decisions on the quality of development in future. Briefly, The use of fuzzy set theory and its application, Fuzzy Inference System, for evaluating the effects of the subway on the development of station areas helps us to efficiently plan subway line networks, restructure the development process of peripheral areas, and make optimal decisions on interventions and methods of preventing sprawl and centralized development by identifying activity centers and properly understanding the redistribution of basic activities in these centers. It is noteworthy that with attention to imperfections in Aristotelian logic and the strengths of fuzzy set theory, as already mentioned, the basic aim of this paper is to provide a model for the analysis of the development of station areas and the shifts of activity centers along subway lines with an approach to fuzzy logic and in line with a proper management of the resulting economic and development opportunities.

This study analyzes the development of activity centers along the *Blue Line* of the Tehran subway system. The development of station areas along the two corridors in both 1996 to 2003 (before subway opening) and in 2003 to 2011 (after subway opening) was simulated and compared based on the fuzzy inference system.

2 BACKGROUND STUDIES

Most previous studies have shown that transportation system and urban structure have a mutual and reciprocal relationship with each other. Transportation systems, especially the subway system, change the activity distribution along the major corridors by increasing the relative advantage and changing the relative accessibility of these areas compared to other areas of the city (Soltani et al., 2013). In fact, a subway system can have an important effect on the development of activity centers and shift them along subway lines. Activity centers refer to areas of strong development of a particular activity, such as residence, employment or services. City planners consider the development of activity centers along subway lines following subway opening and attempt to develop effective strategies to ensure that developments along subway corridors achieve the desired goals.

However, forecasting activity center development is complex because center identification is based on human judgment, which involves multiple criteria and nonlinear interactions. A systematic approach to imitating human judgments is thus required for center identification. Analysis of activity centers comprises two major tasks: First, creating criteria for evaluating the activity performance of specific areas; second, identifying activity centers based on the criteria performances of specific areas. As Lin et al. (2006) have stated, three methods (density function, index analysis, and multivariate analysis) were used in previous studies for activity center analysis. Only one criterion is generally applied to the density function, such as Feng et al. (1994), to describe the relations between activity densities and locations, which are mostly defined by the distances to the central business district (CBD). Identifying activity centers based on one criterion is inadequate because a specific activity is usually related to multiple characteristics. For example, a residential center can be characterized by high population density, and low population density with median/high residential floor space in the case of a high-income community. Identifying residential centers purely based on population density is problematic in the latter case. The index analysis generally applies multiple criteria to evaluate the activity development of a specific area, such as Mcdonald (1987). Because index analysis is rarely used to verify the goodness of fit between model judgments and individual judgments, the main criticism of this method focuses on its validity. Multivariate analysis develops a discrimination function to identify the activity centers through factor analysis, classification analysis and discrimination analysis, such as Chen (1980). The process of multivariate analysis primarily depends on the crisp statistics and subjective judgment of researchers. Crisp statistics have difficulty in directly describing activity centers owing to the insensitivity and subjectivity of human feelings. Additionally, the thresholds for discriminating the development level of activity centers are generally determined by researchers or statistical mechanisms (average, mode, discrimination analysis, etc.) and might not accurately reflect people's feelings. The methods of density function and index analysis also suffer from the above-mentioned deficiencies. To imitate common people's judgments, this study applied the fuzzy inference system to analyze subway station area development. The reviews of Teodorovic (1999), Bonivento et al. (1998), and Jang and Sun (1995) indicate that the fuzzy inference system is a very promising mathematical approach to modelling problems characterized by subjectivity, ambiguity, and uncertainty, such as identifying activity centers. Fuzzy inference system is one of the most famous applications of fuzzy set theory and can cope with all the above-mentioned problems. Fuzzy Set Theory (FST), with an expressive power that lies far beyond that of classical set theory in terms of handling uncertainty, can be used to deal with ambiguity and also uncertainty in determining the degrees of development. Multi-valued logic related to fuzzy set theory enables intermediate evaluation between definitely developed and definitely undeveloped; i.e. fuzziness describes the degree to which the development has occurred. Moreover (Kaur, 2012), fuzzy set theory is widely acknowledged to capture expert knowledge. It allows us to describe the expertise in a more intuitive, more human-like manner and without thinking in terms of mathematical models.

Based on the capabilities of FST, the fuzzy inference system can circumvent the deficiencies of existing conventional methods. Generally, the advantage of applying FIS for evaluating the degree of development is due to the following mechanism (Lin et al., 2006): The fuzzy inference system can circumvent the deficiencies of existing methods for analyzing activity centers via the following mechanisms: First, the premise of the fuzzy rule can use multiple criteria. Second, the rule base and membership function are both established via the questionnaire survey of individual judgments, which can be used to establish the goodness of fit between the model judgments and individual judgments. Third, the linguistic variables, other than statistical variables, used in fuzzy rules make the inference process more closely approach the judgment process of individuals. Finally, linguistic outputs are useful for clearly describing and discussing the decision making process.

3 METHODOLOGY

3.1 STUDY AREA

What today is called metropolitan Tehran encompasses a 25-year-old expanse of 22 districts, an area of 621 square kilometers and a population of 7.5 million. The inauguration of Tehran's subway system and its primary stations goes back to 1998 – that is, 18 years ago. In that year, the *Tehran-Karaj* subway line was inaugurated. Later, in 1999, Line 2 West (from *Imam Khomeini* Square to *Sadeghieh* square) and then a large part of Line 1 (from *Mirdamad* to *Ali Abad*) in 2001 were constructed. Finally, Line 2 East was operated in 2005 (Tehran Traffic and Transportation Masterplan, 2007). Areas studied in this research included 11 station areas along subway lines one and two. Specifically, *Mirdamad*, *Darvaze Dolat*, *Panzdah-e-Khordad* and *Javanmard-e-Ghasab* stations comprise Line 1 whereas *Sadeghieh* and Tarasht stations comprise Line 2 West and *Shahid Madani*, *Sabalān*, *Fadak*, *Golbarg*, and *Elm-o-Sanat* stations comprise Line 2 East. This study defined the station areas as the area within a 400 m radius circle around the station, in accordance with the definition used by the planned area of Transit-Oriented Development (TOD) recommended by previous studies, such as Bernick and Cervero (1997). These station areas were divided into four types in terms of nature and location:

