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TRANSIT- ORIENTED DEVELOPMENT IN IRAN
CHALLENGES AND SOLUTIONS

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Road, Housing and Urban Development Research Center (BHRC)
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EDITORIAL PREFACE:

TRANSIT-ORIENTED DEVELOPMENT IN IRAN. CHALLENGES AND SOLUTIONS.

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This Special Issue of TeMA, the Journal of Land Use, Mobility and Environment, collects the proceedings of the Joint workshop, which was held by the Center for Technology of Society (ZTG) of the Technische Universität Berlin (TUB) and the 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". Although the contents of the workshop targeted TOD in Iran, it had a partial look at the experiences of Germany. Identifying the problems that have limited the positive effects, user-friendliness, and good accessibility of public transport systems in Iran, as well as putting the state of the art of the topic practiced in Germany into discussion with Iranian experts were the most prominent targets of the workshop. Topics on the borderline between urban transportation planning, urban planning, and urban design need to be addressed in the dialogue facilitated between the Iranian and German experts.

TOD is a multi-disciplinary term dealing with both transportation and urban planning (Cervero, 2007). It is generally associated with the concepts raised by North American urban planners and linked to ideas such as new urbanism, smart growth, infill development and affordable housing (Gargiulo et al, 2013; Ratner & Goetz, 2013). Nevertheless, it has been set as the main approach of a variety of planning practices in other world regions such as Europe during the past two decades (Bertolini et al., 2008). The concept has been defined as a policy and planning instrument to address urbanization problems such as traffic congestion and air pollution; and achievement of some secondary goals such as increasing urban quality and creating livable cities (Moeinaddini et al., 2012). It uses planning instruments to create a compact, dense, mixed-use area around existing or new transit stations, which are also pedestrian and cycle-friendly reinforcing the use of public transportation (Calthorpe Associates, 1992; Atkinson-Palombo & Kuby, 2011; Levinson, 2016). Considering its multi-disciplinary character, the general goals of TOD could not be achieved without support from local institutions. In other words, the institutional barrier is a serious obstacle for a successful TOD project (Tan et al., 2014). This means that in a sectoral planning culture of some developing countries (such as Iran), in which the policies and priorities of the central government depend on the choices of individual decision-makers, and overlapping tasks, complexities and contrasts of interests are prominent characteristics of institutions, it is not easy to achieve TOD goals.

Iran is a developing country still facing serious urbanization challenges. Rapidly increasing urban population, severe air pollution, traffic congestion and a high mortality rate in car accidents, coupled with serious health risks due to air pollution, are among major issues. In recent decades, the urban planning system of the country has been developed according to western models tailored to the local institutional context. The approach creates major challenges, as it is usually difficult and even impossible to adopt an "imported" theory developed as a solution for local needs of a country, to another with a considerably different context. It is even more challenging when the policy area is a complex, multidisciplinary topic such as TOD. A successful transfer of planning practice is the outcome of comprehensive knowledge on different planning cultures and institutional contexts. Therefore, in this special issue, the general topic of TOD has been introduced as a planning instrument to deal with some urbanization challenges in Iran; while comprehensive research on local capacities and weaknesses has been carried out. The editors have sought to convey the message that a deep understanding of the local context is the key to transferring a planning policy.

The main questions addressed in this special issue are the following:

- What are the best approaches for integrating land use and public transportation and overcoming barriers to transit-friendliness of urban development in larger Iranian cities?
- What can Iranian decision makers learn from the German experience of integration of urban form and public transportation in Berlin?
- What are the main challenges and problems of TOD projects and approaches in Iran, especially for the Tehran Metro as the most developed urban rail network of the country?

This issue is divided into two main sections: the first examines the future approach to TOD in the country, while the second takes a more empirical approach to evaluating the success or failure of the TOD approach of Iranian cities, especially the experience of the Tehran Metro.

In the first section of this issue, two introductory papers describe the need for a paradigm change towards integrated land use and transport planning and transit-oriented development. As a feedback to one of the questions of this issue regarding learning from German practices, a discussion is presented by Friedemann Kunst about the experience of Berlin in using land use and public transit systems in enhancing sustainable transport. Berlin is given as an example of metropolitan areas around the globe, particularly those located in developing and emerging countries like Tehran and other large cities of Iran. The article titled "from rail-oriented to automobile-oriented urban development and back: 100 years of paradigm change and transport policy in Berlin" explains how the rail-oriented city of early-twentieth-century Berlin was oriented to the US pattern of a car-oriented city after the World War II and how it continued to return to its tradition of providing densely-woven public transport networks in recent decades. The other paper in this section is written by Mahta Mirmoghtadaee titled "challenges of transit-oriented development (TOD) in Iran". The paper describes the large-scale challenges of TOD and integrating land use in transport planning of Iran. A paradigm shift towards this integration is declared inevitable to promote sustainability of urban transportation planning of the country.

The second section is allocated to evaluations of the Tehran Metro as the most developed urban rail network of the country, the site selection of its stations as well as land use, and activities around stations. Houshmand Masoumi and Maryam Shaygan consider the site selection of metro stations of Tehran, evaluating the contemporary density of the catchment areas 800 meters around the stations in a contribution titled "A longitudinal analysis of densities within the pedestrian sheds around metro stations: the case of Tehran". The main target is to assess the ability of station site selection to provide higher population and employment densities around the stations so that the general TOD criteria are fulfilled. The other paper of this section is titled "Modeling the shifts in activity centers along the station areas of the subway lines, case study: Tehran" and is authored by Ali Soltani, Samaneh Shariati, and Ali Amini, who use fuzzy logic to assess the activities around Tehran metro stations. The aim of this assessment is to provide a model for analyzing development of pre-existing stations in order to locate activities and employment in the vicinity of the stations. The third paper of this section is titled "Transit-oriented development background study in Tehran city: land use conditions and travelers' attitudes" presented by Amir Janjani and Amirreza Mamdoohi. The end-user satisfaction of the Tehran Metro station facilities is analyzed by focusing on the case of Sadeghieh station in the west of Tehran. The authors also find high densities of Tehran a good opportunity for providing TOD. The fourth paper by Amirreza Mamdoohi and Hamid Zarei titled "An analysis of the public transit connectivity index in Tehran" focuses on the concept of input and output connectivity power of metro stations in Tehran. The objective of this study is to apply transit connectivity indices to the multimodal transit network in the city of Tehran. Three measures applied as a methodology for measuring transit connectivity are node connectivity, line connectivity, and regional connectivity, where activity density is applied to these measures. The results that show the areas with higher connectivity in those three scales can be used to suggest some ideas on how future investments in rail and bus transport should be prioritized.

The contributions to this issue have all been fully peer-reviewed by an international board of experts located in six countries: Iran, Italy, Germany, UK, Australia, Portugal, and Malaysia.

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A LONGITUDINAL ANALYSIS OF DENSITIES WITHIN THE PEDESTRIAN SHEDS AROUND METRO STATIONS

THE CASE OF TEHRAN

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ABSTRACT

Evaluation of spatial accessibility to public transportation has a weak background in many emerging countries, including Iran. Transit-Oriented Development is of great interest among Iranian planners and academics, but little is known about transit orientation provided by major public transport systems exemplified by the Tehran Metro. Statistical difference tests and polynomial regression done in this study show how residential densities within walking distances of metro stations established at different times after 1998 are significantly different. Both population and employment densities have decreased in more recent stations compared to those opened between 2005 and 2010. Moreover, one-way T-Tests comparing the population and densities of older lines with those of newer lines reveal that, in most cases, densities within walking distances of stations of older lines are higher. The paper concludes that lack of proper site selection and failing to locate new stations near job centers and highly populated areas threatens the transit-friendliness that emerged in the early years after establishing the first metro station in 1998.

KEYWORDS
Transit-Oriented Development, urban development, population density, employment density, walking distance, accessibility, public transportation, Tehran

1 INTRODUCTION

Urban density is an essential part of Transit-Oriented Development (TOD). Its role in integrating urban development and urban transportation planning has been emphasized in a considerable part of the fundamental literature describing the basic approach of TOD (i.e. Calthorpe, 1993; Bernick & Cervero, 1997). The idea is supported by a large body of literature mostly dating back to 1990s that confirm higher residential (Pushkarev & Zupan, 1977; Newman & Kenworthy, 1989, Parsons et al. 1995; Cervero, 1998; Spillar & Rutherford, 1998; Banerjee et al. 2005) and employment (Frank & Pivo, 1994; Nelson & Nygaard, 1995; Transit Cooperative Research Program, 1996) densities generate higher transit ridership. More recent studies confirm that commute travels, trips made around the work place, and travel modes to work are in need of further attention in TOD (Reconnecting America's Center for Transit-Oriented Development, 2008).

This study targets the Tehran Metro system as a public transport system in a less studied context. The problem motivating this research is the lack of evaluations on the efficiency and consumer-orientation of this metro system, especially in case of integration of land use. Since the land use and transportation approaches were not so much included in urban transport planning of Iran back in the 1980s and 1990s, during which the development plans were initiated, it is important to be informed how these old approaches to mass urban rail transport work with the new perspectives of accessibility to public transport, walking, and in general sustainable mobility.

As a rapid transit system, the Tehran Metro serves 94 stations spread along five lines. The system currently carries more than 3 million passengers a day. In 2014, 815 million trips were made within Tehran Metro, which had fewer stations then than today. As of 2015, the total system was 170 kilometers long, 127 kilometers of which are metro-grade rail. It is planned to have a length of 430 kilometers with 9 lines once the whole construction is complete by 2028. The initial plans of the Tehran Metro, which was to be Iran's first metro system, were laid out in the 1970s before the 1979 revolution. In 1976, metro construction studies and executive administration were begun. However, this development was short-lived with the advent of the Iranian revolution and Iran–Iraq war in 1979 and 1980 respectively. In 1985, the "Tehran Metro Execution Plan" was re-approved by the Iranian parliament. Work proceeded slowly due to the continuing Iran–Iraq war and often ground to a halt. Line 5 of the Tehran metro began operations in 1999 and was Iran's first metro system (Tehran Urban and Suburban Railway Operation Co.).

Having in mind the conditions under which the Tehran Metro was planned or implemented, including the war conditions, lack of proper land use and transport knowledge, the harsh influence of transportation engineering leading to lack of interdisciplinary plans, etc., to compensate for the possible deficiencies resulting from the above, assessments on the Tehran Metro with special emphasis on spatial considerations, e.g. TOD evaluations, seem necessary. It is intriguing to know whether there has been any change in the attitudes of decision makers and planners of Tehran Metro regarding the use of urban density in site selection of the stations. Also the differences between the approach to residential and employment densities can be appealing.

The paper seeks to analyze the changes in population and employment density around metro stations of Tehran during the past 18 years, as a determinant of the ideology of urban planners and transport planners to TOD. The pre-assumption is that if planners and decision makers select the site of metro stations in denser city districts with proximity to more residential units and employment centers, they have deliberately provided higher transit-friendly urban developments. The questions that this study is going to answer include (1) Are there any significant differences in population and employment density in the vicinity of the metro stations opened in Tehran between 1998 and 2016? (2) If the differences in density within the walking distance of the stations are found significant, how can this be interpreted?

The core concept of TOD concerns density, which is also dealt with in this study. Other influential attributes providing a transit-oriented environment are beautiful, vital, and walkable neighborhoods (City and County of Denver, 2006), employment in activity sites together with public spaces (Cervero, 1998; Curtis et al., 2009), mix of land uses (Loo et al., 2010), and the like. However, this paper only focuses on the density of the station areas, which is considered basic and the starting point of implementation of TOD. One of the most prominent steps for integrating transit and urban land use is to "develop transit systems to connect existing and planned concentrations of development" (Curtis et al., 2009, 3). Setting this as the main focus of this study, it is assumed that planning other characteristics of a successful TOD can be carried out after or in parallel with densification of the vicinity of the transit stations and stops. It should be mentioned that this study considers only the metro network, so support given by the metro system for creating a TOD is examined. Other modes like buses, taxis, or even paratransit can separately be researched.

The paper continues with an explanation of the methodology, including the data, and the methods applied for hypothesis testing and regression analyses. Section three presents the research findings including the results of the T-Tests and the polynomial regression analysis based on the time periods of opening the stations and also based on lines. This part is followed by a discussion to increase the level of physical understanding of readers concerning the site selection and location of stations, explained by means of examples of stations in central Tehran. A short summary of the findings and discussion ends this contribution.

2 METHODOLOGY

To analyze the longitudinal changes in density within the walking distances around metro stations of Tehran, a sample of stations was selected in a way that they are launched or planned in residential and urban quarters of Tehran. Stations located in the non-urban areas or with little density around them were considered outliers and were omitted from the sample. The sample consists of 84 stations, 73 of which were established between 1998 and 2015 and the remaining 11 are being planned or constructed. Two of three major density types, namely population and employment densities are targeted in the study, the data of which were obtained from the 2011 Tehran Census of the Statistical Center of Iran. The data were provided in the form of statistical blocks that surround the metro stations. The summary of the collected data can be observed in Table 1, the details of which are presented in Table 2 (in the annex) based on stations. The selected stations are surrounded by a minimum of 3 and maximum of 318 statistical blocks as seen in this table. All statistical blocks were arranged to be located in a walking distance of 800 meters on an aerial pedestrian shed basis. The average population and employment density around the stations accounts for 152.1 inhab./ha and 55.2 jobs/ha respectively. Fig. 1 illustrates the geographical location of the stations addressing the years of establishment. Fig. 2 and 3 depict the distribution of population and employment density within the walkable distances from stations.

Part of the analysis done in this study is based on a T-Test analysis between three periods of time consisting of 1998-2003 and 2005-2015 periods as well as post-2015, which includes 12 stations that have not yet been launched. 29 and 44 of the stations established during the first and the second periods were observes. These time intervals were selected in order to find a significant turning point, so that the behavior of the Iranian planning system regarding TOD is examined. It should also be mentioned that between 2003 and 2005 no stations were established. So it is hypothesized that around the years 2004 and 2015 a change in the attitude of urban transport planners occurred, and the result of the designing and planning metro network altered.

The T-Tests taken in this part of the study are one-tailed because, as seen in Table 3, the variances of the above three time categories differ in both population density (1998-2003: 11095.8, 2005-2015: 11219.7, and after 2015: 5305.1) and employment densities (1998-20013: 1803.6, 2005-2015: 1004.7, and after 2015: 421.1). Thus, the T-Test between different samples with different variances is taken.

	POPULATION DENSITY Σpop/Σarea (inhab./ha)			EMPLOYMENT DENSITY Σemp/Σarea (jobs/ha)		
	1998-2003	2005-2015	Still not Opened	1998-2003	2005-2015	Still not Opened
No. of Stations	29	44	11	29	44	11
Standard Deviation	105.3	105.9	73.4	42.5	31.7	20.5
Min	5	14.2	20.8	4.5	6.8	8.4
Max	362.9	557.3	230.3	201	149.6	66.7
Mean Density (inhab./ha for population density and jobs/ha for employment density)	131.2	174	119.6	66.7	52.1	37.2

Tab. 1 Summary of descriptive statistics of the sample stations

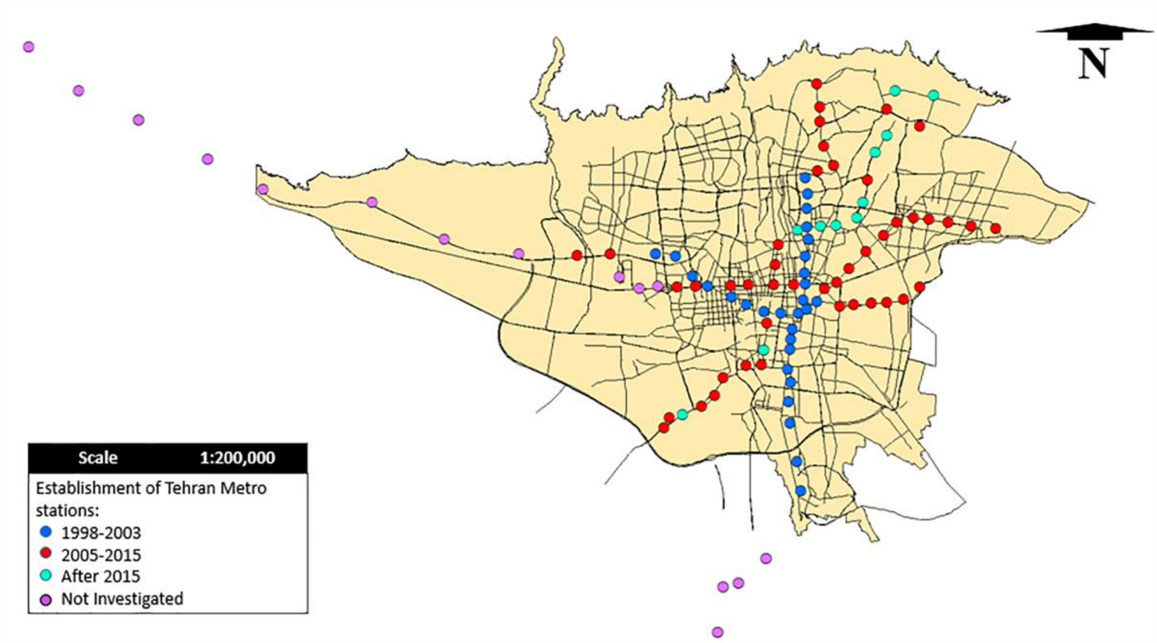

Fig. 1 Location of Tehran Metro stations.

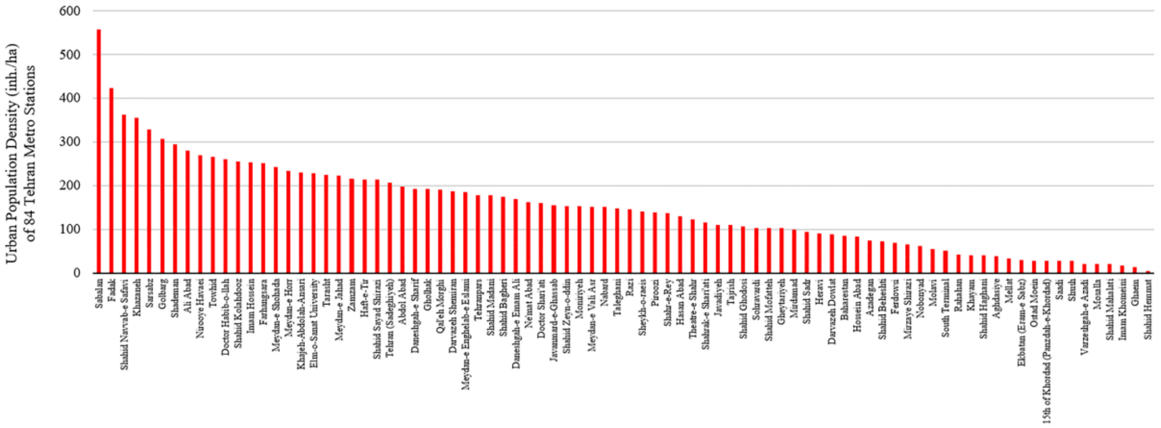

Fig. 2 Urban population density around the 84 observed metro stations of the study

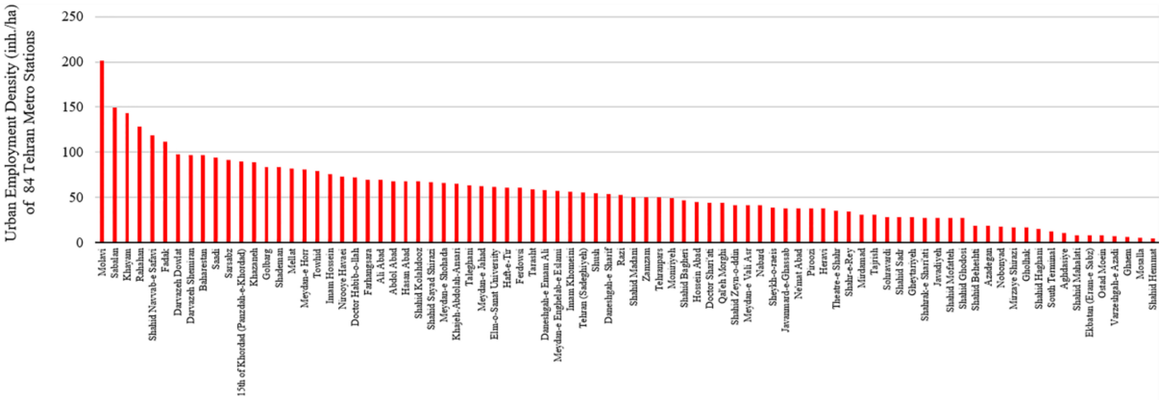

Fig. 3 Employment density around the 84 observed metro stations of the study

To avoid methodological biases related to the time and location of stations, the hypothetical comparisons are conducted also based on lines. As observed in Table 2, lines 1, 2, and 5 are the oldest lines launched. Line 5 is more or less suburban and some of its stations are located in less populous areas. The purpose of opening this line was to connect the city of Karaj west of Tehran to the capital. Thus, the one-way T-Tests were done between older urban lines, namely lines 1 and 2 and more recent lines, which are lines 3 and 4. The Tests were done assuming that the variances were different. Again, the comparisons were undertaken for population and employment densities. In this study, Line 3 includes 25 stations, 23 of which were launched in 2013 or after. The two stations opened before 2013 are Theatr-e Shahr and Shahid Beheshti that were basically stations located on the older lines of 1 and 4. Line 4 includes 15 stations, 12 of which were developed in 2007 and after.