1. Central stations, including *Darvaze Dolat* and *Panzdah-e-Khordad* stations which are both located in cosmopolitan centers and in the special area of Tehran (the historic and worn-out fabric) and were considered as the main destinations of subway lines.
2. Middle stations, including *Mirdamad* and *Shahid Madani* stations which are located in developing regions and new urban centers. *Mirdamad* station area is one of the developing new areas with fairly significant commuting capacity because it is located in the central ring of the city. *Shahid Madani* station is also one of the developing new areas under the influence of modernization and improvement interventions and the extended trend of the above-mentioned area (toward West and East).
3. Passing stations: more subsidiary stations compared to main stations which are located between the suburbs and central regions and are not considered as the main places of generation and attraction for commuting including *Sabalān*, *Fadak* and *Golbarg* stations.
4. Suburban and terminal stations such as *Tarasht*, *Elm-o-Sanat*, *Javanmard Ghasab* which are located in the suburban area of Tehran and *Sadeghieh* Station which is one of the most important initial and final stations in Western Tehran. These stations are considered important points of trip generation. The segmentation and analysis of station areas is noteworthy since they have different effects on the environment depending on the location and nature of each station.

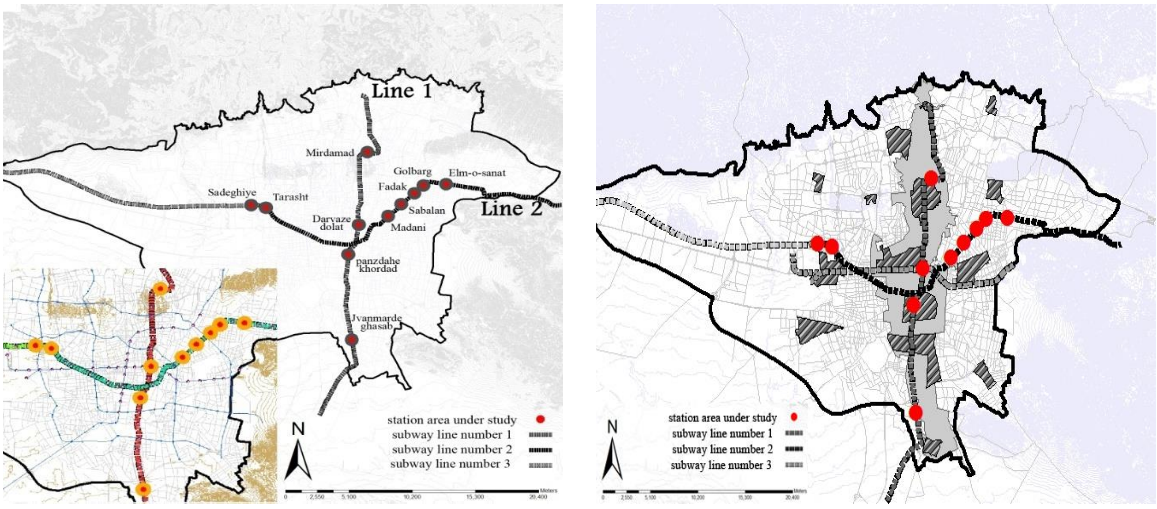

Fig.1 Network of Tehran's subway system and the stations in the case study (on the left) and Location of subway stations in relation to central zones (on the right)

3.2 DATA COLLECTION

Research data were collected through field collection practices, questionnaires and interviews. In this study, two types of questionnaires were used for data collection: 1) a commuter questionnaire survey with a sample size of 1320, and 2) an expert questionnaire for generating fuzzy rules with a sample size of 50. The current study used cluster sampling and a semi-structured interview based on which the survey continues with each of the experts to achieve theoretical saturation (Strauss and Corbin, 1990, 94:96).

3.3 STUDY PROCESS: INFERENCE SYSTEM

The fuzzy inference system essentially comprises three components: A rule base, containing a selection of fuzzy rules, a database, which defines the membership functions of linguistic variables used in the fuzzy rules, and a reasoning mechanism, which performs the inference based on the rules.

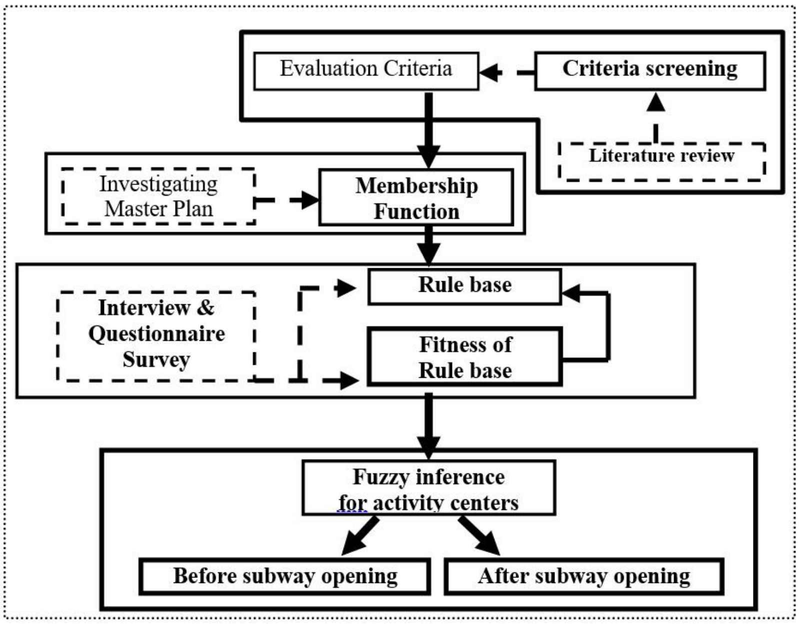

Fig. 2 The study process

The study process or the inference system is illustrated in Fig. 2 and comprises four major parts: evaluation criteria for activity centers, membership functions for the linguistic variables, fuzzy rules, and fuzzy inference system.

3.4 EVALUATION CRITERIA

This study analyzed three types of activity centers: residential, employment, and services. An area with more people, floor space, or trip generation related to a specific activity in a specific area is likely to be a center of that particular activity. Based on the considerations of effective description, interaction with subway and data accessibility, three criteria were applied for each of the center types listed in Table 1 to evaluate the significance of activities for specific areas.

Residence	Service	Employment
Population density	Service occupation density	Employment density
Residential floor space	Service land use floor space	Work trip attraction
Home-based trip generation	Service trip attraction	Commercial, official and industrial floor space

Tab.1 Evaluation criteria for each of center types

In order to generating fuzzy numbers (this process is called Defuzzification), each criterion is normalized using the following function:

$$x = \frac{B_{ij} - \min}{\max - \min} \tag{1}$$

In this formula, i represents the station under study, j represents evaluation criteria, and Bij represents the value of each criterion in each station.

3.5 MEMBERSHIP FUNCTION

A fuzzy set on X is defined by a membership function which indicates the following formula:

$$\mu_A(x): X \rightarrow [0\ 1] \tag{2}$$

Here, the value of μ indicates the membership value or degree (x∈X) and the membership value indicates the degree of membership of x to the fuzzy set A or the linguistic degree x (Tanaka, 1962, 9-22). In fact the membership function can be used to transfer the crisp statistics into linguistic degrees, which describe people's feelings better than statistics do (Lin et al., 2006). For defining the membership function, the linguistic variables and the fuzzy range should be determined. A linguistic variable is one that can be assigned with natural words (Wang, 1992). First of all in fuzzification, the study defined the linguistic variables and determined the fuzzy range. The linguistic variables in this study were already determined with regard to available data in conjunction with the characteristics of urban land and transportation and their interaction with one another. However, since the purpose of fuzzy control is to simulate a knowledge base, a group of experts was asked to choose certain linguistic degrees from among study variables according to approved plans and personal knowledge. In this way, three linguistic degrees (low, medium, and high) were specified for these linguistic variables or criteria. After defining the linguistic degrees of each set, membership functions were defined in Figure 3. These functions are sequential and continuous considering the nature of linguistic variables and they determine the degree of membership of each point in the set. For fuzzy variables, there are different forms of membership functions such as triangular, trapezoidal, piece-wise linear, *Gaussian* and singleton (Hohle and Rodabaugh, 1999). Considering the nature of this study, the form of the functions is trapezoidal. After feeding the values of linguistic variables (fuzzy amplitudes) into the MATLAB software (The Math works Inc., 2014), membership functions were defined.

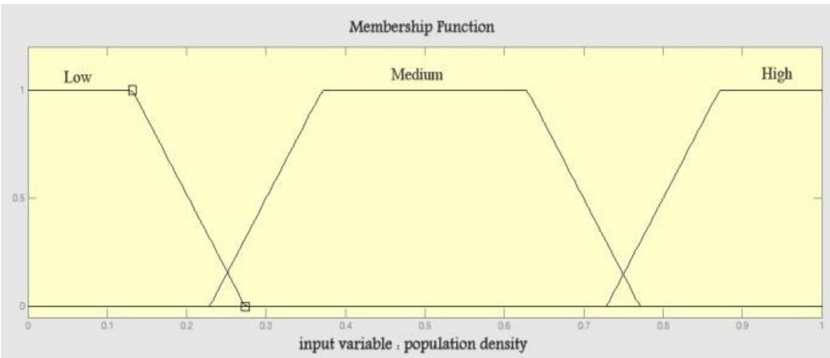

Fig. 3 Membership of output linguistic variables

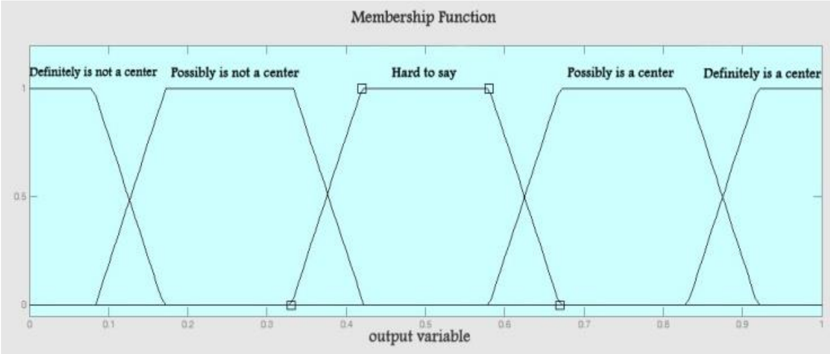

Fig. 4 Membership of inputs linguistic

3.6 FUZZY RULES

The application of fuzzy logic in a real world system is mainly used with fuzzy IF-THEN linguistic rules, which describe the logical evolution of the system based on the linguistic variables (Leung, 1988). In fact, IF-THEN fuzzy rules are conditional statements that show the association of one or more linguistic variables to each another. One simple rule is shown as following (Dubois et al., 1996):

IF<premise>THEN<consequence>

Both premise and consequence are characterized by fuzzy or linguistic elements respectively. Fuzzy rule generation was determined based on a literature review, approved plans and a questionnaire survey of 50 professional experts involved in urban or transportation planning in Tehran. The experts' response for each activity center was graded according to five linguistic degrees: "Definitely is a center", "Possibly is a center", "Hard to say", "Possibly is not a center", and "Definitely is not a center". The membership functions of fuzzy rules were shown in Figure 4. Finally, identification of activity centers based on the questionnaire surveys and the linguistic performance criteria were combined to generate 27 fuzzy rules, as shown in Table 2. This table lists the rule base for identifying residential centers and presents the following findings: first, the criterion of residential floor space dominates the identification of residential centers and presents few trade-off relationships with the other two criteria. It can be concluded that residential floor space is very important for the identification of residential centers. Second, significant trade-off relationships exist between population density and home-based trip generation, meaning these two criteria are interdependent for identifying residential centers. Finally, the relationship between premises and conclusions are discrete and irregular. The other two rule bases for identifying employment and recreation centers are contained in Shariati (2012).