The remaining three stations were common with the older lines of 1 and 2, developed in 1999, 2001, and 2006. The hypothesis of these T-Tests is that the current population and employment densities around the stations of older lines (1 and 2) are higher than those of newer lines (3 and 4).

Finally, in order to investigate the changes in site selection of metro stations and integrating public transit and density, polynomial regression analysis is employed to depict non-linear trends. Polynomial regression taken here follows the general equation of $y = a_3x^3 + a_2x^2 + a_1x + a_0.$ Here the regression analysis was performed with two degrees, so only a_3x^3 and a_2x^2 are shown in the formulations.

3 FINDINGS

Significant differences between two different densities and three time periods were sought by doing four sets of T-Test analyses. The results of the analysis are illustrated in Table 3, where the differences between time classes were observed to be significant or marginally significant. In this study, the differences are treated as marginally significant when the one-tailed p-values fall between 0.05 and 0.10, as one observed p-value out of four proved to be so. Table 3 shows the results of the four comparisons conducted.

The population densities of the observed metro stations significantly increased between 2005 and 2015 compared to 1998 and 2003 (p-value: 0.0479). However, the population densities significantly dropped after 2015 (p-value: 0.0288). The status of employment densities around metro stations is different; job densities around stations established between 2005 and 2015 are lower than those of 1998 and 2003. Similarly, the job densities of the new stations yet to be established are even lower than in the period of 2005-2015. Job densities decreased from 66.7 jobs/ha to 52.1 and then to 37.2 during the mentioned three eras. The above indicates that the mean population and employment densities were treated differently.

	POPULATION DENSITY AROUND STATIONS				**EMPLOYMENT DENSITY AROUND STATIONS**			
	Population Density 1998-2003 and 2005-2015 (Inhab./ha)		Population Density 2005-2015 and after 2015 (Inhab./ha)		Employment Density 1998-2003 and 2005-2015 (Jobs/ha)		Employment Density 2005-2015 and after 2015 (Jobs/ha)	
Time Period	1998-2003	2005-2015	2005-2015	After 2015	1998-2003	2005-2015	2005-2015	After 2015
Mean	131.2	174	174	119.6	66.7	52.1	52.1	37.2
Variance	11095.8	11219.7	11219.7	5305.1	1803.6	1004.7	1004.7	421.1
No. of Stations	29	44	44	11	29	44	44	11
df	60		22		48		24	
t Stat	-1.69		2		1.58		1.9	
P-Value (one-tailed)	**0.0479**		**0.0288**		**0.0603**		**0.0344**	
T Critical (one-tailed)	1.6706		1.7171		1.6772		1.7108	

Tab.3 Results of T-Test of mean difference analysis on population and employment densities of 84 metro stations of Tehran

The T Critical values presented in the last row of Table 3 are calculated by means of degrees of freedom (df) and the upper-tail probability, which is 0.05 here. In three comparisons out of four the T Stat is more extreme than the T Critical, which indicates rejection of the null hypothesis of no difference (p-values of less than 0.05). The remaining one case with lower T Stat value is related to employment density 1998-2003 and 2005-2015, which is marginally significant (p-value between 0.05 and 0.10). The slight change in the value of T Stat and T Critical does not reflect any physical meaning for our longitudinal analysis, since only checking the significance of mean differences of job and employment densities is important for this study.

The above indicates that the mean population and employment densities were treated differently in different times. Fig. 4 indicates these differences based on the year of establishment of stations. Each column of this graph includes the average densities of a couple of stations established in that year. The annual number of stations established differs from 1 to 17 (2001).

The same difference is observed between population densities (40 to 346 inhab./ha) and employment densities (19 to 104 jobs/ha). The density analysis is largely inconsistent and does not reflect any continuous policy or intention behind the selection of metro station sites, i.e. in 2006, five stations were established, which provided a prominent population density of 346 inhab./ha and a job density of 104 jobs/ha. This year produced the most transit-friendly developments, while the three stations launched the next year only had a population density of 40 inhab./ha. In 2013, the average employment density became only 19 jobs/ha.

As explained in the methodology section, the comparisons of population and employment densities were repeated based on lines, assuming that lines 1 and 2 are older and lines 3 and 4 are more recent, while Line 5 is suburban and/or intercity and stays out of analysis. The findings are presented in Table 4, where the results of 5 out of 8 T-Tests show that the densities around stations of older lines are more than those of newer lines. Only 1 out of 8 tests reflects more densities in a newer line (population density of Line 4). In this comparison, the status of employment density is worse, because 3 out of 4 comparisons show lower employment densities in lines 3 and 4. The remaining test shows statistically equal densities. Hence, the hypothesis of higher densities around stations of older lines compared to those of newer lines can be accepted.

POPULATION DENSITY (INHAB./HA)

Lines	Line 1	Line 3	Line 1	Line 4	Line 2	Line 3	Line 2	Line 4
Mean	104.9	125.6	104.9	163.9	227	125,6	227	163,9
Variance	7810.1	3902.6	7810.1	7579	15637,6	3902,6	15637,6	7579
No. of Stations	24	25	24	15	21	25	21	15
df	41		30		28		34	
T Stat	-0.94		-2.047		3.3797		1.7855	
P-Value (one-tailed)	**0.1758**		**0.0248**		**0.0011**		**0.0416**	
T Critical (one-tailed)	1.6829		1.6973		1.7011		1.6909	
Result	Line 1 = Line 2		Line 1 < Line 4**		Line 2 > Line 3***		Line 2 > Line 4**	

EMPLOYMENT DENSITY (JOBS/HA)

Lines	Line 1	Line 3	Line 1	Line 4	Line 2	Line 3	Line 2	Line 4
Mean	55.2	41.1	55.2	56.8	77,8	41,1	77,8	56,8
Variance	2162.1	639.7	2162.1	797.5	708,8	639,7	708,8	797,5
No. of Stations	24	25	24	15	21	25	21	15
df	35		37		42		29	
T Stat	1.3163		-0.1303		4.7658		2.2521	
P-Value (one-tailed)	**0.0983**		**0.4485**		**<0.0001**		**0.016**	
T Critical (one-tailed)	1.6896		1.687		1.682		1.6991	
Result	Line 1 > Line 3*		Line 1 = Line 4		Line 2 > Line 3***		Line 2 > Line 4**	

***Marginally significant at 0.10 level**

****Significant at 0.05 level**

*****Highly significant at 0.01 level**

Tab. 4 T-Test results for comparison of population and employment densities based on lines

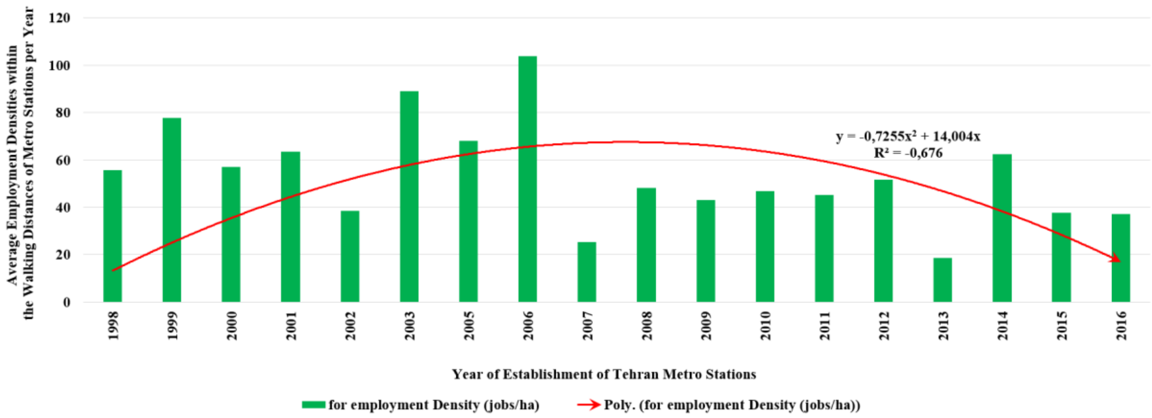

Fig. 4 Average annual population densities around Tehran metro stations since 1998

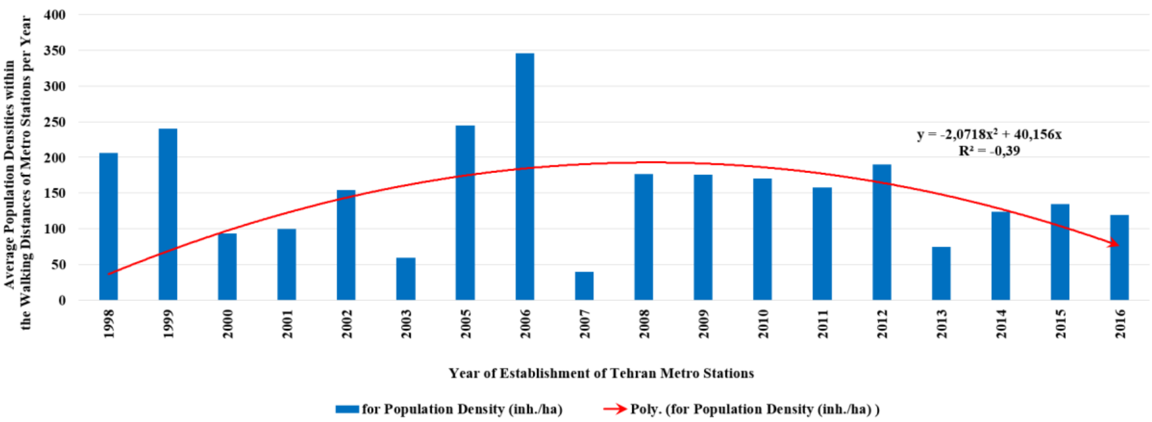

Fig. 5 Average annual employment densities around Tehran metro stations since 1998

The densities are also analyzed based on time on an annual basis of station development by means of polynomial regression analysis. Fig. 5 depicts these differences and highlights how a better approach to integrating urban rail systems was taken for ten years after 2005 and then this attention to connecting public transport to residential functions weakened again after 2015. Fig. 5 shows the same pattern for opening stations around employment centers such as retail centers, shops, offices, commercial areas, entertainment centers, malls, etc. between 1998 and now. The figures reflect the results of regression analysis for both density types. Both population and employment densities in 2016 exceed those in 1998, thus a_2 has a positive sign for both. However, the patterns and curves of the trend-lines are exactly the same. In both figures, it is assumed that those stations that had not been opened until the end of 2015 (11 stations) were open to operation in 2016. The R-squared value of Fig. 4 is 0.676, which means 67.6 percent of variability of population density around the observed stations is explained by the regression model. This value is considered to be an acceptable amount. Likewise, 39 percent of variability of employment density is explained by the model depicted in Fig. 5, which reflects a weaker model.

4 DISCUSSION

This study addresses the basic need for stronger integration of transit with dense land use in Tehran, Iran, as a first step accompanied by other necessary factors including implementation of pedestrian-friendly environments, mixed land uses, beautiful and vital neighborhoods, compact housing, and finally presence of public spaces, employment and working opportunities in the vicinity of transit. To set a clear target for the study, only two types of density, population and employment, were examined. Nevertheless, a complete integration has to cover all the above aspects of transit-friendliness that have been frequently recommended by transport scholars and practitioners, some of which were addressed in the introduction of this paper.

The results of this research are comparable to a handful of international studies that have tried to evaluate TOD, an example of which is a recent working paper reflecting the work of Schuetz et al. (2016), who did not find any change in employment density, housing sales volume, or new housing development within five years after the stations of Los Angeles metropolitan area were opened.

However, the findings of this study show significant changes in population and employment densities. One point that should be noted is that the longitudinal changes in density targeted in this paper are not an impact of investment in public transportation as has been found in a wide range of studies that examined the impacts of land use, urban form, and housing (for instance Cervero & Landis, 1997; Debrezion et al. 2008; Mathur & Ferrell, 2009; Bowes & Ihlanfeldt, 2011; Kheyroddin et al. 2014 (Tehran case)), but they reflect the planning attitudes of urban and transport planners in selecting the metro station sites. The station site selection process in Tehran is the result of a complicated procedure studying very different factors for selecting the best line choices (direction and location) such as geo-technique, underground barriers, surface barriers, slope, etc. Moreover, the city is much denser than its western counterparts, so finding appropriate plots for new stations has been a severe challenge, particularly in the central parts. The above may have caused trade-offs between selecting sites providing the highest densities on the one side, and a broad range of difficulties in implementing and executing the plan. In the case of cities like Tehran, a public transport network is implemented in a highly-dense city with a majority of already established quarters. Having in mind that mobility-related decisions regarding commute urban trips have a very limited influence on residential location choices in Tehran compared to Western cities (Masoumi, 2013), one can conclude that TOD in Tehran may play a very weak role in changing the densities. This assumption is in line with Kolko's findings (2011), who found no significant change in employment density around the majority of transit stations in California opened between 1992 and 2006.

Here, it is worth adding that redistribution of population and relocation after the opening of new stations have not been subject of studies in Iran so far. The above study about self-selection (Masoumi, 2013) only seeks individual preferences for buying or renting residential location based on transportation priorities in general, but it does not consider decisions for choosing a place for living after a metro station has been recently opened. Such studies can contribute interesting inputs to the subject, if reliable disaggregate data are collected from individuals. It is clear that secondary data cannot be helpful for such purposes. In addition to the above, the interaction of stations with one another on the same line or on other lines was not covered by this study. Again, to clarify this issue, individual and household data need to be collected. Furthermore, between the time the stations were planned and the time they were actually opened to operation, population or employment dynamics may well have changed. This can also be a subject for further research.

The findings of this study show a significant (or in one case marginally significant) change in the residential and employment densities within walking distance of the metro stations. Although the stations that were opened between 2005 and 2015 enjoy higher population densities than those opened in the 1998-2003 period, the densities around stations to be opened in the near future will drop again. Thus, relatively good planning of stations in high-density areas has reversed previous low-residential densities before 2003. The same pattern is observed about employment densities. The above is the response of the authors to the question one of this paper.

In response to the second research question of this study, it is worth mentioning that accessibility to public transportation as well as integrating density concerns and mass urban rail transport have not been a priority in site selection of the metro stations in Tehran. Perhaps accessibility has been traded off in favor of technical issues or lack of state-of-the-art knowledge of land use-transport integration. Moreover, the attention of Iranian planners to different densities around stations has been different: residential density has received relatively more attention, while employment density has been neglected. As Kolko (2011) concludes, “employment density is more strongly associated with transit ridership than residential density is”. The findings of the T-Tests in this study show that the attention of transport planners has intentionally or unintentionally been on population densities, which can address trip origins, while destinations such as job locations, employment centers, etc. have gained less attention. Neglecting employment centers as well as a lack of attention to locating metro stations near the main street nodes such as the main squares and intersections are obvious in site selection of the first generation of the stations. Neglecting or disregarding employment in public transport planning runs contrary to the findings of a number of studies like Belzer et al. who recommend planners “to focus on employment patterns, clusters outside of CBDs incorporate transit, and new fixed-guideway investments”. In a more detailed regression analysis of the average densities around stations, it became clear that the general pattern of population and employment densities are the same. However, with a larger-scale look at the findings of all the tests and regression analyses, a general pattern can be concluded concerning population and employment densities.

To clarify the situation, some examples of different station generations are described here. The first example is Shahid Haghani station, which was established in 2001 to serve Vanak square in spite of a long distance of one kilometer to the square (Fig. 6). Passengers who intend to reach Vanak Square have to take a taxi or bus after they get off the metro to reach their destination. The station was opened north of the Abbas Abad hills that accommodate city-level non-residential functions, which limits the proximity of the station to residential use. As seen in Table 2, there are 39.8 inhab./ha of population density and 15.2 jobs/ha within linear walking distance of 800 meters of the station (see no. 60 in the table). These densities provide limited accessibility to the station as an origin of trips. Furthermore, the location of the station offers weak connection to the main destinations in the region exemplified by Vanak Square.

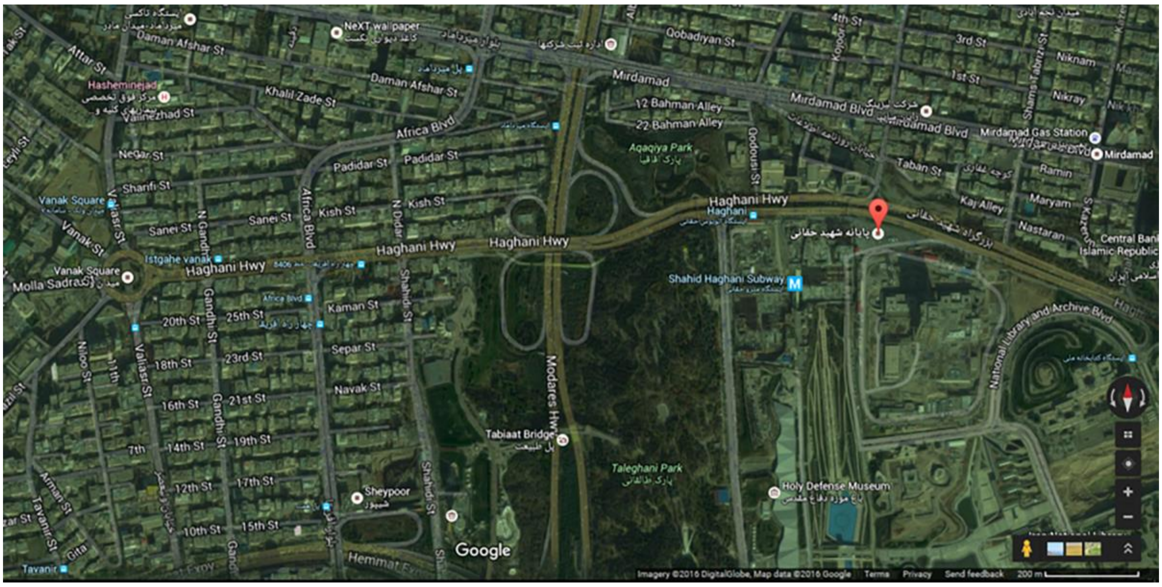

Fig. 6 Haghani metro station (on the right side) and Vanak Square (the left side of the map)

Fig. 7 Enghelab Square is one of the main nodes of Tehran, under which a metro station was established in 2009

Enghelab Square is an example of a more successful station opened between 2005 and 2015. The station is located under a main node called Enghelab Square (Fig. 7), which is surrounded by 185.1 inhab./ha of population density and 56.9 jobs/ha of employment density as shown in Table 2 (station no. 41). These figures are considerably higher than those of Haghani station in terms of connectivity to street nodes and the main intersections. Thus people can more easily reach their destinations in the city center. Nevertheless, the good attributes of Enghelab station are not inherited by many other stations, particularly the new generation of stations yet to be opened in the future.

More recent stations to get opened to operations soon are four stations, namely Shahid Mahalati, Aghdasiye, Hossein Abad, and Heravi (all located in the north and northeast of the city as seen in Fig. 1), none of which are located near major local or regional employment centers. The job densities of the above are between 8.4 to 37.8 jobs/ha, which are similar to the below-average population densities of between 20.8 and 90 inhab./ha (Table 2). Such decreasing levels of density within walking distance of stations can make the patterns seen in figures 4 and 5 more extreme, and worsen the walkability around stations.

It may be claimed that, during the first years of establishment, stations in the metro network were constructed in central areas with higher densities, followed by less dense areas closer to the periphery of the city. Two responses can be imagined for this assumption; firstly, the whole network was planned once by French consultants in the 1970s and later revised by Iranian planners. Thus, the mid-city stations were not the first planning outputs, but the stations were all planned together.

Secondly, still large areas with high residential and employment densities in the central city are not covered by the network. Therefore, there is still capacity to add stations to high-density quarters, especially those near the central business district. This is important because the city is relatively monocentric compared to several other megacities.

5 CONCLUSION

This study found significant differences in the densities within the walking distances of metro stations in Tehran. This longitudinal investigation of densities asserts neglecting the widely accepted and practiced principles of transit-friendly development. Locating new metro stations in the vicinity of populous or, even more importantly, areas with a high number of jobs is recommended. In other words, technical challenges should not be envisaged as the only planning priorities, but spatial determinants should also be a part of planning norms. This recommendation becomes more decisive when we consider that the present 170 kilometer network will extend to 430 kilometers and the current 5 lines will increase to 9 by 2028. Hence there are still quite a large number of stations to be added to the system.

There may be different reasons for the drop of densities around stations. One can be that many potential places in the central areas for planning new stations have already been taken for older stations. However, overpopulation of the city accommodating millions of people in only 730 Km² necessitates a tightly-weaved network of lines in the central areas. In other words, there is a potential for planning new stations in the very dense areas of the center.

This shortcoming raised here is in association with poor site-selection for new stations. It is also shown by this paper that the attitude of planners and decision makers has relatively leaned towards residential densities, while the new literature supports proximity of stations to job centers. This aspect of transportation planning in Tehran, namely locating stations near employment-based destinations, is a dark point.

In conducting this study it was assumed that no changes have occurred in the residential and employment density of the areas surrounding metro stations, motivated by opening the new stations. Further study is needed to prove this hypothesis with the context of Iran. As mentioned in previous sections, the effects of mobility decisions regarding commute travels on residential self-selections in Iran are weak.