IF	Population Density is	AND	Residential floor space is	AND	Home-based trip generation is	THEN	Conclusion
IF	High	AND	High	AND	High	THEN	Definitely is a center
	High		High		Medium		
	High		High		Low		
	Medium		High		High		
	Medium		High		Medium		
	Low		High		High		
IF	High	AND	Medium	AND	High	THEN	Possibly is a center
	High		Medium		Medium		
	Medium		High		Low		

	Medium		Medium		High		
	Low		High		Medium		
	Low		High		Low		
	High		Medium		Low		
	Medium		Medium		Medium		
	Medium	AND	Medium	AND	Low	THEN	Hard to say
IF	Low		Medium		High		
	Low		Medium		Medium		
	High		Low		High		
	High		Low		Medium		Possibly is not a center
IF	High	AND	Low	AND	Low	THEN	
	Medium		Low		High		
	Low		Low		High		
	Medium		Low		Medium		
	Medium		Low		Low		Definitely is not a center
IF	Low	AND	Medium	AND	Low	THEN	
	Low		Low		Medium		
	Low		Low		Low		

Tab.2 The rule base for the recognition of activity center (illustrated by residential activity)

The following examples represent some membership functions which were used in fuzzy inference to indicate the residential centers.

$$\mu\, definiely\;\; is\;\; a\;\; center = \min\left\{\mu_{high}(x_1), \mu_{high}(x_2), \mu_{high}(x_3)\right\}$$
$$\mu\, possibly\; is\; a\; center = \min\left\{\mu_{high}(x_1), \mu_{medium}(x_2), \mu_{medium}(x_3)\right\}$$
$$\mu\, Hard\;\; to\;\; a\;\; say = \min\left\{\mu_{high}(x_1), \mu_{medium}(x_2), \mu_{low}(x_3)\right\} \tag{3}$$
$$\mu\;\; possibly\;\; is\;\; not\;\; a\;\; center = \min\left\{\mu_{high}(x_1), \mu_{low}(x_2), \mu_{high}(x_3)\right\}$$
$$\mu\, definitely\; is\; not\; a\; center = \min\left\{\mu_{medium}(x_1), \mu_{low}(x_2), \mu_{low}(x_3)\right\}$$

3.7 FUZZY INTERFACE

This study applied the Mamdani fuzzy model (Mamdani and Assilian, 1975) to conduct fuzzy inference. The main components of Mamdani FIC are as follows (Abraham, 2005):

1. Knowledge base: knowledge base stores all data, information, rules and relationships which are used by the expert system, and one of the methods for representing knowledge in the knowledge base is using If-Then rules. By combining these rules, it is possible to solve complicated problems.
2. Fuzzification interface: fuzzification inference receives the certain inputs and defines how related they are to appropriate fuzzy sets in dependency rules.
3. Defuzzification interface: the input of a defuzzifier is a fuzzy set, and the output is a certain amount. In fact, in this section, the rules that are consistent and compatible with the degree of membership of each function become activated and the output of the inference engine, which is a membership function, is turned into a defuzzified value (Zahedi, 1999). Defuzzification is carried out in different ways such as the center of gravity method, the center of aggregates method, the height method, the center of the largest surface method and the average maximum method. The method used in this study is the center of gravity method (COG).

4. The inference engine: the inference system is in fact the brain of the expert system which processes the stored rules and knowledge. The inference engine can be established based on different logic like fuzzy logic and it usually employs statistical computations for fulfilling its tasks.

The process and output of the fuzzy inference model used in this study are presented in figures 5 and 6.

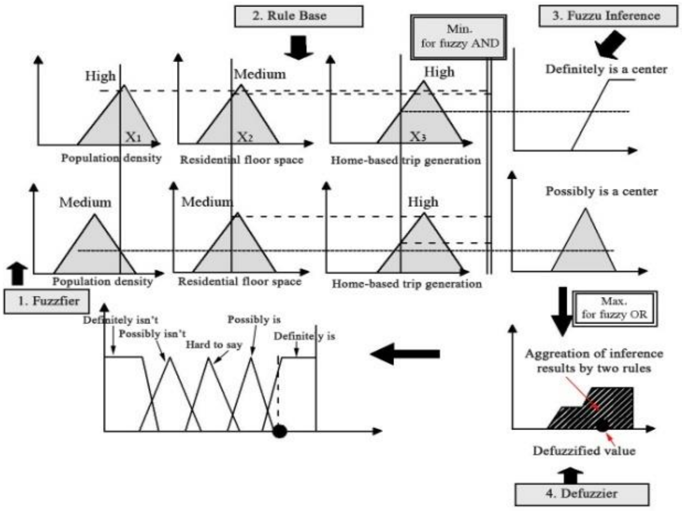

Fig. 5 The Mamdani fuzzy inference system illustrated by inference on the residential center

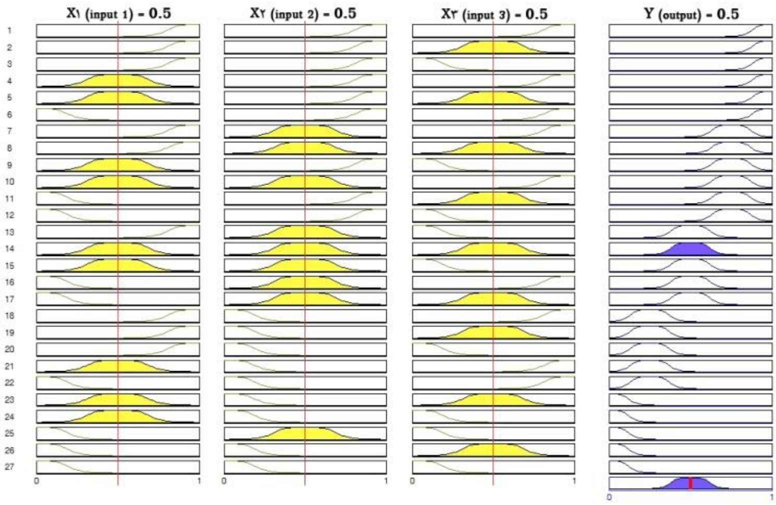

Fig. 6 Inputs (Xi) and output (Y) of the fuzzy inference

The fitness between the inference conclusions determined by the fuzzy inference system and the real recognition identified via the questionnaire survey should be examined to assess the validity of the study method (Mamdani and Assilian, 1975). The fitness is measured as follows:

$$\text{Fitness} = Ns/N \quad (4)$$

where N is the total number of subway stations analyzed and Ns is the number of subway stations for which the inference conclusions and survey results are the same. The fitness values range between 0 and 1, and the validity of the inference system increases with the fitness value. The fitness of the inference for residential centers is 0.81, whereas that for employment centers was 0.63, and that for services centers was 0.54, which represented an acceptable level.

4 FINDINGS

This study analyzed activity development for station areas along the two subway lines in 1996, 2003, and 2011 using the rule base and membership functions generated previously. Fuzzy calculations were performed using MATLAB fuzzy logic toolbox.

4.1 RESIDENTIAL ACTIVITIES

Residential activities are among activities that may undergo new arrangements under the influence of changes in the transportation network. The impact of changes in the transportation network, for example, the operation of the subway network, on the distribution pattern and development rate of residential land use at the local or regional level is relatively unlikely in the short term. In other words, the emergence of significant changes in the long term thus needs more time. Figure 7 shows the shifts in and development of residential activities in the case study station areas. According to this figure, residential activity has weakened over the past 18 years in *Darvaze Dolat* and *Panzdah-e-Khordad* station areas (central stations of Tehran), *Mirdamad* station area (located in the central zone adjacent to the central area of northern Tehran) and *Shahid Madani* (located in the developing regions). These station areas are considered the main attractors and points of transfer for commuters and draw a large proportion of non-residential and regional functions to themselves. In fact, the development process of this type of function and the resulting population congestion problems in central urban areas have led to a reduction in the importance of residential activity in these station areas and its shift toward the surrounding areas of central regions.

Residential activities in urban areas under development and changing to new regional centers, including the station area of *Shahid Madani*, are on the decline. In fact, residential real estate in this area and central areas has gradually faced degradation due to the emergence of social, traffic and visual disarray problems following the operation of subway stations. The changes in property prices and environmental degradation due to the occurrence of such problems have resulted in lower residential satisfaction and the subsequent decline in residential activities in these areas. Overall, the results of fuzzy inference imply that the operation of the subway has driven residential use to suburban areas. In other words, residential activities in suburban areas including *Tarasht, Sadeghieh, Golbarg*, and *Elm-o-Sanat* stations - which were considered the main points of trip generation - have experienced a growing trend to meet the existing demands through the establishment of appropriate stimuli by the subway (including improved accessibility to central areas). In fact, the subway system makes it possible for residents to take long trips between their place of work and residence. Indeed, with the existence of this system, people can work in urban centers and live in the suburbs and establish this connection through the transportation system. The impact of the subway on residential activities in station areas of Line 2 East, the space between central and suburban areas, was found not significant.

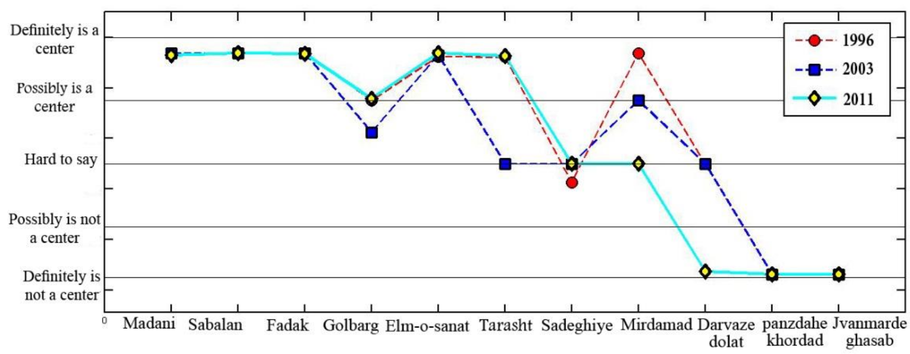

Fig. 7 Inference conclusions of residential activity

4.2 EMPLOYMENT ACTIVITIES

Figure 8 shows the development changes for employment activities -commercial, administrative and industrial- in the period 1996 to 2010. As the comparative diagram of fuzzy inference implies, commercial, administrative and industrial land use has increased in the period 2002 to 2010 in station areas under development and transformation to urban centers (*Shahid Madani and Mirdamad*) because of the promotion of the economic factor resulting from proximity to urban centers, increased access and comparative advantage, and hence an increase in the value of existing real estate under the influence of the operation of the subway in these areas. For example, in accordance with fuzzy inference, the station area of *Shahid Madani* in the period 1996 to 2002 was not identified as an employment center.

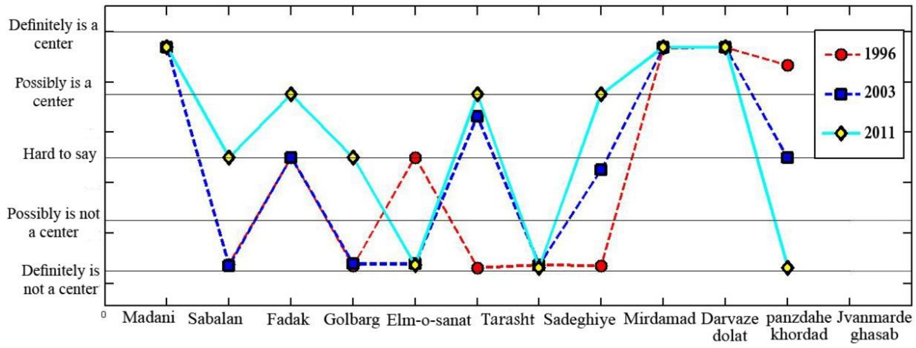

Fig. 8 Inference conclusions of employment activity

However, in 2010, changes in employment activities were such that this area was located near the "Possibly is an employment center".