ANNEX

No.	Station Name	No. of Statistical Blocks Around Stations	Date Established	Line No.	Population Density ∑pop/∑area (inhab./ha)	Employment Density ∑emp/∑area (Jobs./ha)
1	Shahid Mahalati	47	Still not opened	3	20,8	8,4
2	Aghdasiye	58	Still not opened	3	38,0	11,0
3	Hossein Abad	35	Still not opened	3	83,7	44,6
4	Heravi	90	Still not opened	3	90,0	37,8
5	Khajeh-Abdolah-Ansari	177	Still not opened	3	230,3	65,1
6	Shahid Sayad Shirazi	143	Still not opened	3	213,8	66,7
7	Shahid Ghodosi	95	Still not opened	3	107,5	27,1
8	Sohravardi	147	Still not opened	3	103,7	28,7
9	Mirzaye Shirazi	131	Still not opened	3	65,8	17,1
10	Razi	266	Still not opened	3	145,2	53,0
11	Zamzam	127	Still not opened	3	216,5	50,0
12	Ne'mat Abad	91	2015	3	161,7	38,0
13	Ghaem	16	2015	3	14,2	6,8
14	Nobonyad	64	2015	3	62,9	17,4
15	Shahid Zeyn-o-ddin	169	2015	3	152,7	41,2

16	Meydan-e Jahad	219	2015	3	222,7	62,3
17	Meydan-e Vali Asr	165	2015	3	151,1	41,2
18	Abdol Abad	179	2015	3	198,3	68,2
19	Shahrak-e Shari'ati	181	2015	3	115,0	27,6
20	Qal'eh Morghi	278	2014	3	190,1	44,1
21	Moniriyeh	172	2014	3	152,5	49,6
22	Rahahan	165	2014	3	42,6	128,5
23	Javadiyeh	280	2014	3	111,0	27,5
24	Azadegan	20	2013	3	74,6	18,5
25	Nirooye Havaei	186	2012	4	268,8	73,0
26	Tajrish	110	2012	1	110,6	30,6
27	Sheykh-o-raeis	308	2011	4	140,4	38,7
28	Doctor Habib-o-llah	136	2011	4	259,7	72,0
29	Ostad Moein	100	2011	4	28,9	7,8
30	Shahid Sadr	139	2011	1	93,5	28,5
31	Towhid	183	2011	4	266,7	79,7
32	Piroozi	259	2010	4	138,2	38,0
33	Shahid Kolahdooz	118	2010	4	254,4	67,5
34	Nabard	243	2010	4	150,9	41,2
35	Farhangsara	3	2010	2	251,0	69,9
36	Gheytariyeh	120	2010	1	103,0	28,4
37	Theatre-e Shahr	134	2010	3 & 4	123,0	35,5
38	Meydan-e Shohada	225	2009	4	242,2	66,4
39	Gholhak	167	2009	1	192,7	16,8
40	Doctor Shari'ati	159	2009	1	160,5	44,5
41	Meydan-e Enghelab-e Eslami	192	2009	4	185,1	56,9
42	Mirdamad	120	2009	1	99,0	31,0
43	Shahid Bagheri	133	2008	2	174,5	46,4
44	Tehranpars	124	2008	2	178,7	49,9
45	Ferdowsi	132	2007	4	68,6	60,9
46	Ekbatan (Eram-e Sabz)	40	2007	4	30,4	8,2
47	Varzeshgah-e Azadi	34	2007	5	21,3	7,1
48	Darvazeh Shemiran	192	2006	2 & 4	187,4	97,2
49	Imam Hossein	221	2006	2	253,5	76,0
50	Sabalan	318	2006	2	557,3	149,6
51	Fadak	195	2006	2	422,9	112,1
52	Golbarg	195	2006	2	307,2	84,0
53	Shahid Madani	259	2005	2	178,2	50,6
54	Sarsabz	191	2005	2	327,8	91,7
55	Elm-o-Sanat University	138	2005	2	228,0	62,0
56	Mellat	140	2003	2	33,5	81,7
57	Baharestan	160	2003	2	85,5	96,5
58	Javanmard-e-Ghassab	181	2002	1	154,4	38,4

59	Shahr-e-Rey	141	2001	1	137,7	34,4
60	Shahid Haghani	55	2001	1	39,8	15,2
61	Shahid Hemmat	4	2001	1	5,0	4,5
62	Mosalla	50	2001	1	21,3	5,7
63	Shahid Beheshti	117	2001	1 & 3	73,2	19,1
64	Shahid Mofatteh	191	2001	1	103,7	27,5
65	Haft-e-Tir	217	2001	1	214,2	60,9
66	Taleghani	147	2001	1	147,5	63,1
67	Darvazeh Dowlat	156	2001	1 & 4	88,1	97,7
68	Saadi	145	2001	1	27,7	93,8
69	15th of Khordad (Panzdah-e-Khordad)	163	2001	1	28,8	90,2
70	Khayam	214	2001	1	40,5	143,0
71	Molavi	233	2001	1	55,3	201,0
72	Shush	111	2001	1	27,6	54,5
73	South Terminal	76	2001	1	51,6	12,7
74	Khazaneh	293	2001	1	355,8	88,7
75	Ali Abad	263	2001	1	280,8	69,5
76	Imam Khomeini	116	2000	1 & 2	16,5	56,2
77	Daneshgah-e Emam Ali	139	2000	2	170,2	57,8
78	Tarasht	90	1999	2	225,3	59,5
79	Daneshgah-e Sharif	78	1999	2	193,2	53,8
80	Shademan	179	1999	2 & 4	294,7	84,0
81	Shahid Navvab-e Safavi	231	1999	2	362,9	119,1
82	Meydan-e Horr	158	1999	2	233,5	81,3
83	Hasan Abad	138	1999	2	130,7	68,2
84	Tehran (Sadeghiyeh)	70	1998	2 & 5	206,3	55,7

Tab.5 Detailed data of 84 metro stations including their pedestrian shed density

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IMAGE SOURCES

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Fig. 5: Via Google Maps.

Fig. 6: By Houshmand Masoumi.

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FROM RAIL-ORIENTED TO AUTOMOBILE-ORIENTED URBAN DEVELOPMENT AND BACK

100 YEARS OF PARADIGM CHANGE AND TRANSPORT POLICY IN BERLIN

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ABSTRACT

Transport and its side effects are major problems in rapidly growing cities. Car traffic dominates these cities and pollutes the environment without being able to sufficiently secure the mobility of the urban population and goods. A paradigm shift in urban and transport policy will be necessary to change this situation. In spite of its different development dynamics, Berlin is an interesting example to discuss development strategies for rapidly growing cities because in the course of more than 100 years, a twofold paradigm shift has occurred in the city both conceptually and practically: Berlin has shifted from a city dominated by rail traffic to an automobile-oriented city, and has then gradually transformed back into a city in which an intertwined system of public and non-motorized individual means of transport secures the mobility of the urban population. The interdependencies on the conceptual level between urban planning and transport policies as well as on a practical level between urban structures and transport systems can be studied using the example of Berlin. Experiences with the implementation of automobile-oriented planning and the special conditions in the first decade after reunification led to protests, reflection, and a revision of the transport policy. A strategically designed process of integrated planning has brought about a trend reversal, and steered the development of transport in the direction of clearly formulated sustainability-oriented objectives. In this process, the reintegration of transport and spatial planning and a reorganization of institutional structures at the administrative level was of particular importance. Compact, rail-oriented settlement structures like in the metropolitan region of Berlin make it easier to dispense with automobiles than sprawled structures. The residual role that qualitatively improved automobiles will take in the cities of the future will have to be determined by research and practice. What is certain is that an attractive public transport system should form the backbone of urban transport services.

KEYWORDS
Transport management, urban transportation history, transportation and land use, public transportation, Berlin

1 INTRODUCTION: THE BERLIN EXAMPLE

The states of traffic in the rapidly-growing cities of emerging economies are strikingly similar: Be it in Lagos, Tehran, Cairo, Beijing, or Sao Paolo - cars clog up the city, including freeways, streets, and squares. Public transport systems exist, but they are caught up in traffic jams, are pushed into the ground and cannot keep up with the rapid growth of the city.

The downside of individual traffic-driven urbanization are the mega-jams that occur in a permanent and unwinnable race between the construction of new freeways and further increasing motorization. Air and noise pollution are far beyond levels that are harmful to health and economic activity, and for pedestrians and cyclists, public streets and squares are often only available at the risk of one's life. Under the car-oriented transportation system, not only does the quality of cities, as a habitat for many millions of people, suffer severely, but also the mobility of large groups of people is restricted: an alternative to personal car use is often missing in suburbs and urban peripheries, and people without automobiles are "prisoners" of public transport or depend on the often inadequate offers of the informal transport sector, especially if they are disabled, which hinders their participation in city life. Nowadays, work and education often require mobility over large distances.

The outlined problems and the growing understanding of the interrelatedness between petroleum combustion and climate change, between motorization, suburbanization and mobility deficits, and the finite nature of fossil fuel reservoirs have brought about a rethink at least among experts and international organizations that has been under way for some time (Habitat III, 2015). Moreover, interesting examples of redirections of the urban and transport policy can be seen in all parts of the world, although they are still exceptions in a "mainstream" characterized by automobile dominance. Calling for a clear change in policy is easier than implementing it.

What is needed, however, is a paradigm shift from a policy that merely responds to demands driven by the increasing number of cars to a policy that actively seeks to influence the type of traffic that is demanded. One of the most important approaches to do so is a city development strategy focused primarily on public transport and including the supplementing pedestrian and bicycle traffic ("Transit-Oriented Development"). A prioritization of these modes of transport means placing the theme of accessibility on the center stage of planning, rethinking land uses and distances, which also requires tight cooperation and interaction between urban planning and transport planning.

What insights can a review of the developments in Berlin contribute to this topic? Compared to the major cities in Asia, Latin America and Africa, the German capital with about 4.3 million inhabitants in the metropolitan area is only a medium-sized city, currently growing by approximately 50 000 inhabitants per year, and the economic and institutional conditions of the urban and transport development are also hardly comparable. Berlin is interesting as a city that exemplifies the reciprocal influences of spatial urban development and traffic system development over a period of more than 100 years since the times of industrialization. Berlin not only invented and put to use means of mass transport, but also experienced the traffic effects of different urban concepts (and urban visions).

The destruction of the Second World War and the long-standing division of the city were the backdrop of the extensive experiments with new concepts for town and transport planning. In spite of a comparatively smaller role of the automobile in the "capital of the GDR" compared to West Berlin, the administrations of both parts of the city maintained the plan of a shared main road network for the entire city on the basis of the early post-war plans[1]. Since about the turn of the millennium, Berlin has tried to bring forth the paradigm shift to sustainable urban- and transport policy, including the approach of Transit-Oriented

[1] Official consultations at the administrative level have been documented even or the "Cold War"-period (Kalender 2012, p.408)

Development. The experiences and the lessons that can be drawn from the developments in Berlin are likely to be of interest also for the major cities of the global south.

2 URBAN AND TRANSPORT DEVELOPMENT IN BERLIN IN THE ERA OF CHANGE IN TRAFFIC SYSTEMS AND MODELS

2.1 THE "GOLDEN AGE" FOR PUBLIC TRANSPORTATION: FROM THE BEGINNING OF INDUSTRIALIZATION UNTIL THE FIRST WORLD WAR

Transport within cities has played a role in Europe only since around 200 years ago, because only then cities (as a result of the proliferation of carriages and carts) started to exceed the dimension of walking distances (the main reference of this section are Kutter, 2005 and 2015). Until the nineteenth century, Berlin was a mid-sized residential city with a very limited urban area. This changed rapidly with the development of the industrial city. Between 1870 and 1920, the city population increased from around 0.8 to 3.8 million inhabitants, spread in a diameter of approximately 35km. This was made possible by the introduction of largely rail-based means of mass transport: first the tram (and bus), then the subway and the electric "commuter rail" (later "S-Bahn"). The emerging spatial zoning of the city into residential areas and industrial areas resulted in larger distances between homes and jobs, which could only be overcome by new public transport systems. On the other hand, the establishment of such infrastructure was the prerequisite of any urban expansion, since public transportation over long distances virtually had a monopoly. In a surprisingly short time, a comprehensive and tightly-knit network of trams, a wider-meshed network of subway lines and a radial S-Bahn system were created in Berlin to connect the city and surrounding areas. The city expansion and its spatial structure were defined by the availability of public transport infrastructure. Today, the star-shaped regional settlement pattern along the S-Bahn axes, which essentially originated at the beginning of the last century, can still clearly be seen (Fig. 1).

Fig. 1 Metropolitan settlement star 2016: radial railway network characterizes the settlement structure

In a sense, this created a balance between the built structure and the system of public transport in the beginning of the 20th century, a state which is today occasionally seen as a vision for integrating settlements and traffic development under the name of TOD concept. This state is built, however, on the premise of a monopoly of public transport, which is no longer available in its old form.

2.2 EMERGENCE AND DOMINANCE OF MOTORIZED INDIVIDUAL TRANSPORT: FROM THE BEGINNING OF THE 20TH CENTURY TO THE POST-WAR PERIOD

There were two different causes leading to radical changes during the next decades, which reinforced and supported each other: The first lies in a revolutionary change of the guiding principles of urban planning. The experience of living conditions of the "Wilhelminian times" in speculatively built, highly compressed and unhealthy neighborhoods in Berlin (and similar in many European industrial cities) led to the concept of much less dense and less mixed-function urban structures, loosened by green spaces. The new planning paradigm culminated in the "Athens Charter" of 1933, an urban manifest with universal ambition and impact. A significant urban expansion, and thus the increase in movements and distances was inevitably connected with these new planning principles.

After the First World War and the large housing shortage in Berlin, the new model with large residential settlement projects was implemented mainly in urban peripheral areas (Fig. 2).

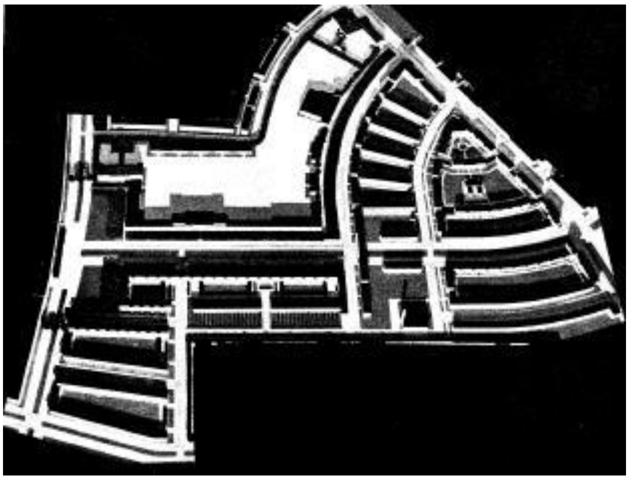

Fig. 2 Famous "White City" in Berlin- Reinickendorf: typical settlement from the 1920s (housing monostructure, low density, green spaces)

The second cause was the first gradual, in the 1920s progressive development of motorized individual transport in Berlin. It is very interesting that this development was anticipated by urban planners already when it was still difficult to foresee the future importance of the automobile. In the competition for the development of concepts for the Metropolitan growth area "Greater Berlin", a large-scale ring and radial road network was designed already in 1910 with expressways and arterial roads and even urban road breakthroughs (still predominantly for the horse and cart movement). These conceptual basic elements have been repeatedly taken up, extended, and perfected in many of the later plans[2]. Then, in the "Weimar period", after the First World War, the car experienced its first big boost. The to date most advanced transport technology promised the reduction of mobility constraints to a previously unknown extent by

2 The winning concept of the competition "Greater Berlin" by Jansen followed street-oriented concepts in the "Straßenausbauplan (road expansion plan)" 1927, in the "Generalbebauungsplan (general building plan) by Speer 1943, in the "Zehlendorf Plan" 1946, in the "Plan Berlin 1948", the "Flächennutzungsplan (land use plan)" of 1950, and the "Generalstraßenplan (general road network plan)""1965 (Kalender, 2012).

enabling individual mobility and freedom of accessibility, and spurred the imagination not only of urban and transport planners (Fig. 3). After a visit to the United States in 1924, the head of the department of transport of the Berlin police headquarters encouraged the Berlin traffic "to Americanize and to displace the tram from the center" (Wilhelm Mosle, cited in Kalender, 2012). Eighteen main arterial roads, connected through three rings and other measures are proposed in the plans of the "Haupttiefbauverwaltung" (central civil engineering department) of 1927, which were intended to increase the efficiency of road traffic (Fig. 4). With respect to their fundamental orientation, urban planners differed only very little from traffic engineers, a discipline that emerged at this time. The famous city planner, Martin Wagner, developed the first concepts in 1929 using the U.S. examples for inner-city elevated roads, which planners continued to use for decades [3] (Fig. 5).

Fig. 3 City of the future ("rush hour")

The first development plans after the serious damage wrought by the Second World War in Berlin were designed under the impression of the urban concept of "modernity" following the ideas of the Athens charter and entailed a complete reorganization of the city, with a floating network of urban motorways. Public transportation played a very minor role in the planning. Later more pragmatic plans were supported with regard to respecting the still-existing city structure, but the intended transport system still followed the idea of a downright radical infrastructure construction for the (not yet existing!) car traffic: the first land use plan from 1950 foresaw 100 km of grade-separated "rapid streets" and 300 km of "main streets" for the city. Interestingly, the plans were justified with reference to urban planning-arguments ("adjustment of the metropolitan transport network on the insights of modern city construction" (Architektengemeinschaft Tepez/Hunnecke/Block, cited in Kalender 2012 p. 350). Despite the political division of the city after the Second World War, the idea of a network of radial and ring highways was maintained in both parts of the city in the decades following the war. In spite of the different societal systems, the transport policy stance in both East and West was based on the principles of modernity, resulting in quite comparable outputs. However, due to the more abundant financial resources, the plans were implemented to a larger extent in the Western part of the city. Until today, the network of main roads in the Eastern part of Berlin is

3 "It is today already foreseen that, like other world cities, we should have second traffic floors for fast moving cars […] we have to succeed to, where possible, build grade-separated road crossings on the important traffic points." (Martin Wagner, 1929, cited in Kalender, 2012, pp. 211).

characterized by strong radial highways and weaker tangents. A beltway to bypass the inner city exists only in the Western part. Also the planned expansion of the underground network got stuck in the East, where instead the tramway system was preserved. The division of the city and the walling of West Berlin prevented mass motorization driven by city expansion and suburbanization of the peripheral areas, as was observed in other West German cities in the second half of the century.

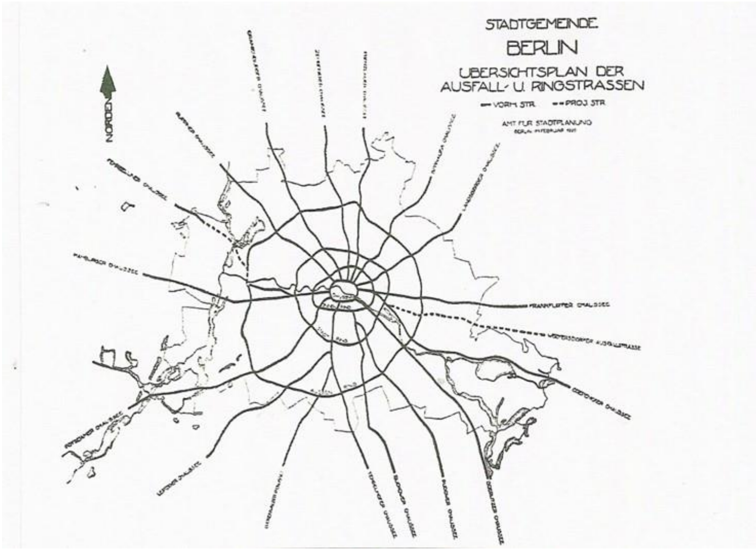

Fig. 4 Schematic road network plan, Berlin city planning office 1929

Fig. 5 Planned urban freeway intersection in central district Kreuzberg, land use plan 1965 (later abandoned)

It is worth emphasizing that in the described development phase, the original balance of the city structure and public transport was radically replaced by a prioritization of individual mobility (in the sense of the mission statement of "car-friendly city"). For the former West Berlin, one can conclude without reservation that the guiding principle of planning was no longer the quality of access by public transport, but the accessibility by the individual automobile. Planning methods and standards imported from the United States and an increasing autonomy of traffic engineering led to a progressive disintegration of urban and transport planning. In the 60s, even the large housing estate (such as the "Märkisches Viertel") were built without any rail connection.

In East Berlin, individual motorization was lower than in the Western part, and public transport retained greater significance. Nevertheless, also the urban expansions at the eastern outskirts of the city followed the paradigm of a "car-friendly city" with ample space allocated to individual car transport, until the end of the GDR.

2.3 RE-ORIENTATION OF THE TRANSPORT POLICY WITHOUT STRATEGY: THE POST-REUNIFICATION PERIOD FROM 1990 TO 2000

The student riots of the 1960s and 1970s in West Berlin were partly caused by the planning and transport policy of the city government as the students opposed a controversial highway project through the inner city and the destruction of housing. Only in 1981, after elections had brought about a change of government, was the plan to build an urban motorway that would have touched the Western part of the city center abandoned. Also in other parts of West-Germany, the "car-friendly city"-paradigm had increasingly come under fire towards the end of the last century. In response, the last revision of the West Berlin land use plan of 1987 entailed the cancellation of 300 km of additional major roads of the 1965 plan.

The city-wide planning after the fall of the Wall put a clear emphasis on not only restoration and modernization, but also further expansion of public transport rail systems (tram, underground, suburban rail, and regional rail). A large budget was invested in the implementation of this plan in the years to come. In addition, the often interrupted road network was linked again and modernized, albeit without significant capacity-increasing street constructions. Against the background of an expected major growth of the city and its surrounding, the early vision of a public transport-oriented urban (and regional) development was revisited: The stated goal was to shift the modal split significantly in favor of public transport, mainly by directing the settlement growth in the city and the surrounding communities towards the main axes of public transport. However, in the first decade after unification, the efforts to translate this postulated transport policy objective at the urban and regional scale into integrated strategies and concepts were not very successful. A major obstacle was that it took some years to establish new institutions in the unified Berlin and Brandenburg (surrounding Berlin) and its smaller municipalities and communities.