Overall, despite the negative impact of the subway on residential use, the development of this system has managed to create a favorable condition in middle and central station areas for employment (commercial/ administrative use) leading to an increased rate of development in these areas and in connection with non-residential functions. In addition to these areas, the share of employment activities in suburban areas east of the central zone of Tehran, including the station areas of *Golbarg* and *Elm-o-Sanat*, has grown with an increasing trend following the utilization the subway. In fact, unlike the suburban areas located in west central zone maintained a low level of employment activities, these areas show the unstable development of employment activities during the past 18 years. In fact, the development of the subway system in these areas has created added value in economic terms, affected the environment, and gradually provided the possibility for change in the type, composition and area of continuous activities, albeit limited. With a declining economic performance in the years 2002 to 2010, the station areas of *Sadeghieh* and *Javanmard-e-Ghasab*, which are the main input and output ports of Southern and Western Tehran, will gradually convert into regions which most likely are no longer a center for commercial, administrative and industrial activities with their negative employment growth rates. A change in the role of these station areas during the period 1996 to 2010 clearly showed the influence of external factors on the subway system in the shifts of activity centers (Figure 9).

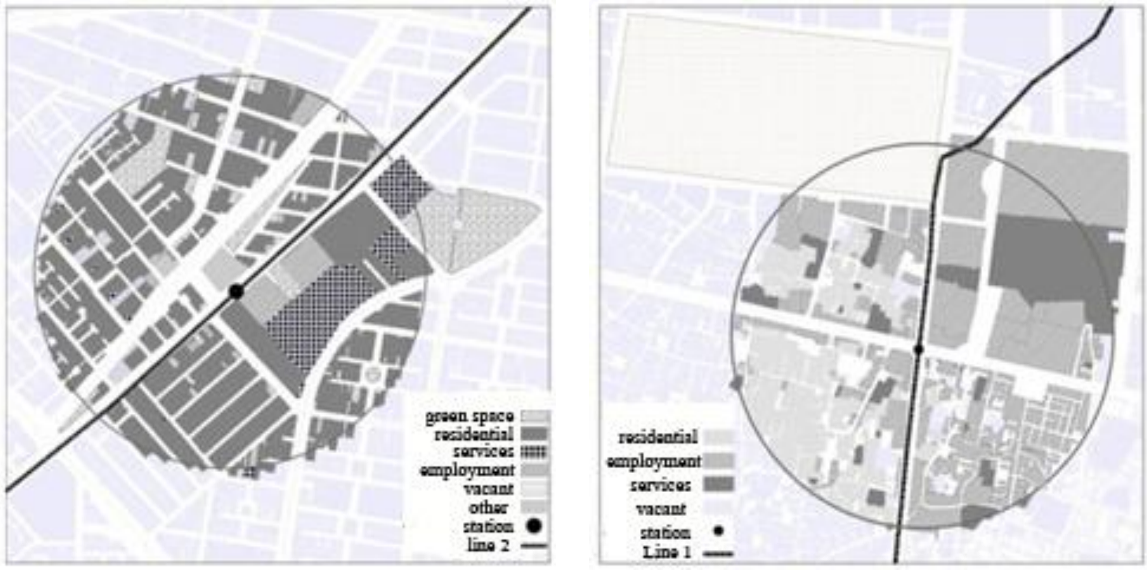

Fig. 9 Fadak station area as a residential center (on the left) and Panzdah-e-Khordad station area as an employment center (on the right)

4.3 SERVICE ACTIVITIES

Among activities that are compatible with the subway are service activities that connect subway stations with an appropriate link to the urban context. By service activities, we mean land uses such as educational, health, cultural, religious and sport that provide services to residents in the surrounding areas at different levels depending on the type of function. Figure 10 shows the results of fuzzy inference in connection with the shifts of such functions along subway lines and stations. According to the figure, the area of service activities and their distribution have not changed in central and suburban eastern and western station areas including *Sabalān*, *Golbarg* and *Tarasht* in the period 1996 to 2002. However, the area (floor space) of service activities in these areas in the period 2002 to 2010 has developed in a way that one such activity center is under development and formation in these areas. It is expected that, with the continuation of this trend, these areas will definitely become service activity centers in the coming years.

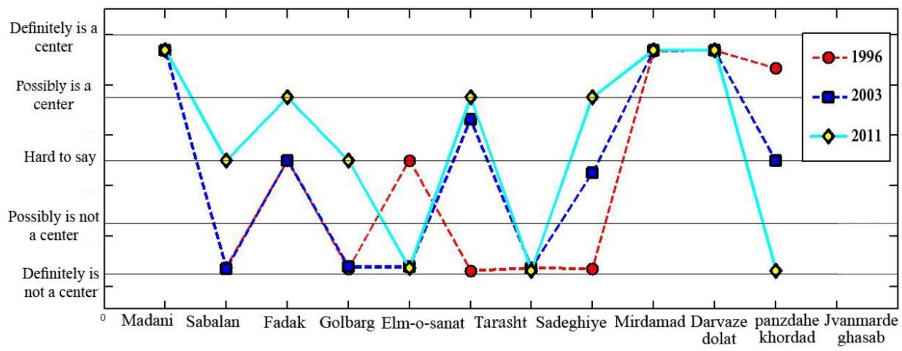

Fig. 10 Inference conclusions of services activity

The development of *Darvaze Dolat* and *Panzdah-e-Khordad*, as central station areas, and the developing *Shahid Madani* station area are not significant in the interval before and after the subway opening. These areas have been service activity centers in the years before the subway opening and have constantly strengthened their position by maintaining this level of activity in the years of operation. Central regions and the suburban northern and southern regions of Tehran exhibit different levels of development in service activities such that, unlike the *Mirdamad* station area, no change has occurred in the service activities of *Javanmard-e-Ghasab* station area in the years after the subway opening. Overall, based on changes from 1996 to 2011, the opening of the subway as an external stimulus has led service activities toward central and suburban areas in the East of Tehran as well as in developing areas (Figure 11).

Fig. 11 Javanmard-e-Ghasab as a station with development constraints (on the left) and Shahid Madani station area as a services center (on the right)

5 DISCUSSION

Mirdamad and *Shahid-Madani* station areas, which are being developed and combined into the area of a cosmopolitan center and within the sphere of an urban center, can be considered as independent subsidiary centers and be re-scheduled for the reduction of pressure on the main centers existing in *Darvaze-Dolat*, *Panzdah-e-Khordad*, *Imam-Khomeini*, *Imam-Hossein*, and *Haft-e-Tir* station areas.

The *Mirdamad* station area which is located in the northern central zone and within a cosmopolitan center is consistently and continuously developing and now, after almost two decades, can be identified as an important administrative and commercial center. However, the areas around *Shahid-Madani* station should continue to develop until the full conversion of the area into an employment center. Therefore, in this part of the study, we used the land use map and fuzzy inference system designed in earlier stages in order to predict and simulate the development of *Shahid Madani* station area and to analyze the relationship between floor space and center identification.

As previously mentioned, an employment center was identified based on three criteria, as listed in Table 1: employment density, commercial, administrative, and industrial floor space, and work trip attraction. According to a study by Lin (2006), since an increase in commercial and administrative floor space is associated with an increase in the other two criteria (employment density and work trip attraction), this study too, like similar experiences in the field, assumes that all three criteria increase and grow at the same rate. Figure 12 illustrates inference conclusions for different rates of specified criteria increases in the case of the developing *Shahid-Madani* station area. According to this figure, the *Shahid-Madani* station area will most likely become an employment center if the rate of increase in commercial, administrative and industrial floor space exceeds 200% to 250%. This area will definitely be an employment center if the increase in commercial, administrative and industrial floor space exceeds 300%.

Therefore, based on the inference results, it is suggested that urban planners, by considering plans for facilitating development around *Shahid-Madani* station, reconsider and analyze the rules and regulations as well as the capacities and opportunities available in this area. It is also suggested that they enhance the infrastructure for commercial and administrative use in order to achieve the objectives of decentralized and multi-organ structural development with new sub centers (Sub-CBD). Furthermore, it is recommended that urban planners, along with the development of such functions, promote and provide proper environmental quality to meet the needs of residents in consistency with the principles of transit oriented development (TOD).

Generally, the emphasis on the development of such station areas (*Shahid-Madani* station and other similar areas) is because an urban structure with several major and minor centers along with a reliable transit system which can purposefully disperse the distribution of desired activities, and increase the use of public transportation in addition to the creation of multi-functional urban cores. Therefore, one of the desirable solutions for Tehran is to plan multi-functional centers around the rail network as a way of promoting quality of life and improving accessibility for nearby residents.

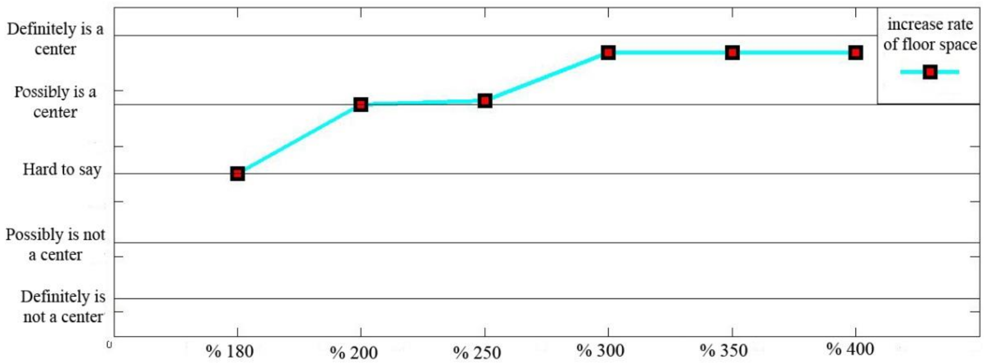

Fig. 12 Strategy analysis of employment activity for *Shahid-Madani* station area

6 CONCLUSION

This study analyzed the development of activity centers along the *Blue Line* of the Tehran subway system. The development of station areas along the two corridors in both 1996 to 2003 (before subway opening) and in 2003 to 2011 (after subway opening) was simulated and compared based on the fuzzy inference system. Strategic analysis was also conducted for the land use plan in the *Mirdamad* and *Shahid- Madani* station areas for 2020. Based on the inference conclusions, urban development strategies can be well developed.

In terms of location, the station areas under study are located in different areas with different levels of development. Some stations such as the *Darvaze-Dolat* and *Panzdah-e-Khordad* are established in central regions that have fully developed in physical characteristics. Some station areas are faced with development constraints for reasons such as physical and environmental conditions, such as *Elm-o-Sanat*, *Sadeghieh*, *Javanmard-e-Ghasab* and *Tarasht*. Some stations are located in areas of the city that have not fully developed or have the ability to accept new functions, higher density, etc. under the influence of renovation and improvement interventions (particularly distressed areas) such as *Shahid-Madani*, *Sabalān*, *Fadak*, *Golbarg* and *Mirdamad*. Analyzing the effects of the subway on the development levels of these areas can evoke the unique opportunities of subway stations for their immediate areas considering their nature and location. In general, research findings suggest that the subway system in the central and middle parts of the city (except for the main center of the city) has created benefits for certain land uses and has benefited from other land uses by increasing the levels of accessibility and subsequently increasing the volume of commuting compared to other regions. For example, an increase in the volume of urban trips in these areas has created advantages for employment activities including commercial, administrative and even service activities that benefit from traffic congestion. The promotion of the desirability level due to increased demand has emerged in the form of increased turnover, increased commercial and administrative real estate prices, and reduced residential real estate prices because of traffic congestion, noise, vibration and visual disarray. Finally, with positive and negative changes in property prices, the cycle of change in land use and increased trips has begun and altered the pattern of land use and distribution in these areas as follows:

1. Reduced importance of residential use in old and developing urban centers in the interest of maintaining and strengthening the development of employment levels and service activities in these areas.
2. Reduced number of residential centers along subway lines whereas new service and employment centers are growing and taking shape in a greater number of station areas.
3. The absorption of residential activities into suburban and terminal areas whereas employment and service centers are growing and expanding toward newly developed urban areas. Service centers are also taking shape in some suburban areas.

It is noteworthy that these changes are not proportionate to the zoning and land use proposed in the approved plans. By comparing the current situation of these areas and land use changes in the period 1996 to 2010 with the approved plan proposals of land use and their area, it can be argued that the development and shifts of these centers have occurred under the influence of the operation of subway system in these areas.