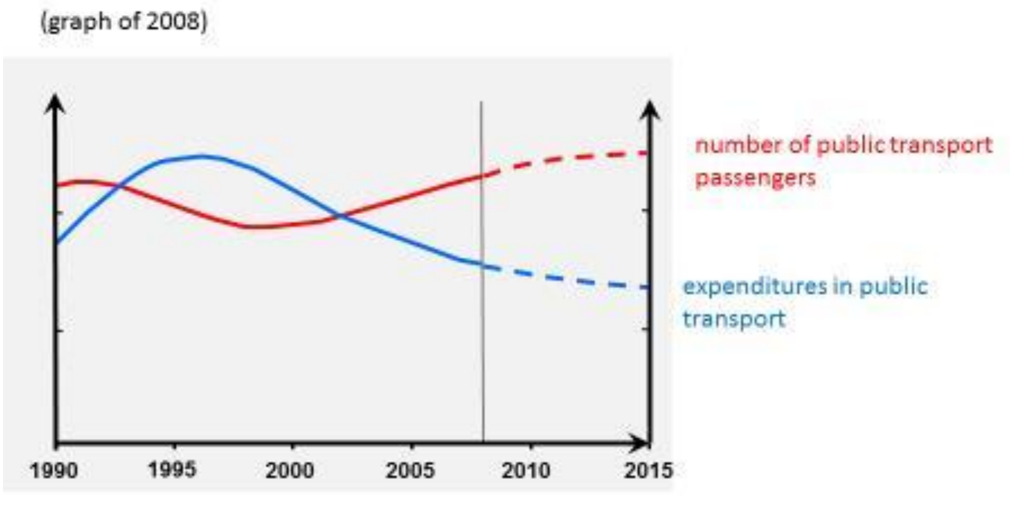

Fig. 6 Investment in public transport and transport demand (decade after reunification)

Taking stock after 10 years the results were sobering when compared to the stated objectives: Despite massive investments in the public transport system, public transit use had decreased significantly (Fig. 6), car mobility and at the same time traffic jams and the problems associated with the traffic (congestion, accidents, air pollution, noise) had increased. Quality of life in the affected districts had become worse, which resulted in declining attractiveness. How could this happen? The most important reason was rapid "catching-up-motorization" in the former East Berlin and the surrounding communities to the level of the former West German communities, thereby enabling or facilitating migration of those Berliners interested in self-development into the neighborhoods not covered by public transport but enjoying low land prices. These conditions forced car-oriented lifestyles.

Because overarching regional planning and controlling institutions were largely missing in the first years, such suburbanization was not initially slowed down. But also within Berlin, measures to reduce an important incentive to the use of cars in the city center were lacking. A generous supply of free public parking and many new parking lots in private parking blocks and underground garages had encouraged private automobile use for trips to the city center.

2.4 START OF STRATEGICALLY-BASED AND INTEGRATED SPATIAL AND TRAFFIC DEVELOPMENT AFTER 2000

In the year 2000, regional elections resulted in a government change that was accompanied by a change in organization of the senate departments (Berlin state ministries). A crucial prerequisite for a better coordination and integration of urban, transport (and environmental planning) was the institutional integration of previously separate departments. The merging of urban planning and transport has remained since then.

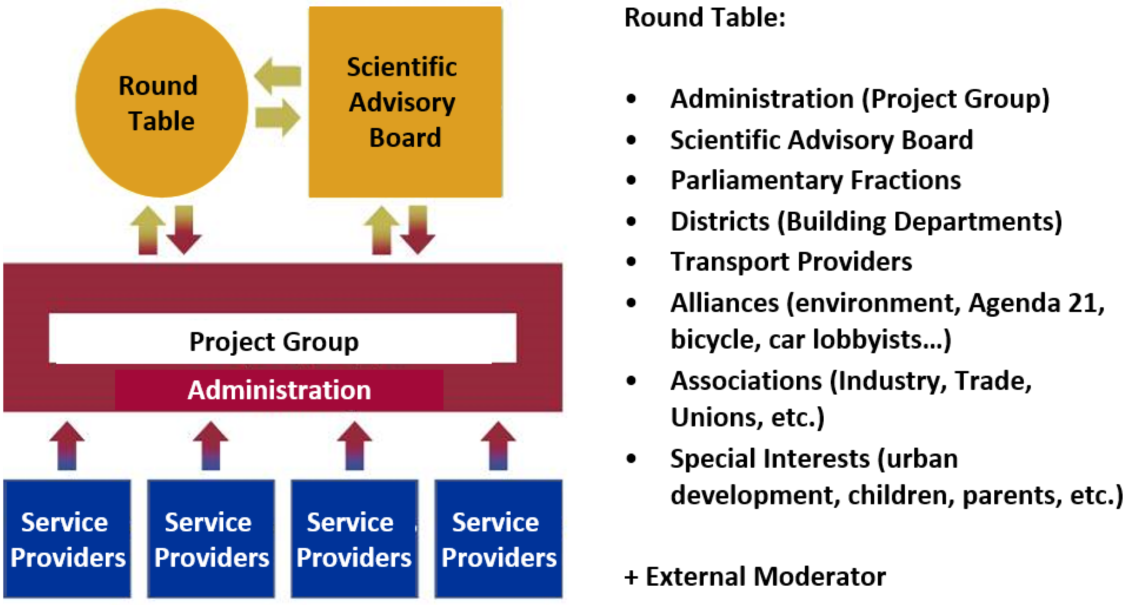

Fig. 7 Comprehensive urban transport strategy: consultative working process

Against the background of the clear failure to achieve the set urban policy objectives in the first decade after reunification, the new city government called on the administration to develop an integrated transport strategy, to be put up for discussion. This assignment was carried out over a period of approximately two years, and the plan was approved in 2003. Since then, the so-called "urban development plan for transport" has been implemented and its effects and the achievement of objectives observed and evaluated. In 2011, a first revision and adjustment on the level of important measures was carried out[4], and currently the strong population growth of recent years is a reason for a further revision of the plan.

The key reason that the plan has now been effective over a longer period of time as the fundamental strategy of integrated transport policy is that the process of planning is broad and consultative, that is, it is organized with the involvement of the important transport policy actors and stakeholders in the city (Fig. 7). Transport policy requires a high degree of continuity due to the duration of maturation of many measures from conception to implementation. To ensure this continuity, a comprehensive analysis of the causes of the failure of previous plans and of the expected framework of planning, including the financial resources expected to be available, preceded the planning (Kunst, 2007).

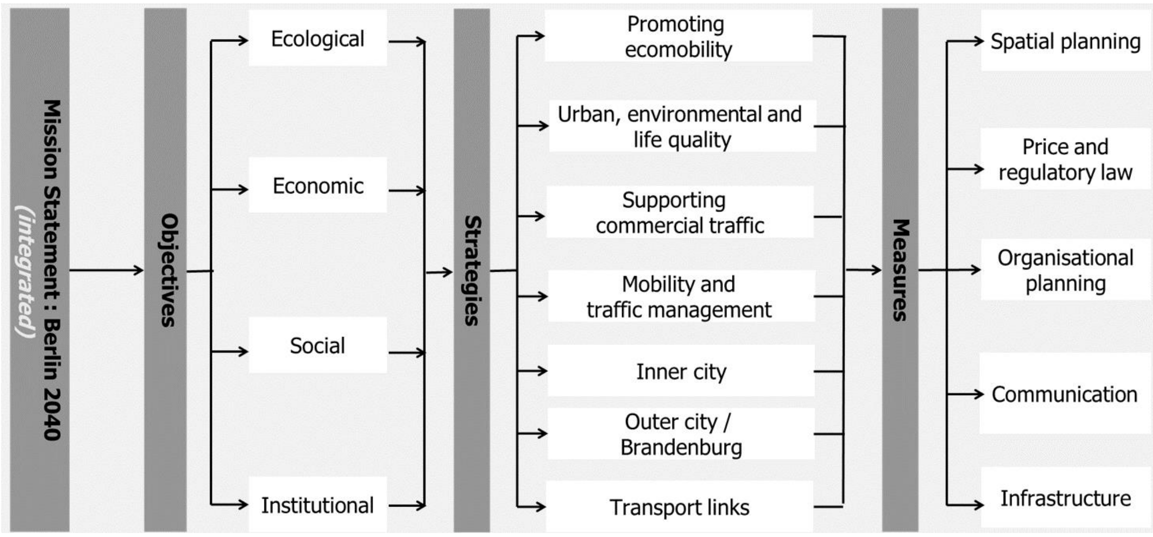

Fig. 8 System diagram of urban transport strategy: from vision to measures

The main planning objectives have been formulated as: Assurance of mobility for all groups in the population (and the economy) while at the same time limiting transport growth, prioritization of public transport and the "basic mobility" on foot and by bicycle, and a substantial relief of the urban environment from the impacts of transport. The differentiated objectives represent the spectrum of "sustainability" and were as far as possible backed up by specific values for the intended targets in order to allow for a clear feedback on whether or not the goals have been reached. The concept itself consists of a network of more than 100 measures from various different fields of action. It was important not only to include the traditional measures of transport infrastructure development, but also to take into account cross relations with urban planning through measures aimed at reducing the creation of traffic. Moreover, measures aimed at supporting public transportation were consistently linked to measures limiting the individual car use (in particular through parking policy). To facilitate comprehensibility and application, the overall strategy was divided into thematically distinct sub-strategies (Fig. 8). Alternative versions of the overall concept underwent an ex-ante effect analysis by means of a model-based analysis, and the most effective combination of measures was ultimately selected.

[4] In this context, it is worth mentioning that the greatest conflict in the Senate's revision was the intention to extend the Western bypass highway into the East in order to relieve the inner city of congestion. The decision in favor of the project would almost have broken the governing coalition.

Fig. 9 System of public transport: integrated rail networks in Berlin in 2015 (tram replaced by bus in Western part after World War II)

Repeated analyses of ex-post effects since 2003 show that a clear trend reversal compared to the traffic and settlement development of the first decade after reunification has been reached. Considering the modal split values at the times of representative household surveys in 1998 and 2013, the share of individual car use in the total volume of trips in the city has decreased by more than 10%; this has been made possible by a growth in the modal share of public transport, pedestrian and bike travels. Altogether, today 70% of all urban trips are done by transport modes of the "environmental combination". Despite a significant population increase, and as a result, transport growth in recent years, the share of car traffic has decreased further. The current target is to enhance the environmental modes of transport so as to limit the share of personal car use to 25% within the next few years. The public transport system consists of five different but integrated networks of public transport modes (Fig. 9.). By fulfilling high standards of accessibility and service quality, the mobility of the Berlin population can be secured without private cars. Promotion of multi- and intermodality plays an important role, i.e. fostering the combination of the different means of public transport and the "active", non-motorized modes, as well as carsharing. This could expand the reach of rail-based transport and also further increase the freedom of choice among different means of transport.

3 CONCLUSION: FINDINGS FROM BERLIN FOR POST-FOSSIL MOBILITY STRATEGIES

A first and important insight is that the change from car-oriented urban development to a development based on sustainable transportation can succeed. It should be mentioned that the heritage of rail orientation of Berlin's development, reflected in the settlement structure, has undoubtedly facilitated the renewed attention to public transport. Destruction of large parts of the city as a result of the war, the reconstruction in the spirit of a new paradigm of urban planning and the long lasting division of the city did not wipe out the city's rail-oriented heritage. Cities that that have grown as car-oriented cities are much more difficult to reorganize for a public transport development. The second limitation is the duration of the re-orientation process: From the onset of criticism of the "car-friendly city" until a clear policy change, several decades had to go by in Berlin. The learning process took much time and has not yet been completed.

What were the main causes for the (relative) success? I would like to mention the following factors, each of which is important on its own, but which create additional dynamics when working together:

- Firstly, the substantive coordination of settlement and transport development in the city and region by means of coordinated planning and controlling of the implementation of such plans: Despite some shortcomings in implementation, the realization has grown that urban planning is an important factor in traffic generation and the choice of transport mode.
- Secondly, a good public transport system that combines different (in Berlin five) sub-systems with varying efficiency, power, speed, and line network density. The remaining deficits in access can be reduced (and the catchment area increased) by encouraging, in particular, bicycle use. Crucial are high standards in the quality of public transport service and an integrated ticket tariff, giving easy access to all parts of the public transport system
- Thirdly, coordination and integration of transport-effective measures of various types over an extended period of time: Traditional infrastructure for public transport is not enough as long as the topic of parking in the city is not addressed. Traffic management measures must support the quality of bus traffic. Easily accessible and up to date information about the current traffic situation in the city and public transport offers is a prerequisite for the optimization of individual transport modes.
- Fourthly, an appropriate institutional framework: The above-mentioned cooperation in the metropolitan area bridging the regional boundaries was considerably facilitated by the existence of the "joint regional planning agency", a joint authority formed by the states of Berlin and Brandenburg. Moreover, it was a particularly important requirement for development and implementation of an integrated transport strategy in the city to have an institutional integration of the authorities responsible for spatial and transport planning.
- And finally, a clear political will for changing the orientation of urban development and the related transport policy, which of course is in an interplay with the political acceptance of a modified transport policy in the public. In Berlin and other big cities in Germany, a trend of decreasing car dependency, especially in younger people has been visible for several years (Kuhnimhof et al. 2011). The automobile begins to lose its appeal as a status symbol and an "end in itself". To be able to use a car remains important also within a concept of multimodal transport and owning a car does not. These altered perspectives may still characterize only a minority of the urban population, but a minority with political clout: opinionated functional elites with influence on the political representatives of the city.

Berlin has taken a long step towards a public transport-oriented transport policy. In passenger transportation, it is quite possible to live in the city without possessing a car. Nevertheless, the city is still far from reaching the goal of a "post-fossil mobility" and "carbon-free transport". Evidently, the state of a broad monopoly of public transport as in the era of industrialization cannot be restored. The automobile will continue to play a major role in the cities. For the inner city's commercial and freight traffic, the car will remain largely indispensable in the future. In the periphery of Berlin and the edges of the metropolitan region, the quality of the available public transport cannot fully compete with individual cars, despite the efforts for planning a more compact and rail axis-oriented settlement. Consequently, the traffic patterns of the inhabitants are still more oriented towards personal car use.

The technological development of the automobile with new engines, more environmentally-friendly fuels, and modern telematics will alleviate some of the major current issues of urban transportation, and will contribute to maintaining a role for cars in the future urban transport. It is, however, not yet clear what role that will be precisely (Kunst, 2014). If the goal is to further replace the automobile in German cities by other modes of transport, a broader policy and behavior change and additional changes to the institutional framework (particularly the tax and land law) will be necessary in order to transform the space and to remodel settlement structures, allowing for a traffic-reduced future.

What is certain, however, is that due to its city-incompatible land consumption, the automobile should only play a very special (and minor) role in the future of fast-growing mega cities if these cities are to be organized efficiently and the goal is to make them attractive as a habitat. Only an attractive public transport system will be able to ensure the mobility of all groups of population.

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IMAGE SOURCES

Picture on the cover page: Author.

Fig. 1: Author.

Fig. 2: Das Neue Berlin: Großstadtprobleme, M.Wagner, A.Behne editors, reprint of 1929 edition, Birkhäuser Verlag Basel, Berlin, Boston 1988.

Fig. 3: By Alexander Leydenfrost (1949), archive oft the author.

Fig. 4: Kalender, 2012.

Fig. 5: Köhler et al. 2015.

Fig. 6: Author.

Fig. 7: Author.

Fig. 8: Senate department for urban development and the environment.

Fig. 9: Author.

AUTHOR'S PROFILE

Dr. Friedemann Kunst is working as a private consultant for municipalities and international organizations. Until his retirement in 2013, he was head of the department of transport and traffic within the Senate ministry of urban development. He was responsible for planning and the operation of the integrated transport system in the German capital. Friedemann Kunst has studied architecture in Stuttgart and urban and transport planning in Berlin. He is a member of the German Academy for Urban Design and Regional Planning.

GERMAN ABSTRACT

Verkehr und die Folgen des Verkehrs sind eines der großen Probleme schnell wachsender Metropolen. Der Autoverkehr beherrscht die Städte und belastet die Umwelt, ohne ausreichend die Mobilität der Stadtbevölkerung und der Güter sichern zu können. Nur ein Paradigmenwechsel in der Stadt- und Verkehrspolitik ist geeignet, diese Verhältnisse zu verändern. Trotz seiner Lage in Europa und seiner nicht vergleichbaren Entwicklungsdynamik, ist Berlin zur Diskussion von Entwicklungsstrategien für schnell wachsende Metropolen interessant, weil dort im Laufe von etwas mehr als 100 Jahren konzeptionell und praktisch ein zweifacher Paradigmenwechsel vollzogen worden ist: zunächst von einer fast ausschließlich durch den Schienen-ÖPNV geprägten Stadt zu einer automobilorientierten Stadt und dann schrittweise zurück zu einer Stadt, in der die Verkehrsmittel des „Umweltverbundes" die Mobilität der Stadtbevölkerung sichern. Sowohl die Wechselwirkungen auf der konzeptionellen Ebene der städtebaulichen und verkehrlichen Leitbilder, als auch auf der realen Ebene zwischen Stadtstrukturen und Verkehrssystemen können in Berlin exemplarisch studiert werden. Erfahrungen mit der Umsetzung automobilorientierter Planung und besondere Entwicklungsbedingungen in der ersten Dekade nach der Wiedervereinigung haben zu Protesten, zur Reflexion und zu einer Revision der Planung geführt. Mit einem strategisch angelegten Prozess integrativer Planung ist es gelungen, Trends der Verkehrsentwicklung im Sinne der formulierten Nachhaltigkeits-Ziele umzukehren. Eine besondere Bedeutung hatte die Reintegration von verkehrlicher und räumlicher Planung und die Neuordnung institutioneller Strukturen auf Ebene der Verwaltung als Voraussetzung besserer Kooperation. Der Reorganisationsaufwand, der erforderlich ist, um eine metropolitane Siedlungsstruktur verkehrsärmer und ÖPNV-affiner zu gestalten, ist abhängig von der jeweiligen Ausgangslage. Kompakte, schienenorientierte Siedlungsstrukturen ermöglichen eine stärkere Zurückdrängung des Automobils als disperse Strukturen. Welche residuale Rolle qualitativ veränderte Automobile künftig in Metropolen übernehmen, ist noch in Forschung und Praxis zu klären. Sicher ist jedoch, dass ein attraktives ÖPNV-System das Rückgrat des städtischen Verkehrsangebotes bilden muss.

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CHALLENGES OF TRANSIT ORIENTED DEVELOPMENT (TOD) IN IRAN

THE NEED FOR A PARADIGM SHIFT

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ABSTRACT

Transit oriented development (TOD) has gained popularity as a means to address urbanization problems such as traffic congestion, air pollution and affordable housing strategies. It simply refers to integration of urban development and public transportation facilities, together with some other characteristics such as “intensified land uses near TOD stations”, “landownership and car-ownership variety”, mixed use, “lower car dependency”, compact form, mass transit stations, open spaces, walkability, etc.
The major contention of this paper is to discuss the general concept of TOD, its benefits and challenges in Iranian urban context. It is discussed here that TOD has several positive outcomes considering the existing urbanization trends in Iran. It may be used as a practical instrument to deal with a rapidly urbanizing country in which the motorization rate is increasing and air pollution is a serious cause of human loss of life. However there are several challenges to be faced. The need for an Iranian version of TOD, which re-visits the theory according to local situations, is the first challenge. A paradigm shift in the government, shifting the priority from housing schemes to mass transit systems is the second challenge needed to be taken into consideration. The third challenge is the overlapping and parallel institutions dealing with mass transit systems in urban and regional transportation planning and insufficient planning instruments. The integrated transportation and urban planning system is necessary here, and there is an urgent need to develop national TOD guidelines with the potential to develop local versions for each city.

KEYWORDS
Transit oriented development, Iran, challenges, paradigm shift

1 INTRODUCTION

Transit oriented development (TOD) has gained popularity as a means to address urbanization problems such as traffic congestion, air pollution and affordable housing strategies. It simply refers to integration of urban development and public transportation facilities, together with some other characteristics such as "intensified land uses near TOD stations", "landownership and car-ownership variety", mixed use, "lower car dependency", compact form, mass transit stations, open spaces, walkability, etc.

Rapid urbanization in Iran coupled with socio-economic changes in recent decades and the apparent need to improve public transportation system has caused strategic shifts from housing construction to improvements in public transportation facilities. As one of the approaches for enhancing urban life quality, TOD has recently gained importance thanks to the Iranian government. The major contention of this paper is to discuss the general concept of TOD, its benefits and challenges in the Iranian urban context. It is divided into three parts: in the first part a brief literature review on TOD and its common characteristics will be introduced, in the second part, the positive outcomes of TOD to solve the problems of rapid urbanization and socio-economic changes in Iran will be discussed; and in the third part, the challenges to realize TOD in Iranian cities will be introduced.

2 WHAT IS TOD? A BRIEF LITERATURE REVIEW

A very rich and extensive literature is available on TOD. The term has been most often associated with North American urban planners and originates from concepts such as new urbanism, smart growth, infill development and affordable housing (Ratner & Goetz, 2013).