In addition to the above results, fuzzy inference system processes can be used for determining and simulating new sub centers (Sub-CBD) through the city and its districts. For example, according to the inference results, *Shahid-Madani* station area has achieved a level of development in employment and service activities that we can consider it as one of the regional centers. According to different theories about transportation sustainable development, such as the transit villages, the development of such areas along with subway lines is useful for the formation of a semi-centralized structure in Tehran to prevent low-density sprawl around new transit infrastructure and achieve a level of sustainable development. It is also noteworthy that the fuzzy inference system can circumvent the deficiencies of existing methods for analyzing activity centers via the following mechanisms: First, the premise of the fuzzy rule can use multiple criteria. For example, the premise of the previous example can be changed to: If the population density is high and the residential floor space is high, two criteria should be considered. Second, the rule base and membership function are both established via the questionnaire survey of individual judgments, which can be used to establish the goodness of fit between the model judgments and individual judgments. Third, the linguistic variables, other than statistical variables, used in fuzzy rules make the inference process more closely approach the judgment process of individuals. Finally, the linguistic outputs are useful for clearly describing and discussing the decision making process.

REFERENCES

Abraham, A. (2005). Adaptation of fuzzy inference system using neural learning. *Fuzzy systems engineering* (pp. 53-83). Springer Berlin Heidelberg. doi:http:// 10.1007/11339366_3.

Barlett, J. E., Kotrlik, J. W., & Higgins, C. C. (2001). Organizational research: Determining appropriate sample size in survey research. *Information technology, learning, and performance journal, 19*(1), 43.

Bonivento, C., Fantuzzi, C., & Rovatti, R. (1998). Fuzzy logic control: Advances in methodology. World Scientific Publishing Co., Inc..

Cervero, R. (2004). Transit-oriented development in the United States: Experiences, challenges, and prospects (Vol. 102). Transportation Research Board.

Cervero, R., & Landis, J. (1997). Twenty years of the Bay Area Rapid Transit system: Land use and development impacts. *Transportation Research Part A: Policy and Practice, 31*(4), 309-333. doi:http://10.1016/S0965-8564(96)00027-4.

Daisa, J. (2004). Traffic, parking, and transit-oriented development. *The New Transit Town: best practices in transit-oriented development*, 114-129. doi:http://dx.doi.org/10.5860/choice.42-0424.

Dubois, D., and Prade, H. (1996). What are fuzz rules and how to use them? *Fuzzy Sets and Systems, 84*(2), 169-185. doi:http://dx.doi.org/10.1016/0165-0114(96)00066-8.

Fejarang, R. A. (1993). Impact on property values: A study of the Los Angeles metro rail. In PUBLIC TRANSPORT PLANNING AND OPERATIONS. PROCEEDINGS OF SEMINAR H HELD AT THE EUROPEAN TRANSPORT, HIGHWAYS AND PLANNING 21ST SUMMER ANNUAL MEETING (SEPTEMBER 13-17, 1993), UMIST. VOLUME P370.

Gatzlaff, D. H., & Smith, M. T. (1993). The impact of the Miami Metrorail on the value of residences near station locations. *Land Economics*, 54-66. doi:http://dx.doi.org/10.2307/3146278.

Höhle, U., & Rodabaugh, S. E. (1999). Mathematics of Fuzzy Sets: Logic, Topology, and Measure Theory (Vol. 3). Springer Science & Business Media.

Kaur, A., & Kaur, A. (2012). Comparison of fuzzy logic and neuro-fuzzy algorithms for air conditioning system. International journal of soft computing and engineering, 2(1), 417-20. doi: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.648.6698&rep=rep1&type=pdf.

Klir, G. J., & Folger, T. A. (1988). Fuzzy sets, uncertainty, and information. Prentice-Hall International Inc., New Jersey.

Leung, K. S., & Lam, W. (1988). Fuzzy concepts in expert systems. *Computer, 21*(9), 43-56.

Lin, J. J., Feng, C. M., & Hu, Y. Y. (2006). Shifts in activity centers along the corridor of the blue subway line in Taipei. *Journal of urban planning and development, 132*(1), 22-28. doi:http://dx.doi.org/10.1061/(asce)0733-9488(2006)132:1(22).

Mamdani, E. H., & Assilian, S. (1975). An experiment in linguistic synthesis with a fuzzy logic controller. *International journal of man-machine studies, 7*(1), 1-13. doi:http://dx.doi.org/10.1016/s0020-7373(75)80002-2.

Pacheco-Raguz, J. (2010). Assessing the impacts of Light Rail Transit on urban land in Manila. *The Journal of Transport and Land use, 3*(1), 113-138. doi:http://dx.doi.org/10.5198/jtlu.v3i1.13.

Pedrycz, W. (2001). Fuzzy equalization in the construction of fuzzy sets. *Fuzzy sets and systems, 119*(2), 329-335. doi:http://dx.doi.org/10.1016/s0165-0114(99)00135-9.

Shariati, S. (2012). Exploring the Spatial Impacts of Tehran Subway System, M.S Thesis in Urban and Regional Planning, supervised by Dr. A. Soltani. Shiraz University.

Strauss, A., & Corbin, J. (1990). Basics of qualitative research (Vol. 15). Newbury Park, CA: Sage.

Tanaka, C. (2002), Fuzzy Set Theory & its Practical Applications, translated by Ali Vahidian Kamyad and Hamed Reza Tareghian, Ferdowsi University Mashhad, publication No.327.

Teodorović, D. (1999). Fuzzy logic systems for transportation engineering: the state of the art. *Transportation Research*

Part A: Policy and Practice, 33(5), 337-364. doi:http://dx.doi.org/10.1016/s0965-8564(98)00024-x.

Transport and Traffic Organization of Tehran Municipality, (2012). Comprehensive studies of transportation and traffic in Tehran metropolitan. No 934.

Wang, L. X., & Mendel, J. M. (1992). Generating fuzzy rules by learning from examples. *IEEE Transactions on systems, man, and cybernetics, 2*2(6), 1414-1427. doi:http://dx.doi.org/10.1109/21.199466.

Zahedy, M. (1999). Fuzzy Set Theory and its Applications, Tehran, University Publication.