However, there are strong arguments referring to its origins in the ideas behind the development of streetcars, underground and commuter railway routes and urban forms, dating back more than a century to a period which predated private car ownership (Pojani & Stead, 2014; Knowles, 2012).TOD generally raises the concept of more intensified development near mass transit stations. Calthorpe has defined the concept as: "A mixed-use community within a typical 2000 feet (around 600 meters) walking distance of a transit stop, and core commercial area" (Calthorpe Associates, 1992). The term generally refers to the process of focusing compact, pedestrian and cycle-friendly urban development with public and civic spaces together with housing and activity sites; around existing or new transit stations (Pojani & Stead, 2014; Knowles, 2012; Chisholm, 2002). The design, configuration and mix of uses emphasize a pedestrian-oriented environment and reinforce the use of public transportation, rather than the private automobile (Calthorpe Associates, 1992; Atkinson-Palombo & Kuby, 2011).

In an official document published by the "Institute for transportation and development policy 9ITDO" the following eight key principles were introduced to guide the development of TODs (ITDP, 2014): 1)Walk: develop neighborhoods that promote walking, 2)Cycle: prioritize non-motorized transport networks, 3) Connect: create dense networks of streets and paths,4)Transit: locate development near high-quality public transport, 5)Mix: plan for mixed use, 6)Densify: optimize density and transit capacity,7) Compact: create regions with short commutes, and 8) Shift: increase mobility by regulating parking and road use.

TOD may appear in several scales and in different conditions. Calthorpe Associates classified TODs according to their prominent functions as: "Urban TODs" located at primary transit points with an orientation to commercial and job development; "Neighborhood TODs" located close to the primary transit system with an orientation to housing, retail and services; and "Secondary Areas" of lower-density housing, schools, community parks, and commercial and employment uses, which surround TODs and are located within hiking distance of the TOD transit stop (CAAMA, 2011).

A similar classification made for the TOD strategic plan in the City of Denver introduces the following types of TOD: downtown, major urban center, urban center, urban neighborhood, commuter town center, main street, and campus/ special events station (Atkinson-Palombo & Kuby, 2011).

TOD projects have been experienced in different countries. As the concept is based on a multi-disciplinary approach integrating urban development and transportation planning, collaboration of related intuitions is very crucial for translating the theory into planning policy. At the same time, planning instruments should be adopted to be able to fulfill the planning concept. The example of Amsterdam indicates that this complex planning concept cannot be transferred in its entirety and only adoptable parts will be relevant (Pojani & Stead, 2014). The case of Copenhagen, on the other hand, shows an early TOD experience which started with the famous Finger Plan of 1947, and was continued by Orestad New Town in 1995: The Master Plan which focuses development around stations on a new driverless light rail mini-metro system, considered to be sustainable development with the Metro at its core and limited possibilities to use private cars (Knowles, 2012). TOD has gained increasing interest in the US. There are many new projects under way, especially near rail transit systems. This growing demand for walkable, mixed-used transit neighborhoods close to transit systems has been mostly due to the factors such as demographic change (changes in family structure: more single-person households, young professionals and empty-nesters), traffic congestion caused by motor vehicles; high gasoline prices; new focus of federal, state, and local policy supporting rail transit systems (Ratner & Goetz, 2013). The cities of Denver and Phoenix are examples of two recent TOD practices in US. In both cases a special planning system was adopted to realize TOD projects. In Denver, approval of a new rail transit program called "FasTracks" ran parallel with land use planning with focus on TOD principals. The City and County of Denver completed a new land use and transportation plan called "Blueprint Denver" in 2002 that changed the zoning in transit station areas to allow higher-density and mixed use development. The following planning documents have also been prepared: 1) overall TOD Strategic Plan; 2) station area plans; 3) TOD station Typology. This project is supported by local institutions and authorities responsible both in urban and traffic planning. Covering different scales from individual station areas to an entire region is another important issue (Ratner & Goetz, 2013). "Overlay Zoning" is another policy instrument which has been developed to encourage TOD in Phoenix.

According to the overlay zoning ordinance of Phoenix, a list of land uses which are prohibited, conditionally allowed, and explicitly allowed have been developed. Overlay zoning is used to achieve TOD design principles such as higher density and mixed-use environments which are walkable and pedestrian-friendly (Atkinson-Palombo & Kuby, 2011). In addition to planning and policy instruments, there are other influential factors leading to the success of a TOD project. Thomas and Bertolini (2017) have shown that "political stability at the national level, relationships between actors in the region, interdisciplinary teams used to implement TOD and public participation" are crucial factors for a successful TOD project. The results indicate that in a sectoral planning culture of some developing countries (such as Iran) in which the policies and priorities of central government depend on the choices of individual decision-makers, it is not easy to achieve TOD goals. In another word, an institutional structure is a critical factor to achieve successful TODs. Institutions may work both as an obstacle and facilitator of TODs: formal institutional barriers are complexity in governance due to multiple stakeholders with different viewpoints and unclear roles; and informal barriers are identified when there is no commitment or ambition to achieve the goals (Tan et al., 2014).

3 POSITIVE OUTCOMES OF TOD FOR IRAN

3.1 RAPID URBANIZATION AND SOCIO-DEMOGRAPHIC CHANGES

Iran is an emerging country, still encountering development challenges. The country's demographic and socio-economic situation has drastically changed in recent decades. Once an agriculture-based society with most of the population residing in rural areas, during the last decades of the 20th century, Iran changed into a more urbanized country with a shift from agriculture to a market economy and the resultingd creation of a modern but oil-dependent urban sector. Recent national census data (2011) show that the share of the population living in urban areas has grown up to 70% and the number of cities has increased from 201 in 1956 to 1331 in 2011, amongst which eight cities now have more than one million inhabitants (SCI, 2011). Figure 1 indicates the prominent share of urban areas and urbanization in the population distribution and lifestyle which will also lead to the need to improve and develop sustainable transportation systems.

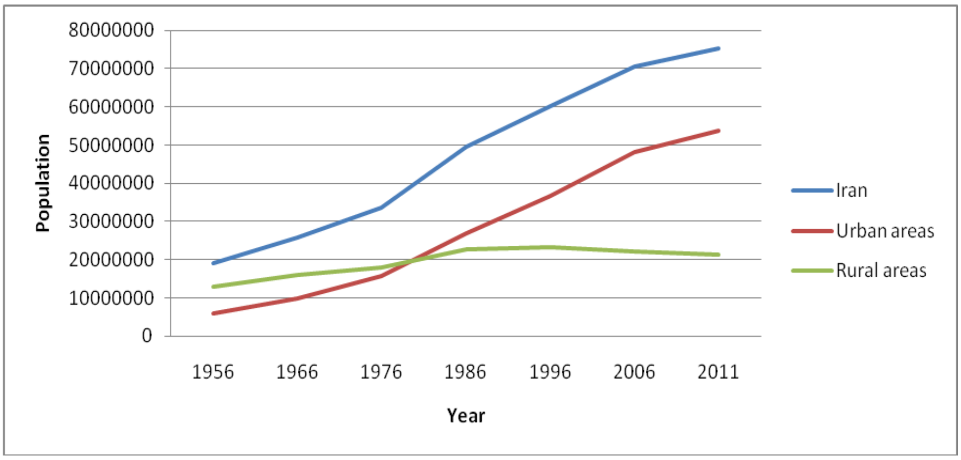

Fig.1 Urbanization trend in Iran

Changes in family size and aging are among other socio-demographic trends: statistics show a shift from extended families to nuclear ones, with recent changes to even smaller family size: the average household size (in both urban and rural areas) decreased from 5.02 in 1976 to 3.55 in 2011 (SCI, 2011). Although the relationship between household size and travel demand is very complicated and needs to be studied in every society, it is logical to claim that the smaller the household size (tendency everywhere as income rises) the higher the trip rate per capita, and as the income also affects travel choices, there is a higher propensity to use private motorized modes. Studies show that as household incomes increase, so do the number of trips that household members make (TFL, 2011). The drastic changes in the demographic situation of the country together with rising participation of women in economic activities will affect the need for mobility, and should be taken into account in transportation planning.

3.2 GROWING MOTORIZATION

Gradual growth of motorization rate is a common phenomenon which may affect modal split. Some previously done research shows that "of personal characteristics, car ownership is the most important variable to explain modal choice: If people own a car, they use it" (Dieleman et.al., 2002). However, this should be evaluated together with other variables such as travel behavior and access to public transportation facilities. Recent data of the Central Bank of Iran shows that while average household size in urban areas decreased from 4.09 in 2005 to 3.44 in 2014; car ownership rate for each urban family increased from

28.8% in 2005 to 45.8% in 2014 (CBI, 2014). This is the average data for urban areas. Yet the critical issue is that the figure is much higher in metropolitan regions: recent data of the Tehran Municipality published in 2014 indicates that the car ownership rate per 1000 inhabitants is 400 (TTO, 2014). A study of the number of registered vehicles in Iran also shows the considerable difference between the number of registered cars and mass transit vehicles.

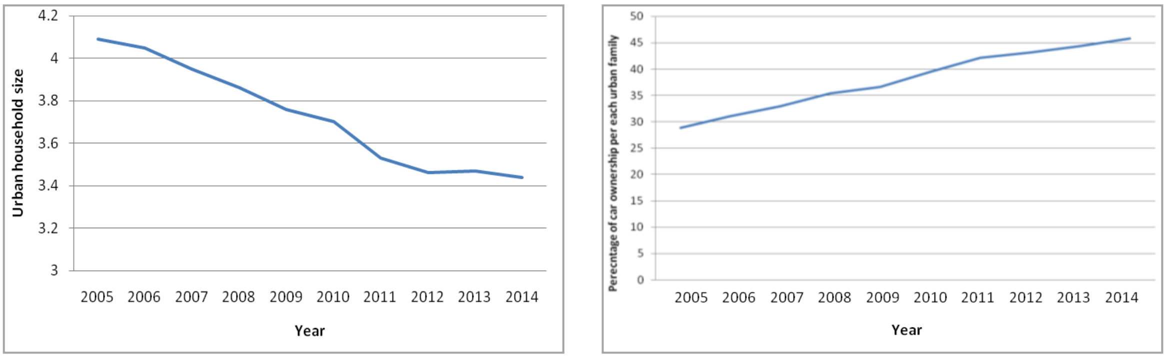

Fig.2 Decreasing size of urban households (on the left) and Increasing car ownership rate (on the right)

Although there are some improvements in the development of public transportation systems- mainly bus, BRT, "shared taxis" and metro- especially in big cities, Tehran Municipality data demonstrate that the share of public transportation in Tehran has only slightly increased from 49.3% in 2005 to 58.2% in 2014 (TTO, 2014). The increasing motorization rate alone, is not considered to be a serious threat: in several industrialized countries (especially in Europe), the car ownership rate is much higher than in Iran, and at the same time, the share of public transportation in daily trips is comparably bigger. The main issue is the coincidence of motorization growth and insufficient public transportation facilities. TOD can be introduced here to deal with the problem. It has been defined as a measure to encourage use of mass transit modes, walkability and decrease car dependency. By integrating urban development and public transportation, it may work as an instrument to reduce car dependency (Chisholm, 2002).

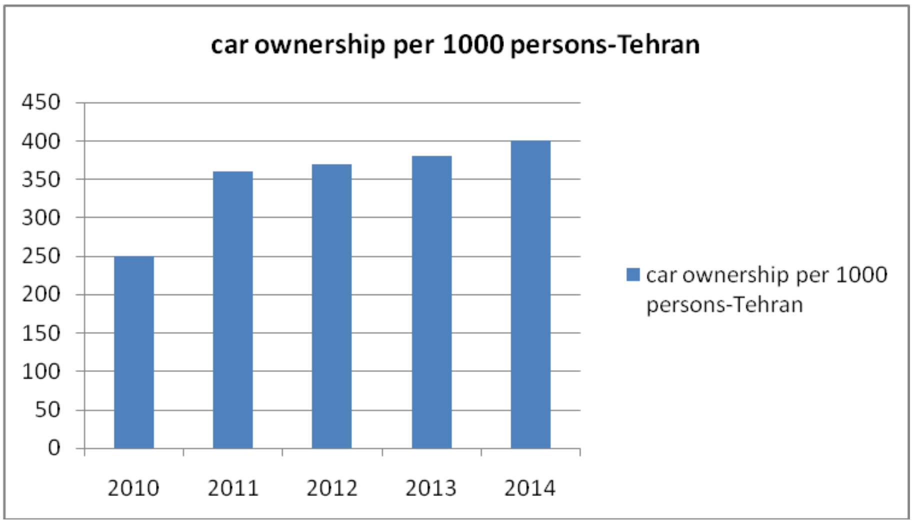

Fig. 3 Increasing car ownership rate in Tehran

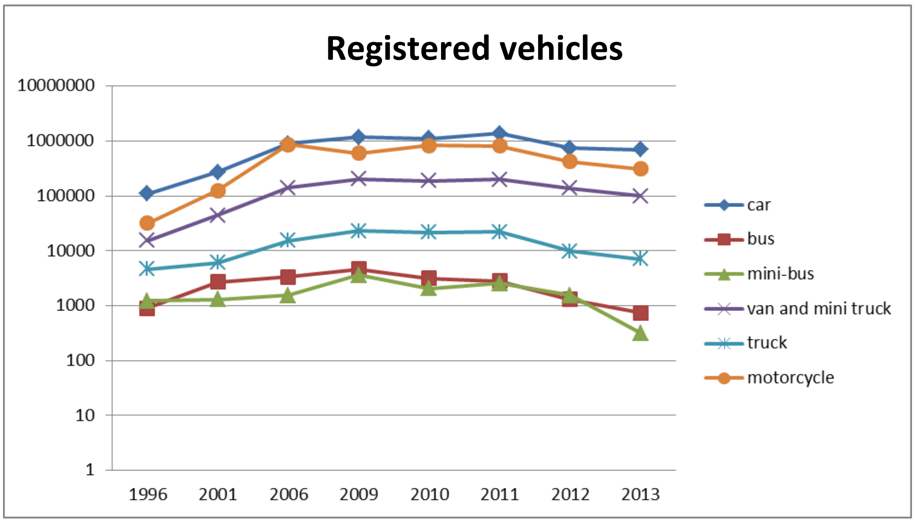

Fig. 4 Registered vehicles

3.3 AIR POLLUTION

Insufficient public transportation is not only an issue in newly developed settlements: it is also a cause for concern in large and small cities alike, especially in metropolitan areas. So-called car-oriented development has other consequences: the most serious is air pollution and environmental degradation which is now a serious problem in metropolitan areas and considered to be the main reason for cardiovascular diseases and death in big cities. According to Abbaspour and Soltaninejad (2004): "the vehicle fleet and motorization, with a large number of old and poorly maintained vehicles as well as growing domestic vehicles, are responsible for much of the recognized pollutants discharged into the atmosphere in metropolitan areas of Tehran. Transportation-related pollutants are carbon monoxide (CO), reactive and non-reactive hydrocarbons, nitrogen oxides, (NOx) sulfur oxides (Sox), and lead (pb)". The annual report of "Air quality control company" of Tehran also indicates that mobile sources of air pollution, such as private cars, shared taxis, motorcycles, vans, trucks, bus and minibuses, are responsible for 85% of annual air pollution (AQCC, 2015). Each year due to severe air pollution which causes serious health risks for the inhabitants, there are several days off in which kindergartens, schools, factories and even state offices are closed. This unexpected situation has serious economic consequences, specially in Tehran which is responsible for more than 70% of the country's economic turnover (Eghtesadonline, 2016).

World Health Organization data shows that cardiovascular diseases are the most important cause for health factors such as "the sum of years of life lost due to premature mortality" (YLL) and "years of healthy life lost due to disability" (YLD) in Iran. According to the same data, "Ischaemic heart diseases" were the leading cause of death, killing 97.7 thousand people in 2012. Road injury is also the cause of death for 32 thousand people in 2012 (WHO, 2012).

Development of mass transit systems has proved to be the best solution to control air pollution. The existing literature indicates that TOD as a traffic management strategy would reduce air pollution (Wu, 2014). Cervero and Sullivan (2011) claim that: "Carbon emissions and energy consumption of Green TOD can be nearly 30% less than that of conventional development". The improvement of transportation infrastructure as the most important means to reduce air pollution, needs considerable investment by public and private sectors. It is argued here that it is worth the cost, considering the savings in terms of life, time and quality of the living environment.

4 THE CHALLENGES OF TOD IN IRAN

4.1 TOD AND MOBILITY AS NATIONAL PRIORITIES

A critical review of the current situation in Iranian cities indicates the serious need to improve public transportation systems: it would reduce air pollution and traffic congestion, decrease car accident risks and finally improve the quality of life for the rapidly urbanizing society. The importance of the transportation sector in Iran can also be discussed from other viewpoints: a vast country with a privileged location at the crossroads of international trade routes; a mountainous land in which settlements are separated with long distances, needs an interconnected transportation system (World Bank, 2005).

The new Iranian government faces the challenges inherent from hurriedly taken decisions by previous governments to provide housing units for the population without sound plans for the provision of related urban services and infrastructures. In an attempt to tackle the issue, one of the main strategies of the new government is "urban mobility" and "rail-based urban development" mentioned frequently in the speeches of the Minister of Roads and Urban Development (Akhoundi, 2016). Although this is not a very novel policy and has its roots in the history of urbanization dating back to the early days of the industrial revolution; it shows a devotion and apparent shift in national policies toward more sustainable planning. However, paving the way to achieve transit-oriented or "rail-oriented" urban development will not be achieved easily and there are several barriers which should be overcome.

In the present paper, the main obstacles regarding the development of TOD in Iran will be discussed. They have been recognized as the following:

1 The need for an Iranian version of TOD
2 Low priority in national housing strategies
3 Overlapping and parallel institutions and insufficient planning instruments

4.2 THE NEED FOR AN IRANIAN VERSION OF TOD

The general concept of TOD has been initially raised as a solution for American cities. Therefore the whole idea has a so-called "western" orientation. Although there are some similarities between American and Iranian cities especially in the case of scales, climatic and geographical variations, long distances between cities and car-dominated urban growth, there are also several mismatches in urban governance, land speculation, legal and institutional structure, etc. Therefore a more localized TOD concept should be developed in Iran. As was discussed in the literature review, successful TODs are the direct outcome of formal and informal institutions responsible both in urban planning and transportation systems. Each planning culture has its own specific institutional context which may support or delimitate TODs. A "Copy and Paste" approach to transfer a concept from one country to another does not work and complex planning practices cannot be transferred in their entirety. Iranian planners should develop the concept according to local planning instruments and institutions.

The available literature on TOD in Iran shows the lack of a comprehensive approach which encompasses different aspects. However, several challenges have attracted the attention of researchers. These include "dissatisfaction of local residents (near subway stations) due to a lack of standard facilities and weak social activities" (Abbaszadegan et al., 2011), "different effects of opening metro stations on the value of properties in southern (poor) and northern (rich) areas of Tehran, a positive effect on the south and negative effect on the north" (Kheiroddin et al., 2014), and "the possibility of an increase in the economic value-added of properties near metro stations" (Soltani, et al., 2011).

Another subject which has been very seriously considered in both the literature and in practice is the need to develop commercial complexes near metro stations. These multi-functional high-density buildings, mainly managed by the municipalities, have already been planned near some metro stations in cities like Tehran, Shiraz and Mashhad, and are claimed to be a safe solution to finance further development of metro system (Montazeri, 2012). A review of the current approaches shows that the high value of land and property in metropolitan areas has affected research and practice of TOD in Iran and there is even the danger of its misuse as a "scientific" justification for land speculation by the private sector or even municipalities. Realization of TOD projects needs a multi dimensional and comprehensive approach considering its multiple aspects both in theory and practice. Cutting down the subject and focusing on its individual aspects will lead to dissatisfaction. As an example although TOD has been proved to reduce air pollution, one case study in the impact of BRT system in Tehran, shows that BRT by itself cannot control air pollution and traffic congestion (Asadollahfardi et al., 2016). It indicates that development of a mass transit line without considering other aspects of TOD will not lead to the expected goals. In the case of this study the negligence of walkability as a TOD principle was the main reason for being unable to achieve the expected results. For a comprehensive local approach, the roles of different stakeholders and local authorities should be considered. Land prices, the legal and social limitation of increasing densities near transit stations, and the danger of a narrowed down definition of TOD in which other aspects such as walkability, green and open spaces have been neglected, should also be taken into account.

4.3 LOW PRIORITY IN THE NATIONAL HOUSING STRATEGIES

Drastic demographic and socio-economic changes have visible impacts on all development issues. The need for provision of more housing units for the fast growing, young population has been a national priority in recent decades. The government initiated many housing schemes for middle-low income social groups, the development of New Towns in the suburban areas of big cities and the MEHR Housing Project, considered one of the most important. Growth of residential areas has been so rapid, leaving no space for the parallel development of urban infrastructures. What is apparent now as the result is the emergence of residential quarters with very limited public services, apparently inadequate public transportation facilities. As an example, the development of new towns, as a strategy to absorb the surplus population of big cities, to provide housing for low-income groups, and accommodate employees of industrial sectors, was started in the 1990s (Ziari & Gharakhlou, 2009). However, after more than 20 years from their establishment with thousands of residents all around the country, the regional railway system to connect them to the main cities is still in progress.

New Town	Approval of comprehensive plan	Target population estimated for 2036	Estimated time for the operation of regional railway*
Parand	1998	700000	2015
Hashtgerd	1993	500000	2014
Golbahar	1993	530000	2016
Baharestan	1993	320000	2015
Fouladshahr	1994	350000	2017
Sahand	1998	450000	2017
Pardis	1995	560000	2017
Sadra	1995	550000	2017
Majlesi	1993	140000	2017
Binaloud	2002	160000	2017

Tab.1 Estimated operation time of regional railways for some of the Iranian new towns

***plans are behind schedule and the dates are only estimation**

There are some debates supporting the positive role of private investments in the improvement of mass transit systems. However, the current situation does not provide a safe and secure environment for private investment: Ambiguity on relationship between State and the private sector, lack of security and monetary rewards for private suppliers, and interference of political decisions are among major issues raised to indicate the weak role played by private companies in mass transit system development (World Bank, 2005). When compared with safe and profitable investment in housing projects, the logic behind unbalanced development of mass transit systems and residential development becomes clear.

4.4 OVERLAPPING AND PARALLEL INSTITUTIONS AND INSUFFICIENT PLANNING INSTRUMENTS

Parallel and overlapping tasks of public and private institutions constitute a general barrier in the efficient fulfillment of national strategies in Iran. The transportation sector is also affected by this trend. Currently and after the merger of two ministries of "Roads and transportation" and "Housing and urban development" and the establishment of the "Ministry of Roads and Urban Development", the separate tasks of those ex-ministries have been diverted to the new one. The new ministry is now in charge of the whole transport sector excluding urban transport which is under the Ministry of the Interior and the City Councils (World Bank, 2005). Although urban transportation planning is mostly down to the municipalities, parallel sub-institutions are responsible for different transportation modes (metro, shared taxies, buses, etc.). Some recent research has emphasized the importance of an "integrated transportation approach" as a holistic strategy which integrates different levels such as management (users, stakeholders), function and land use planning in transportation sector of Iran (Soltani & Fallah Manshadi, 2013). Integrated approach should be applied also in the bigger scale of regional planning. Inner city transit networks should be connected to the regional access ways e.g. national railway network. In this way, public transportation system will be integrated in the whole country. This approach needs even higher level of integration, as at least tasks of two ministries and several sub- level institutions should be harmonized. Recently there are discussions on moving the central railway stations out of the cities and locating them in suburban areas. This idea which has been raised by Tehran Municipality considered being incompatible with the integrated transportation approach. The "Ministry of Road and Urban Development" expressed its serious disagreement on this idea and supports the integration of national railway network with inner city transportation to achieve more integrity in regional level (Hanachi, 2016).

Another obstacle to realize TOD projects is insufficient planning instruments. Iran has a centralized planning system in which traditional "Comprehensive plans" and "Detailed Plans" are main local level planning instruments " (Rasoolimanesh et al., 2013). Standard instruction has been developed to guide preparation and approval of these legal documents which is also valid for the whole country. This uniform content leaves no place for any amendment or changes. As it has been seen in the case of US planning experiences, special land use and transportation plan has been developed for the City of Denver to allow TOD requirements such as special zoning and higher density. Or in the case of Phoenix, "overlay zoning" has been used as a planning instrument to support TOD projects. Iran should also develop its own planning guidelines according to its local context. Considering the geographic, cultural, economic and social variety of the country and the cities, a uniform TOD guideline couldn't cover the requirements of the whole country. Thus, it is suggested here that a general guideline should be developed in national level and each city should prepare its own localized version according to its unique physical and institutional context.

5 RESULTS AND DISCUSSION

The current paper presents a brief overview of both positive outcomes of TOD for Iran and the actual challenges considering the existing situation in the country. TOD may be applied as a policy to solve several critical problems especially in metropolitan areas of Iran. Transportation is a very serious issue in the cities and its inadequacy cause critical problems: the urbanization rate is increasing and rural migration will lead to empty villages and overpopulated urban areas. The gradual decrease in family size combined with the increasing motorization rate will bring even more cars to the existing streets and highways. More cars mean more air pollution, more congestion and also more car accidents. The loss of lives, health, time and working hours can be easily calculated and transferred to numbers to demonstrate the economic consequences.

Now it is time for a paradigm shift. The starting point here is the need for local theories supporting transit oriented development. TOD as a western model for integration of urban development and public transportation may work well for some countries, but not definitely for Iran. Recent local practices even demonstrate the danger of "narrowing down" the concept and using it as an instrument to increase densities and profit making. TOD should be re-visited according to the Iranian planning and economic system. Its principles addressing density, open space, walkability and less car use should be thoroughly considered and translated into Iranian standards and norms.

Another urgent need is to shift priority from housing projects to public transportation. Although mass housing schemes have been a priority for the Iranian government for a long period, now it is the time for a strategic shift and focus on public transportation provision in the cities and regions. In so doing, there are numerous challenges to be faced: a shift from housing provision to public transportation is not easy. There are many public and private investors supporting housing projects, due to the secure and promising market. Similar investments in public transportation cannot be as safe and secure. The government should support investors with new economic models and strategies.

Strategies cannot stay on paper; they should be transferred to the real world and practiced there. Here the need for an efficient institutional model is apparent. Parallel institutions and several ministries are now responsible for public transportation inside and outside cities. They have overlapping and even contradictory tasks which cause disharmonized outcomes. It is not easy to put different institutions together to fulfill an identical goal; however, this is the only practical solution to achieve an integrated transportation system. Available planning instruments in Iran do not fit into TOD requirements. The need for a national TOD guideline with the potential to develop local versions for each city is very crucial and should be considered in national urban and transportation planning priorities.

Paving the way to achieve TOD in Iran is not easy. Looking at the serious risks which an inadequate mass transit system will create in cities should raise urgent attention by the decision makers. Long-term plans are needed to deal with the pressing problems. Knowledge dissemination and awareness raising are other instruments to fulfill the tasks.

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IMAGE SOURCES

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Fig. 1: SCI (Statistical Centre of Iran), 2011

Fig. 2: CBI (Central Bank of the Islamic Republic of Iran), 2014

Fig. 3: TTO (Tehran Traffic Organization), 2014

Fig. 4: SCI Yearbook, 2013

Tab. 1: New Towns Development Company, Retrieved from:http://ntoir.gov.ir/index.aspx?fkeyid=&siteid=1&pageid=189

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MODELING METRO USERS' TRAVEL BEHAVIOR IN TEHRAN: FREQUENCY OF USE

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ABSTRACT

Transit-oriented development (TOD), as a sustainable supporting strategy, emphasizes the improvement of public transportation coverage and quality, land use density and diversity around public transportation stations and priority of walking and cycling at station areas. Traffic, environmental and economic problems arising from high growth of private cars, inappropriate distribution of land use, and car-orientation of the metropolitan area, necessitate adoption of TOD. In recent years, extensive research into urban development and transportation has focused on this strategy. This research in which metro stations are considered as a base for development, aims to model metro users' travel behavior and decision-making procedures. In this regard, the research question is: what are the parameters or factors affecting the frequency of travel by metro in a half-mile radius from stations. The radius was determined based on TOD definitions and five-minute walking time to metro stations. A questionnaire was designed in three sections that include travel features by metro, attitudes toward metro, and economic and social characteristics of respondents. Ten stations were selected based on their geographic dispersion in Tehran and a sample of 450 respondents was determined. The questionnaires were surveyed face to face in (half-mile) vicinity of metro stations. Based on a refined sample on 400 questionnaires ordered discrete choice models were considered. Results of descriptive statistics show that 38.5 percent of the sample used metro more than 4 times per week. Trip purpose for 45.7 percent of metro users is work. Access mode to the metro stations for nearly half of the users (47.6 percent) is bus. The results of ordered logit models show a number of significant variables including: habit of using the metro, waiting time in stations, trip purpose (working, shopping and recreation), personal car access mode to the metro station, walking access mode to the metro station and being a housewife.

KEYWORDS: Transit oriented development, Metro, Ordered logit model

1 INTRODUCTION

In recent decades, achieving sustainability has been discussed as a general concern by many researchers, and various strategies and tools were specifically offered to achieve this goal in the field of urban transit planning. The public transit system is often regarded as an instrument that helps to attain sustainable urbanization. However, expanding these systems is a costly process that has different impacts on urban and regional areas (Miller et al, 2016). Transit Oriented Development (TOD) is a bundle of strategies to achieve sustainable transport in metropolitan areas (Barton, 1998; Calthorpe, 1993; Cervero, 2004). There is no accepted standard definition regarding both theoretical and operational aspects of TOD (Nasri, 2014). Different definitions of TOD include these factors: density, diversity, design and mixed land uses, walking and cycling priority and public transport system quality (Cervero et al., 2002; Arrington and Cervero, 2008; California Department of Transportation, 2001; Parker, 2002). Density captures the intensity of activity through such measures as residential units or jobs per unit area. Diversity captures the variety of land use in an area, such as the ratio of residential units to jobs or the distance from a residential unit to a retail destination. Design refers to street network patterns within an area, such as the percentage of intersections (Stewart and Moudon, 2014).

The growing trend of Tehran's population and focus of facilities, services and administrative centers have led to an increase in trips by residents (Tehran master plan, 2006 revised in 2013). Apart from cultural issues and the preferential use of private cars in Tehran, lack of a public transportation system with proper coverage and quality and also inconsistency between land use conditions and public transit infrastructure have lowered the share of the public transport sector in Tehran (Tehran master plan, 2006 revised in 2013).

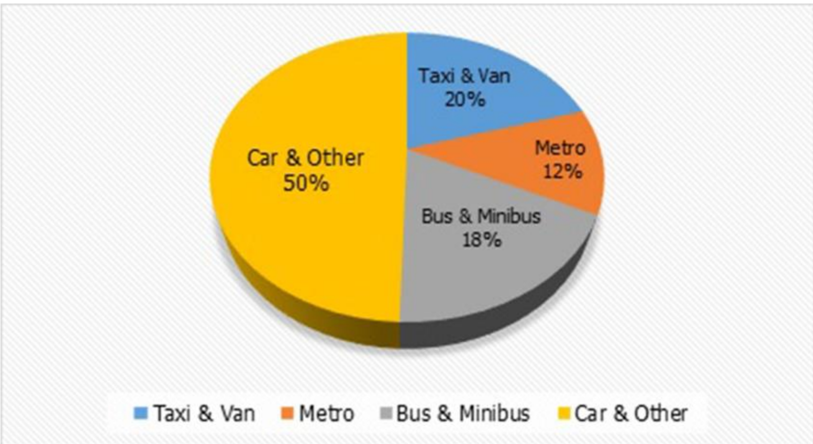

Fig. 1 The share of vehicles in daily trips in Tehran

Efforts for improving the current conditions and increasing the share of public transport, especially metro, have drawn the attention of decision-makers, authorities, urban development and transport planners to the strategy of TOD (TURPC, 2015). Planning to promote using the metro requires a true understanding of users' behavior mechanisms. This research, considering metro stations as a base for development, aims to model metro user's travel behavior and decision-making procedures. In this regard, the research question is: what are the parameters or factors affecting the frequency of travel by metro in a half-mile radius from stations. The radius was determined based on TOD definitions and five minute walking time to metro stations. In section 2 the literature is reviewed, followed by methodology in section 3 specifying the scope of the case study, questionnaire design, data collection and modeling. Section 4 is dedicated to research findings containing the results of descriptive statistics, modeling phases, and finally section 5 comprises the discussion and conclusion.

2 LITERATURE REVIEW

The TOD concept was originally developed by Peter Calthorpe (American architect) and the implementation history of TOD projects primarily goes back to the USA and the cities of San Francisco and Atlanta in this country. Following America, attention of the European countries was also drawn to this strategy and cases compatible with TOD were observed in the cities of Copenhagen, Munich, Stockholm and Zurich in Europe (Bernick and Cervero, 1997; Cervero, 1998; Curtis et al., 2009; Mu and Jang, 2012).

By implementing TOD projects and the pervasiveness of this strategy, the researchers measured various aspects of the current situation and results of TOD projects. Mu and Jang (2012) assessed the implementation conditions of TOD in Dalian, China. Along with the introduction of Dalian City as a case study and regarding the density and diversity of land use and the relevant maps, transportation infrastructure situation and mode choice of travel in this city, strengths and weaknesses of Dalian city are discussed in moving towards TOD.

Cervero and Kockelman (1997) studied the impact of environment structure characteristics (density, diversity and design) on changing trip styles in San Francisco and found that modern urbanism with proper density, diversity and design of land use reduces the share of travel by personal car and increases the use of non-motorized transport vehicles. Ewing and Cervero (2010) maintained that, after controlling for socio-demographic characteristics and other confounders, design variables have greater connection with walking and transit use than diversity or density measures.

Renne (2007) studied TOD based on a comprehensive vision and view of stability and livability. The study area included five public transportation stations in Perth, Australia. Data included two primary and secondary categories. The former included the data from 2503 households randomly selected from five areas to assess livability and sustainability and the latter included secondary data of local offices and organizations. Introduced indicators for measuring TOD were divided into six categories including travel behavior, local economy, environment structure, social environment and policy context.

Based on an analytical framework, Nasri and Zhang (2014) examined the differences in travel behaviors of TOD area residents in both Washington and Baltimore. In this context and in order to analyze the effectiveness of TOD in encouraging the area's residents to use public transportation, walking, cycling and other sustainable modes of transportation, changes in vehicle miles traveled (VMT) was investigated. For modeling travel behavior in TOD and NON -TOD areas, multi-level mixed effect regression modeling as well as the travel data between 2007 and 2008 in the above cities were used. The data included economic and social information, activities, travel distance, mode choice, travel time, purpose of travel and information of the origin and destination of households in the vicinity of metro. The results showed that people residing in TOD areas were less inclined to use private cars. Accordingly, VMT had respectively decreased about 38 percent in Washington and 21 percent in Baltimore compared to NON -TOD areas, even with the same pattern of land use. In order to measure the level of TOD in Arnhem and Nijmegen urban areas, Singh et al (2014) proposed the potential and actual indexes of TOD. The actual index is intended for the walkable area of the station and potential index is used for the whole area and identifying the potential of areas for connection to public transit. Given that all indexes cannot be quantified, all of them cannot be used for index calculation. Spatial data are obtained in GIS format and non-spatial data at the regional level are obtained from the secondary data. In data collection, there were problems such as isolation of resources, lack of full map coverage, incompatible administrative boundaries and conflicting classification of land use. Regarding such issues, indexes such as residential density, commercial density and diversity of land use, mixed use and number of commercial units are used.

Vale (2015) used three aspects to assess and categorize areas of stations: transportation, land use and walking conditions. He implemented the node-place model with an evaluation of the pedestrian connectivity of station areas of Lisbon. Papa and Bertolini (2015) examined the relationship between TOD and rail-based access by comparative analysis of six European cities. Comparisons showed that rail-based access is higher in cities where residents and businesses are focused around the station or have higher connectivity networks.

A literature review of the TOD framework shows that the factors of land use condition (density and diversity), quality of public transport and pedestrian-oriented design of a TOD site are very important in reducing private car use and increasing the share of sustainable modes (public transport, walking and cycling). Since changing people's trip mode to public transportation plays a key role in TOD, identification of user behavior is very important. Lack of studies on the factors influencing metro use leads this study to evaluate the parameters affecting frequency of travel by metro, with a behavioral approach focusing on the city of Tehran.

3 METHODOLOGY

For modeling frequency of travel by metro, a questionnaire was designed. Ten metro stations were chosen based on geographic dispersion of stations for completing questionnaires in Tehran. An ordered discrete choice model was chosen to model the weekly frequency of metro use. Discrete choice models are powerful tools which consider the behavioral nature utility as a random variable (Ben-Akiva, 1985). They also have a high capability of modeling choice-making and dealing with utility. Discrete choice models include two general categories, ordered and un-ordered models (Ben-Akiva, 1985). The basic assumption of ordered models considers a continuous variable a hidden variable that shows intention value of a respondent to a specific option. In fact, what is observed is a reflection of the hidden desire of the respondent defined as a discrete variable (Mckelvey, 1993).

3.1 TEHRAN'S METRO CASE STUDY

With 20 years of history and 94 stations along five lines, Tehran metro was ranked 34th among the world metros in 2015 based on the number of stations (TUSROC, 2015). Line 1 of the metro with a share of 36.5% has the largest share of trips by metro (TUSROC, 2015). This line connects the north and south of the city. Figure 2 demonstrates the growing number of trips made by metro during the years 1998 to 2013.

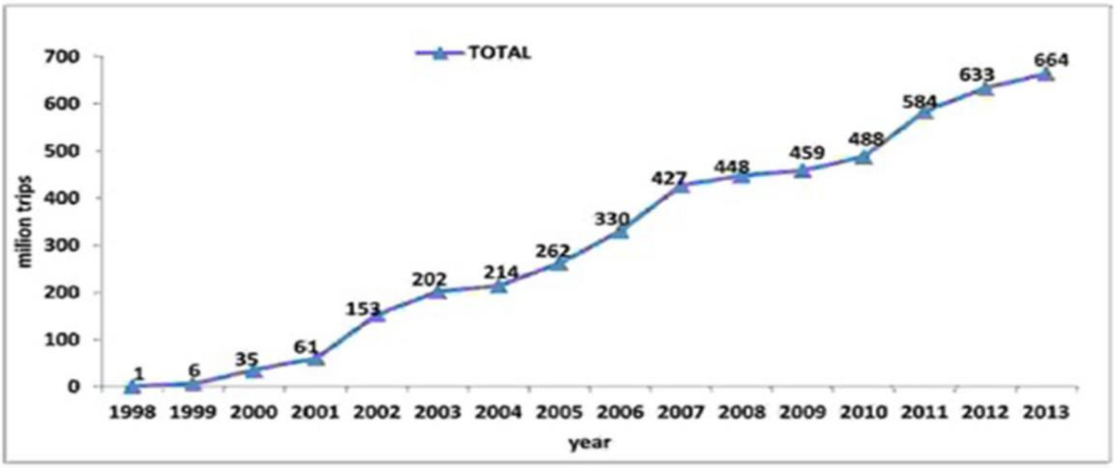

Fig. 2 Number of trips by metro in years 1998 – 2013

Nevertheless, the share of public transportation and especially the metro is very low compared to that ofprivate cars. Given the importance of metro stations and their capacity in creating development, Tehran metro stations are considered a basis for development in this study. Ten metro station were chosen based on geographic dispersion of stations for completing questionnaires in Tehran.

Table 1 shows the specifications of ten metro stations and in figure 3 the locations of them are illustrated. Among the selected metro stations, four metro stations (Imam Khomeini, Sadeghiyeh, Theater Shahr and Shahid Beheshti station) are located at the intersection of two metro lines.

STATION NAME	LINE NUMBER	AVERAGE NUMBER OF DAILY PASSENGERS
Sadeghiyeh	2 , 5	57873
Imam khomeini	1 , 2	38032
Shahid beheshti	1 , 3	23194
Theater shahr	3 , 4	39031
Niroo havaei	4	16889
Fatemi	3	-
Tehranpars	2	17060
Sarsabz	2	18741
Ghaem	3	-
Mirdamad	1	18589

Table.1 Specifications of 10 metro stations in Tehran (TUSROC, 2015)

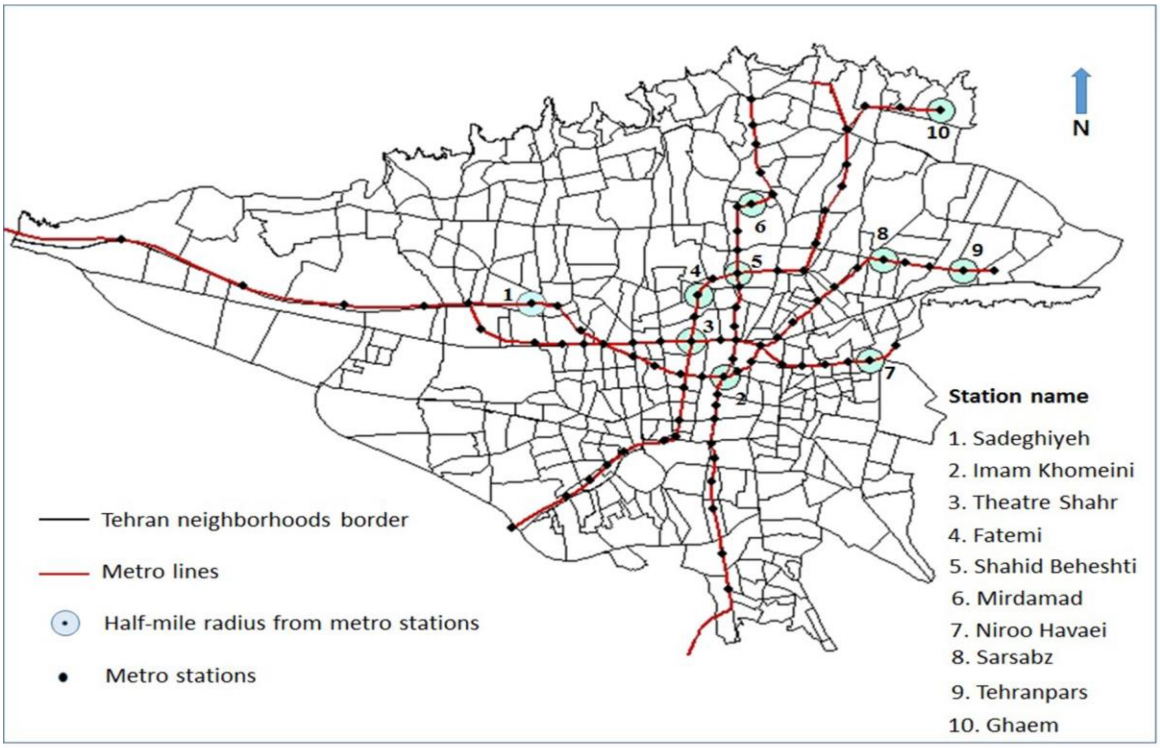

Fig. 3 Location of 10 metro stations in Tehran

3.2 QUESTIONNAIRE DESIGN & DATA COLLECTION

After reviewing the literature and consulting with experts and urban transport engineers, features affecting the use of metro were identified and a questionnaire was designed on this basis. Also the available questionnaires of reference (for example research of Renne, 2007) were reviewed and used as guides to design a set of questions modified for this study. The final questionnaire consisted of three sections: travel

features by metro (4 questions), attitude towards metro (16 questions) and social-economic characteristics of respondents (10 questions). After designing the questionnaire, two pilot experiments were conducted. At every stage, 20 questionnaires were distributed. The first took place in Shahid Beheshti station and was stopped according to the metro security guard interference. The second was conducted at a bus stop near the Sadegiyeh metro station. It was a good candidate for our survey as people waiting for buses after leaving the metro had more free time to answer questions than people leaving metro stations for different destinations. The pilots confirms that the questionnaire had no ambiguity.
Due to the lack of information on population variance, a Morgan table was used to determine the sample size required and 450 passengers were accordingly selected as the sample. The survey method, face to face and simple random, took place during three weeks in January 2016 within a half-mile radius from ten metro stations.The passengers determined the importance of the corresponding features (attitude) in the form of a 5-degree Likert scale including very low, low, medium, high, and very high. For descriptive analysis, codes 1 to 5 were respectively given to the options. Out of 450 questionnaires, 400 of them were used for statistical analysis considering the level of responses to questions.

3.3 MODELING

The trip modeling approach used was discrete choice analysis. Several models with weekly frequency of metro use, as the dependent variable, were made using different coding for the dependent variable, which enabled us to estimate binary, multinomial and ordered logit. Depending on the fitting and significance of explanatory variables, the ordered logit model was selected as the final model. In general, three categories of explanatory variables were tested, including trip characteristics by metro (see table 2), attitudes towards the metro (see table 3) and socio-economic characteristics of the respondents (see table 4). In addition, dummy variables, composed, logarithm of attitudes towards the metro is made in the process of modeling.

4 FINDINGS

4.1 DESCRIPTIVE ANALYSIS

The results of descriptive statistics analysis of economic and social variables (table 2) show that 59 percent of the sample were male, 39 percent were married, 43 percent were tenants, 40 percent had no independent income and 54 percent own cars. According to table 3, some results of descriptive statistics analysis of characteristics of trip by metro include:

- 38.5 percent of individuals use the metro more than four times per week.
- The main trip purpose of 45.7 percent of the sample is work.
- Access mode of about half of the sample (47.6 percent) to the metro station is bus.

SOCIO - DEMOGRAPHICS	CODE	FREQUENCY	%
Age (years)			
15 to 19	1	16	15.4
20 to 24	2	126	31.8
25 to 30	3	82	20.7
31 to 40	4	71	17.9
41 to 50	5	46	11.6
50 to 60	6	10	2.5
Gender			
Female	0	164	41
Male	1	236	59
Marital status			
Not married	0	246	61.5
Married	1	154	38.5
Family housing			
Homeowners	0	224	57
tenant	1	169	43
Employment status			
Full-time	0	127	47.7
Part-time	1	139	52.3
Income status			
I have an independent income	0	238	59.6
No independent income	1	161	40.4
Job type			
Government employees	1	54	12.2
Private employee	2	81	18.3
Self-employment	3	122	27.6
Private employer	4	11	2.4
Housewife	5	35	7.9
Students	6	124	28
Unemployed	7	14	3.1
Other	8	3	0.6
Car ownership			
Without cars	1	214	54.9
One	2	154	39.5
Two	3	18	4.6
Three or more	4	4	1
Level of education			
Lower of diploma / Diploma	1	117	29.3
Associate Degree / Bachelor	2	201	50.4
Msc	3	57	14.3
P.H.D	4	24	6

Table.2 Socio-demographic status of the respondents

SPECIFICATION: TRIPS WITH METRO	CODE	FREQUENCY	%
frequency of use by metro per week			
One	1	88	22
Two	2	48	12
Three	3	62	155
Four	4	48	12
More than four	5	154	38.5
The purpose of trips by metro			
Work	1	180	45.7
Education	2	125	31.7
Shopping	3	49	12.4
Recreation	4	12	3
Other	5	28	7.1
time of trips by metro			
5:45 to 8:30	1	111	27.7
8:30 to 12:00	2	161	40.4
12:00 to 16:00	3	85	21.3
16:00 to 19:00	4	37	9.3
19:00 to 23:00	5	5	1.3
Access mode to the metro station			
walking	1	90	22.7
Bus	2	189	47.6
Car	3	30	7.6
Taxi / van	4	84	21.2
Other	5	4	1

Table.3 The results of descriptive statistics for characteristics of trip by metro

Table 4 shows the importance of some metro characteristics according to people's attitudes. For example, half of the respondents believe that congestion and bustle of the train has greatly affected their tendency to use the metro.

ITEM	ALTERNATIVE (CODE)					SUM	MEAN	SD
	1	2	3	4	5			
Route information in the train and station	2.5	4	26.6	36.4	30.4	100	3.88	0.972
Train safety	0.5	3	19	32.5	44.9	100	4.18	0.881
Lighting and visual space of station	1.3	7.1	35.3	40.4	16	100	3.63	0.880
Reliability	1	4.1	23.7	32.9	38.3	100	4.03	0.937
Congestion and bustle of the train	2	1.5	13.6	26	56.8	100	4.34	0.913
Train ventilation	3.6	7.6	26.6	28.2	34	100	3.81	1.095
Convenience and comfort of the trains	4.1	11.4	15.1	30.5	28.9	100	3.69	1.126
Train speed	1.8	6.1	33.1	35.4	23.7	100	3.73	0.949
Escalators and elevators at station	3	9.8	17.9	29.1	30.2	100	3.74	1.085
The waiting time at station	2.3	8.8	17.4	28.4	33.2	100	3.81	1.063

Social status using the metro	5.8	8	31.6	31.6	23.1	100	3.58	1.102
Social interaction with people	7.1	14.6	38.3	26.2	13.9	100	3.25	1.088
Metro ticket costs	3	10.1	41.9	24.2	20.7	100	3.49	1.025
Habit of using the metro	6.6	10.4	31.4	33.7	18	100	3.46	1.102
Culture of using of the metro	5.1	11.9	22	28	33.1	100	3.72	1.186
Environmental benefits of the metro	2.8	7.8	24.7	30.5	34.3	100	3.86	1.060

Table.4 Results of descriptive statistics analysis for characteristics of attitude towards metro

4.2 ORDERED LOGIT MODEL RESULTS

The results of the ordered logit model (see table 5) showed eight variables: waiting time, habit of using the metro, dummy variables of trip purpose (working, shaping and recreation), personal car access mode to the metro station, walking access mode to the metro station and being a housewife. The habit of using the metro and waiting time in station variables are significantly positive. Thus believing the important of the role of habit on using the metro has a significant positive effect on the weekly frequency of metro use. Also people who believe that the waiting time is an important issue on metro use, travel by metro more frequently. Other results of the model are:

- Work-trip purpose is significant positively. Hence the persons with the working trip purpose are more likely to use the metro.
- Shopping-trip purpose and recreation-trip purpose are significant negatively. Hence those with shopping and recreation purposes are less likely to use the metro.
- Walking access method to metro stations is significant positively. Hence the people who walk to the metro station are more likely to use the metro.
- Personal car access method to stations is significant negatively. Hence the person who reaches the station in a personal car is less likely to use the metro.
- Being a housewife is significant negatively. So the housewife are less likely to use the metro.

EXPLANATORY FACTORS (CODE)					COEFFICIENT
Constant					2.10***
Habit of using the metro					0.17***
Waiting time in station					0.12**
Work-Trip purpose (1) otherwise (0)					0.71***
Shopping-Trip purpose (1) otherwise (0)					-0.7***
Recreation-Trip purpose (1) otherwise (0)					-0.76**
Personal car Access mode to the metro station (1) otherwise (0)					-0.43**
Walking access mode to the metro station (1) otherwise (0)					0.24*
Housewife (1) otherwise (0)					-0.53**
$\mu_1 = 0$	$\mu_2 = 2.45$	$\mu_3 = 2.90$	$\mu_4 = 3.37$	$\mu_5 = 3.73$	
LL(0)= -644	LL(C) = -604	LL(β)= -544	$\rho_0^2 = 0.16$	$\rho_c^2 = 0.10$	

Table.5 Result of ordered logit model
****: Significant at 5%**
***: Significant at 10**

5 DISCUSSION AND CONCLUSIONS

TOD has emerged as one possible solution for sustainable urban transportation and can help to reshape the quality and form of urban growth towards enhanced accessibility and mobility, pedestrian friendliness, increased sustainability and potentially a higher degree of human interaction (Curtis et al., 2009). One main objective of TOD is promoting the use of public transport. Planning to promote metro use requires a true understanding of users' behavior mechanisms. In this study, metro users' travel behavior (frequency of use) in Tehran is studied using an ordered logit model.

For this purpose, a questionnaire was designed in three sections include travel features by metro, attitudes toward the metro, and economic and social characteristics of respondents. For the survey ten stations were selected based on geographic dispersion in Tehran. The questionnaires were distributed face to face in the vicinity of metro stations. After distributing and collecting questionnaires, 400 questionnaires given to the responses level. Results of descriptive statistics show that 38.5 percent of the sample used the metro more than four times per week. The main trip purpose for 45.7 percent of metro users is work. Access mode to the metro stations for nearly half of the users (47.6 percent) was bus. The results of the ordered logit model show a significant number of variables including: habit of using the metro, station waiting time, work-trip purpose, shopping-trip purpose and recreation-trip purpose, personal car access mode to the metro station, walking access mode to the metro station and being a housewife. With the increasing importance of waiting time for users, the possibility of using the metro increases. Thus from a user perspective, the metro is a system with more regular schedules than other travel modes (for example bus). The habit of using the metro increases the possibility of using the metro. People who walk to metro stations are more likely to use the metro during the week than others who reach stations otherwise.

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IMAGE SOURCES

The cover images is from: the authors

Fig. 1: Tehran transportation studies, 2013

Fig. 2: Tehran transportation studies, 2013

Fig. 3: Authors

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AN ANALYSIS OF PUBLIC TRANSIT CONNECTIVITY INDEX IN TEHRAN

CASE STUDY: TEHRAN MULTI-MODAL TRANSIT NETWORK

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ABSTRACT

Public transit is a major priority in modern management of large cities and metropolitan areas in particular. Public transit systems in such cities consist of a large number of nodes and lines which a station (node) is a bridge between the people and the public transit network, based on which the concept of input and output connectivity power for each station can be defined. The objective of this study is the application of the transit connectivity indices to the multimodal transit network in the city of Tehran. The public transit network data employed in this study were taken from the Tehran Traffic Control Company, and Tehran Urban and Suburban Railway Operation Company. The methodology for measuring transit connectivity consists of three measures: Node connectivity, Line connectivity and Regional connectivity, where activity density is applied to these measures. The results of node connectivity analysis shows that most of the node connectivity in concentrated in the city center with many nodes in the center along routes going north and south. Line connectivity analysis shows that there is a concentration of highly connected lines that are near Tehran municipality regions 12 and 16. Finally, we find that areas with more metro and bus facilities with respect to other areas have a better regional connectivity. One of these areas includes Sadeghiyeh Metro Station which is the junction of Tehran Metro Line 2 and Tehran Metro Line 5 which have a high connectivity power. The results of this study can be used to suggest some ideas on how future investments in rail and bus should be prioritized. Particularly in Transit-Oriented Development (TOD) and sustainable development projects, urban planners can design transit stations with high performance to access crucial services in poor areas. Furthermore, a transit network modeling to develop connectivity indices with other transit factors and the relation between connectivity measures and TOD indices can be evaluated in future research.

KEYWORDS:
Public transit, connectivity indices, TOD, complex network.

1 INTRODUCTION

Public transit is a major priority in modern management of large cities and metropolitan areas in particular, due to features such as high efficiency in the use of transport inputs and alignment with sustainable development (Hadas et al., 2011).

Generally, transit users choose a service because of two reasons (Sarker et al., 2014).

- Service quality: such as walking distance, in-vehicle travel time, waiting time, number of destinations served and number of transfers needed to reach final destinations, etc. If all of these factors are taken into account, measuring transit connectivity becomes a multidimensional problem.
- Multiple routes of a transit system: To establish transit system connectivity, it is necessary to determine the extent of route integration and coordination within the network. In this context, connectivity can be used as one of the indicators measures to quantify and assess transit efficiency and performance effectively.

A public transit system consists of nodes and lines which are represented by a complex network of spatial and temporal data. The nodes are termed stops and the lines are termed links. Links in a multimodal transit network have different features from those in a road network. While a link in a road network is a physical part that connects one node to another, a link in a multi-modal transit network is part of transit line that serves a sub-sequence of transit stops (nodes). On the other hand, a stop can be served by different transit lines, and there may be multiple transit links between nodes in a multi-modal transit network. However, on a highway network there is only one link between two nodes (Mishra et al., 2012). Predominantly, a public transit station is a bridge between the people and the public transportation system. Based on this, for each station and each line passing through it, the concept of input and output power is defined by Mishra et al. (2012). The connectivity power for each station including the quality of transit services provided by the station contains fleet capacity, frequency and speed, and activity density around the station (Mishra et al., 2012; Kaplan et al., 2014). Hence the connectivity index can be defined as the summation of output and input connectivity power.

Measures of transit connectivity can be useful for transportation planning agencies in several ways. First, connectivity can be used as a performance indicator for transit stops and/or routes in order to evaluate the overall system performance, allowing public agencies to rationalize public spending in transit accordingly. Second, in rural or suburban areas, where detailed information regarding transit ridership is not available, connectivity can be translated into a measure of performance for developing service delivery strategies. Third, the connectivity measure can assess effectiveness and efficiency of a transit system to prioritize the nodes/links in a transit system, particularly in terms of emergency evacuation. Finally, transit connectivity measures offer transit users the potential to assess the quality of transit service (Welch, 2013).

In other words, the rapid growth of metropolises with increasing populations has created several problems such as traffic and disorder in the urban transportation system. These problems were the main challenges facing urban planning in the late twentieth century that affected the achievement of the goals of sustainable urban development. On the other hand, the increase in motorized transportation and large use of it in cities has caused problems such as severe environmental pollution, traffic congestion, residents' time loss, excessive consumption of energy, insecurity of roads and accidents (Vafa-Arani, 2014). Therefore, life is difficult in these environments and welfare has been reduced. Tehran is also experiencing such issues. The bus rapid transport[1] system along with the development of the Metro system has been adopted in the form of the public transit development policy in Tehran to facilitate public transit and tackle these problems (Taleai et al., 2014).

At the same time, accessibility and extensible land are applied to land use models, especially residential land. However, development of the remaining land in Tehran has been in decline in all 22 districts. It can be expected

[1] BRT

that connectivity as an indicator of transit accessibility is considered the only - main - factor of land use and TOD modeling (Lotfi and Koohsari, 2009). Due to the need for an integrated view in the field of design, planning and implementation of transport and land use policies in metropolises such as Tehran, these indices can be considered essential for establishing relationship between these two fields of urban management. Hence in this paper, public transit connectivity and its concept has been discussed as a bridge between transportation planning and land use (Mishra et al., 2012).

In the city of Tehran, urban managers offer multiple solutions. The most important among these solutions might be evaluation of performance for public transit network. One of the transit performance indicators is connectivity power of stations and lines.

The objective of this research is application of the transit connectivity index provided by Mishra et al. (2012) to the multimodal transit network in the city of Tehran, and its use in order to propose policies for the improvement of city planning in line with transit-oriented development. To compute this index, we rely on a graph theory approach that determines multimodal transit network performance by quantifying measures of connectivity in three steps: node, line and regional connectivity.

The paper is structured as follows. Section 2 introduces the literature review, followed by the methodology section introducing transit connectivity indices (node, line and regional connectivity measures) applied in this study and a description of the study area. Section 4 presents the multi-modal public transit network data for the city of Tehran including Metro, BRT and Bus, followed by section 5 which is dedicated to the findings and results of the study. Section 6 concludes the paper with the final and most important conclusions of the study.

2 LITERATURE REVIEW

Public transit is a connector between people and essential needs of life such as jobs, education and shopping. Urban travelers are concerned with distance between people and public transport stops (level of accessibility) and the mobility of public transportation services, whereby mobility is defined as the ability to travel and accessibility can be measured by the length of a journey from one's house to work with public transit (Sanchez et al., 2004). The most common method of measuring mobility is to evaluate the frequency of a service at a particular node. Thus connectivity helps expand performance to meet the demands of multimodal transportation systems (Hadas et al., 2011). Cheng and Chen (2015) showed that connectivity and accessibility are key related concepts, so that connectivity means the linkage among regions and centers of activity, and accessibility addresses the ability of people to reach destinations by different modes of transportation. Therefore, connectivity is a major indicator of people's access to the multi-modal transportation network. After this study, Papa and Bertolini (2015) proved that rail-based accessibility is higher in urban areas where inhabitants and jobs are more concentrated around the railway network and in lesser measure in urban areas with higher values of network connectivity. In the literature, there are different approaches to define and quantify the concept of connectivity. Broadly, connectivity measures have been investigated in the field of social network and graph theory. However, their application to public transit is confined. The first measure is degree of centrality which has been defined as the sum of graph-theoretic distances from all other nodes, where the distance from one node to another is defined as the length of the shortest path from one to the other (Freeman, 1978). Based on this, nodes with low nearness grades have short distances from others, and will tend to be more accessible. In topology and related fields of mathematics, nearness is a widely used concept and one of the basic elements of relationship in a topological space. Another form of centrality commonly used in the literature is betweenness centrality which can be defined as the share of times that a node relies on another node to reach a third node via the shortest path. In other words, betweenness centrality essentially counts the number of geodesic paths that pass through a node (Mishra et al., 2012). This approach is developed by Sarker et al. (2014) for multimodal transit network.

For multimodal transit networks, Park and Kang (2011) demonstrated transit characteristics when measuring the connectivity index of a node. Two years later, Hadas (2013) presented a unified methodology for extracting, storing and analyzing public transit data as derived from different public transit systems using spatial analysis based on Google Transit data in which network coverage level, average speed, intersection coverage level, stop transfer potential and route overlap were used as connectivity indicators for comparison. This method authorizes partly new spatial and temporal planning with GIS methods that use the topological, geometric, or geographic attributes that characterize an entity.

In recent years, Ceder (2007, 2009, 2010 and 2014) has applied the transit connectivity measure for different cities, and has quantified it for a set of multiple and feasible transit paths for each origin-destination pair, including the three shortest paths and the three most popular paths to account for the probabilistic nature of transit path choice. Furthermore, he constructed a set of both quantitative and qualitative attributes that represent the spatial, temporal, information, and capacity factors; the common denominator for all transit services is the quality of the following connectivity attributes: average walk time, variance of walk time, average wait time, variance of wait time, average travel time, variance of travel time, average scheduled headway, variance of scheduled headway, smoothness (ease) of transfer, availability of easy-to-observe and easy-to-use information channels, and overall intra- and inter-agency connectivity satisfaction.

Mishra et al. (2012) proposed the measures to determine connectivity from a graph theoretical approach for all levels of transit service coverage integrating routes, schedules, socioeconomic, demographic and spatial activity patterns. They introduced the aim of using connectivity as an index to survey and evaluate transit service in the following fields: prioritizing transit locations for funding; providing service transfer strategies, especially for areas with large multi-jurisdictional, multi-modal transit networks; providing an indicator of multi-level transit capacity for planning objectives; evaluating the effectiveness and efficiency for node/stop prioritization; and making a user friendly tool to determine locations with higher connectivity while choosing transit as a mode of travel.

Recently Sarker et al. (2014) developed a new methodology to measure transit connectivity that does not require detailed socio-economic, demographic, transit ridership data and transit assignment models. In this research, the methodology incorporates a graph theory approach to assess the performance of large-scale multimodal transit networks by quantifying indicators of connectivity at multifold levels including transit stops, links and lines. It also considers the unique qualities of each transit line and stop, as well as their accessibility when developing a single connectivity index.

A review of previous studies and the research gap in the field of public transit connectivity measures shows that the main factors of public transit network and land use are not synthesized for measuring this index. The present paper therefore aimed to evaluate the connectivity index as a new approach to the relationship between transportation planning, land use and TOD.

3 METHODOLOGY

The connectivity index is derived from graph theory approach, where a measure of transit connectivity was proposed by Mishra et al. (2012) to determine multiple lines per origin–destination pair in the complex multimodal network. In other words, this index measures the degree of connection to each node in the multi-modal public transport network.

In this study, the methodology for measuring transit connectivity consists of three steps: (i) Node connectivity: calculation of inbound and outbound connecting power of transit or service level at stations (nodes), (ii) Line connectivity: The total connecting power of a line is the sum of the averages of inbound and outbound connecting powers for all transit nodes on the line, and (iii) Regional connectivity: The summation of the connectivity of all nodes within that area scaled by the number of nodes.

In the first step, the inbound and outbound connecting power of transit for each node is defined as (Mishra et al., 2012):

$$P_{l,n}^{o} = \alpha(C_l \times \frac{60}{F_l} \times H_l) \times \beta V_l \times \gamma D_{l,n}^{o} \times \vartheta A_{l,n} \times \varphi T_{l,n}$$
$$P_{l,n}^{i} = \alpha(C_l \times \frac{60}{F_l} \times H_l) \times \beta V_l \times \gamma D_{l,n}^{o} \times \vartheta A_{l,n} \times \varphi T_{l,n}$$

where C_l is the average vehicle capacity of line l, F_l is the frequency of each operating line l (60 is divided by F_l to determine the number of operations per hour), H_l is the daily hours of operation of line l, V_l is the speed of line l, and $D_{l,n}^{o}$ is the distance of line l from node n to the destination. The parameter α is the scaling factor coefficient for capacity, which is the reciprocal of the average capacity of the system multiplied by the average number of daily operations of each line, β is the scaling factor coefficient for speed, represented by the reciprocal of the average speed on each line, and γ is the scaling factor coefficient for distance, which is the reciprocal of the average network-route distance.

The inbound and outbound connecting power considers activity density of a transit line l at node n, which represents the ambient urban development pattern in which the transit line is situated, based on both land use and transportation characteristics. The development pattern reflects the land use activity in a particular region which can be captured by the number of households, employment, spatial distribution of activities and facilities in that area. Mishra et al. (2012) defined activity density in a number of ways. In this paper the activity density is set equal to the ratio of households and employment in a zone to the unit area. Operationally, this could be extended to cover particular urban structures or compositions of interest, to account for metrics of sprawl, walkability etc. Hence activity density is defined as:

$$A_{l,n} = \frac{H_{l,n}^{z} + E_{l,n}^{z}}{\Theta_{l,n}^{z}}$$
$$T_{l,n} = \frac{\sum P_{l,n}^{t}}{\Theta_{l}^{z}}$$

where, $A_{l,n}$ is activity density and $T_{l,n}$ is a transfer-scaled index. Also, $H_{l,n}^{z}$ is the number of households in zone z containing line l and node n, $E_{l,n}^{z}$ is employment for zone z containing line l and node n, $P_{l,n}^{t}$ is the total connecting power of line l at node n; Θ_{l}^{z} is the number of lines l at node n.

In the two steps, the line connectivity can be defined as follows:

$$\theta_l = \frac{1}{|S_l| - 1} \sum P_{l,n}^{t}$$

where, S_l is the set of stops in line l.

And in the last step, the regional connectivity index equation is defined as:

$$\theta_R = \frac{1}{|S_R| - 1} \sum P_{l,n}^{t}$$

where, S_R is the set of stops in region R.

3.1 STUDY AREA

Tehran, the capital city of Iran, is geographically located at approximately 35° 45' N and 51°24' E. The area of Tehran is about 776.96 km^2. This city is divided administratively into 22 regions and 123 districts and 374 neighborhoods (Statistical Yearbook of Tehran, 2014).

According to the Census of the Iran Statistics Center in 2011, Tehran has a population of 8,154,051 and 2,597,731 households compared to 2006. In addition, the average population growth is 3.1 in Tehran after ordinary households compared to 2004 (General Population and Housing Census, 2011). Population for the different 22 regions as of 2015 is shown in Fig. 1. As can be seen in this figure, districts 2, 4, 5 and 15 have the highest population. Thus it can be said that these districts produce the most trips.

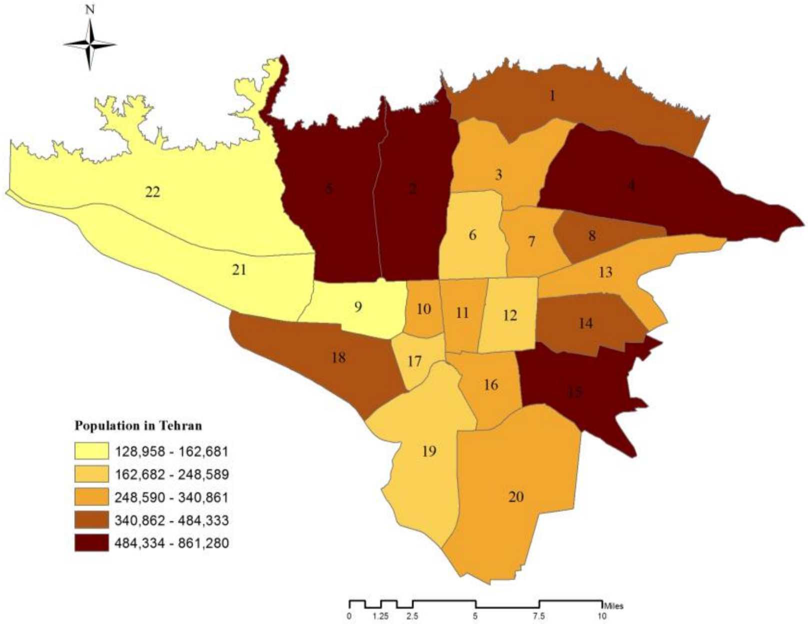

Fig. 1 Population of the 22 municipality districts of Tehran city in 2015

3.2 THE URBAN CONTEXT

An efficient public transport system is critical for developed countries. However, the cities in developing countries are typically characterized by high-density urban areas and poor public transport, as well as control of land use, resulting in pollution, congestion, and a host of other transportation problems. Generally, public transport planning and management is relevant and suitable for developing countries, addresses current transportation system inefficiencies, explores the relationship between mobility and accessibility, and analyzes the results for future use (Verma and Ramanayya, 2014). As one of the developing world's major cities, Tehran has been active over the last few years in the field of transportation infrastructures, including the metro and BRT network.

Tehran Municipality is currently organized as a mono-centric city with a major CBD (districts 6, 7, 11 and 12) where most commercial activities are concentrated. This is surrounded by several residential areas. Therefore, districts 6, 7, 11 and 12 attract the most trips in Tehran, because of the higher land use characteristics. In Tehran, most of the future urban development is anticipated to be accomplished in the north and eastern divisions of the city with lower levels of development in the south of the city (and districts 21 and 22) for decentralization (Allen, 2013).

Tehran's bus system has a huge network of buses, trolleybuses and Bus Rapid Transit (BRT) (Tehran Municipality Statistics, 2013).

- The Tehran Bus Company is one of the Subsets of Tehran Municipality, and it has been established since the 1920s. This company started operations with 246 buses and 5 lines of 30.6 kilometers at 1955. However, 150,000 travelers are carried daily by them, but the quality of both services and vehicles was weak at the end of the twentieth century.
- Tehran Bus Rapid Transit was founded to change attitudes and cause great upheavals in the structure of transport management and urban traffic. Typically, it is a symbol of the application of science and technology in operation to address Tehran's issues. BRT was officially started in 2008. In that time, Tehran BRT had three lines with 60 stations in different areas of the city. As of 2011, BRT had a network of lines with 100 kilometers (62 miles) which carried 1.8 million passengers daily. However,

the proper context of this massive project is applied integrated management and inter-agency coordination between operating organizations and agencies in the field of urban management.

Tehran Metro is called a set of Tehran urban trains and "Tehran Urban and Suburban Railway Company". Planning of the construction of Tehran's Metro started in the 1970s. The first two of the eight projected metro lines were started in 2001. This system consists of four operational lines, with construction beginning on a further two lines in 2007. As of 2014, 815 million trips were made on Tehran Metro. In 2015, the total system was developed to be 110 miles long. It is planned to have a length of 270 mi with 9 lines once all construction is complete by 2028. This service runs trains from approximately 05:30 to 23:00 all days of the week, and carries daily more than 3 million passengers (Statistics of Tehran Urban and Suburban Railway Company, 2015).

Generally for Tehran public transit, the metro is defined as a first layer of a multimodal public transit system, and the BRT network consists of 10 high speed lines as the second layer. However, it will be required to develop both qualitatively and quantitatively.

3.3 MODAL SHARE

Every day in Tehran about 18 million trips are undertaken, chiefly with specific objectives. Trip purposes may be divided into four groups, including work, education, shopping and leisure trips (Tehran Municipality, 2014). In the meantime, it is necessary to become acquainted with the number of trips attracted and produced from anywhere in the city to recognize and appropriate transportation planning. In 22 districts of Tehran at 2011, the number of trips produced and attracted are 6,799,911 and 6,799,906 (Tehran Municipality Statistics, 2012). Also, 22 % of trips are made by bus, 23 % by shared taxi, ten per cent by metro, ten per cent by minibus, seven per cent walking and cycling and the rest by private car (28 %). These vehicles were responsible for 88 % of local air pollution annually (Hashemi, 2010).

3.4 DEVELOPING A VISION AND STRATEGY FOR THE TEHRAN PLAN

Tehran Municipality worked hard to develop a visionary strategic plan for transport ‘Tehran in 2025’ during a five year period (2003–2008). This comprehensive plan is based on the wider ‘Tehran’s Comprehensive Strategic Development Plan – 2025 Outlook’. By 2025 Tehran’s road would be handling some 25,388,000 daily trips. However, if this was to be achieved, it was perfectly obvious that the mass transit options had to be seriously improved. Indeed, in the chosen scenario, public and semipublic actors provided the variety of collective transport needed for a 75 per cent modal share. The backbone of this system would require a dense, high capacity multimodal public transport network (Allen, 2013).

Tab. 1 shows the number of trips required if the ambitious target of 70 percent modal share of trips made by mass transit were to be achieved by the year 2025.

System	Mode	Trips frequency	Trips share (%)
Private	Cars and lorries (LDV and HDV)	3,960,000	22
	Motorcycles	540,000	2
Public	Urban railway	8,100,000	30
	Urban bus	9,036,000	32
	Minibus and vans	2,402,000	8
Semi-public	Taxis all types	1,350,000	5
Total		25,388,000	100

Tab. 1 Modal predicted share of trips by mass transit in 2025 (Tehran Municipality, 2009)

Based on Tab. 1, urban rail and urban bus will have the most trips. Hence, the largest budgets should be allocated to these modes in strategic development. Therefore urban rail and bus networks should be designed with proper planning as regards stations and lines, so that these stations and lines create a public transit network with the best performance. One of the public transit network performance indices is the connectivity index.

4 MULTI-MODAL PUBLIC TRANSIT NETWORK DATA

In this study, Tehran was selected according to the multi-modal public transit network and traffic crisis. The public transit network data employed in this study were taken from the Tehran Traffic Control Company, and the Tehran Urban and Suburban Railway Operation Company. These data include the stations and lines (Bus, BRT and Metro) for different regions and areas of Tehran municipality.

4.1 BUS AND BRT NETWORK IN TEHRAN

Based on the database received from the Tehran Traffic Control Company (public transit sector), the bus and BRT network has 463 sweep lines and 4750 stations at 2015, so that a 6500 bus fleet is active in this network. This database was classified by nine fields such as bus speed and driver code. The data show that 4.5 million people are displaced by buses throughout a day in Tehran, and the bus share of daily mobility is about 20 percent in Tehran. In this study, due to the high volume of the bus database, data were extracted from one day on 05/11/2015[2]. For this day and after filtering there were 5,420,623 records for each bus (based on the bus driver code), and 5342 active buses. This database was analyzed by SQL Server 2014 software. The bus network coverage consists of stations and lines as shown in Fig. 2. As can be seen from Fig. 2, most of the node connectivity is concentrated at the city center with many nodes.

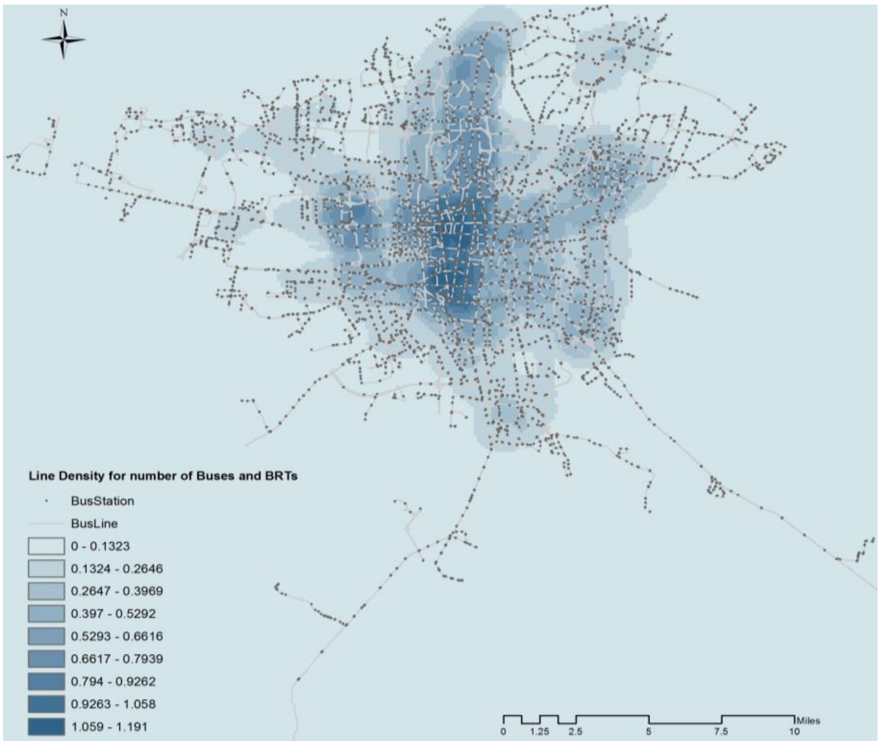

Fig. 2 Bus lines coverage by the number of buses in Tehran Bus network

[2] This day was Monday, a mid-week day, because of public transit usage and travel behavior in Tehran. In addition, the day was not a public holiday.

4.2 URBAN RAIL NETWORK IN TEHRAN

Tehran Metro is concerned as a strategy to improve the traffic in Tehran. However, the ability to take advantage of public transit is not considered in its planning. Such lack of attention to the dimensions of this approach in building subway stations means that large groups of people are denied access to the metro network of Tehran. Tehran metro has an average daily travel demand of more than two million passengers, with low fares being paid by travelers.

According to statistical analysis of the current situation, the current metro trains are active on lines 1, 2, 3, 4 and 5 throughout the 183-kilometer line. In this study, Tehran Metro network data have been collected by Tehran Urban and Suburban Railway Operation Company, the database includes performance information and reports of passenger trips. Tab. 2 shows information on Tehran and Suburban metro lines operating at 2015. Line 2 in Tehran Metro network has the highest number of daily ridership and line 5 the lowest.

Line number	Number of daily ridership (ordinary days)	Number of stations	OD travel time (min)	Number of trains
Line 1	398	29	70	29
Line 2	424	22	47	27
Line 3	138	15	55	8
Line 4	322	18	40	17
Line 5	186	10	52	15

Tab. 2 Tehran and suburban metro lines characteristics

Also, trip generation information is shown for each line at different times in a day (Monday, 05/11/2015). Based on Fig. 3, it is clear that Lines 1 and 3 had the highest and the lowest number of trips, respectively. In addition, the peak of trips is between the hours of 7 to 8 and 17 to 18.

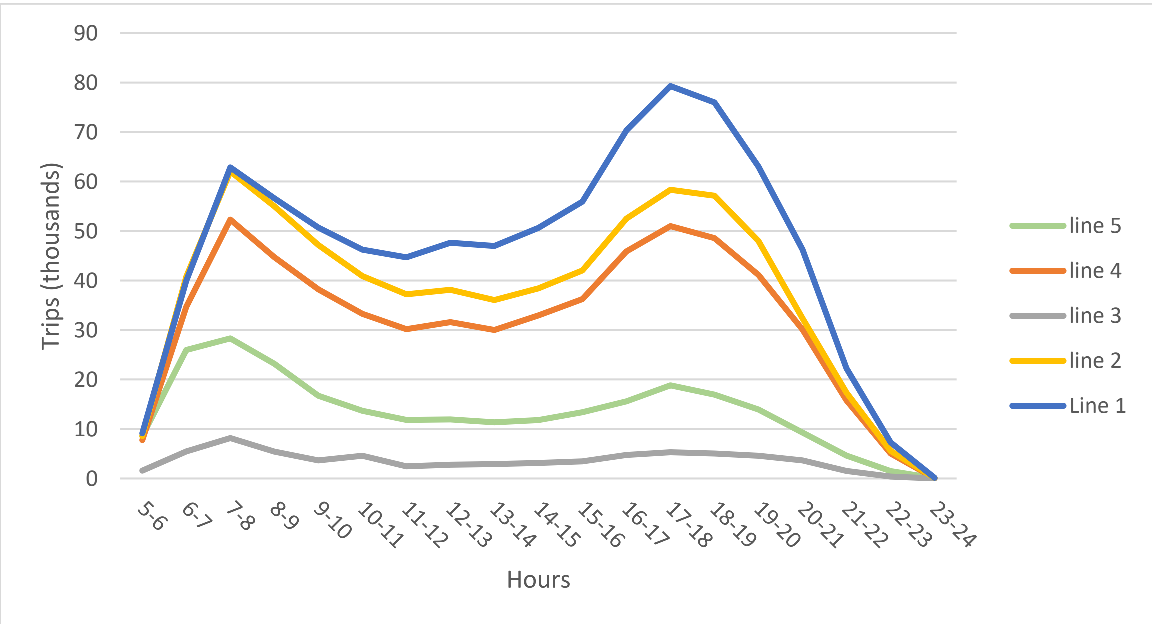

Fig. 3 Number of daily metro passengers by line in Tehran

5 FINDINGS

This section presents the results of the methods described in the previous sections for the multimodal transit network in the city of Tehran. The analysis of transit connectivity in the nodes, lines and regions focuses on the performance factors of transit networks (bus and metro), such as capacity, speed, frequency and distance of buses and metros. Based on section 3, characteristics of the household population and employment are added in the connectivity index. Tab. 3 presents summarized results of regional connectivity measures for the bus and metro networks. Based on these results, the average regional connectivity measure for the bus network is more than the metro network. Therefore, the bus network performs better, based on transit connectivity, than the metro network in Tehran. On the other hand, the standard deviation of this measure for the metro network has a high value, because many areas of Tehran are not covered by metro stations.

Regional connectivity measure	Number of observations (Municipality areas)	Average measure	Standard deviation
Bus network	123	8.43	13.81
Metro network	123	5.03	14.76
The whole public transit network	123	8.01	13.74

Tab. 3 Summary results of the regional connectivity measure

5.1 NODE CONNECTIVITY MEASURE

Tehran's multimodal transit network has many stations, comprising metro, bus and BRT. To measure the node connectivity index, it is calculated for each node (station) due to the modes.

Fig. 4 shows the node connectivity results for the bus and BRT transit network in the city of Tehran at the bus station level. As the map shows, most of the node connectivity in concentrated at the city center with many nodes in the center along routes going north and south, because these nodes are placed on the BRT and bus lines with high frequency and capacity. In general, the highest node connectivity is in area 1 in region 12.

Fig. 5 plots the node connectivity for the metro network. It can be observed that the best connected nodes are concentrated in the city center. The Tehran metro network has five lines and 86 stations, with nine stations connecting the two lines. These stations have the best connectivity on the metro network, because the metro performance factors (capacity, frequency and connected lines) are better than other stations.

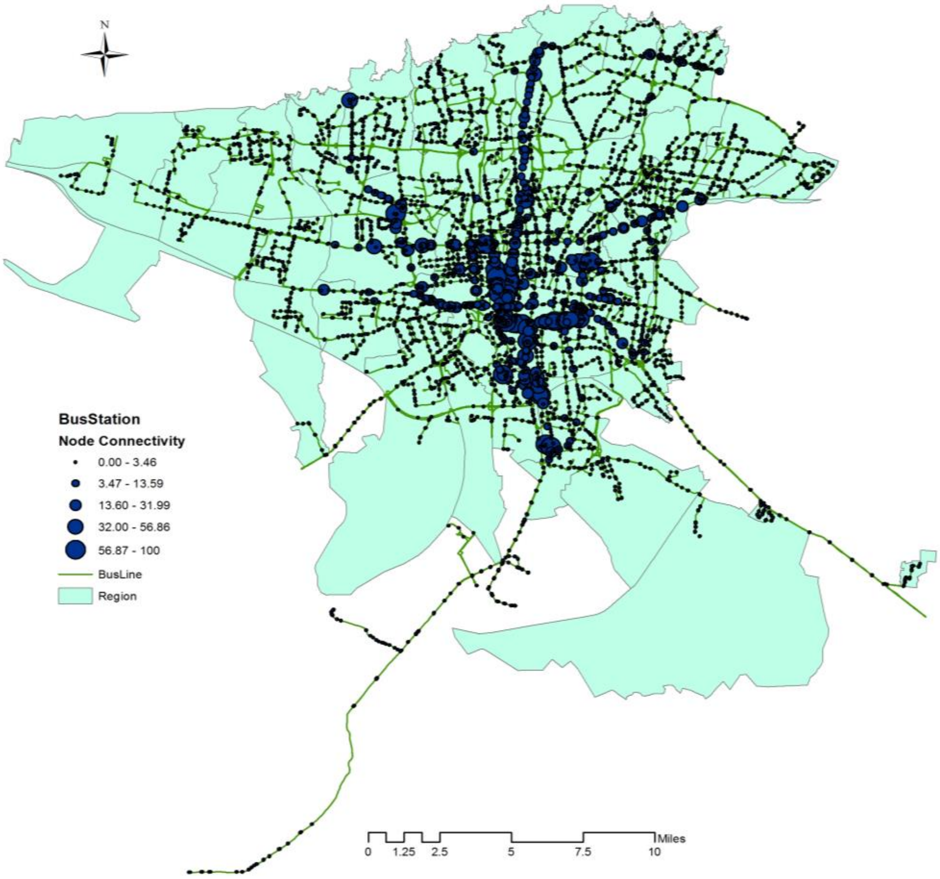

Fig. 4 Node connectivity for the bus and BRT network

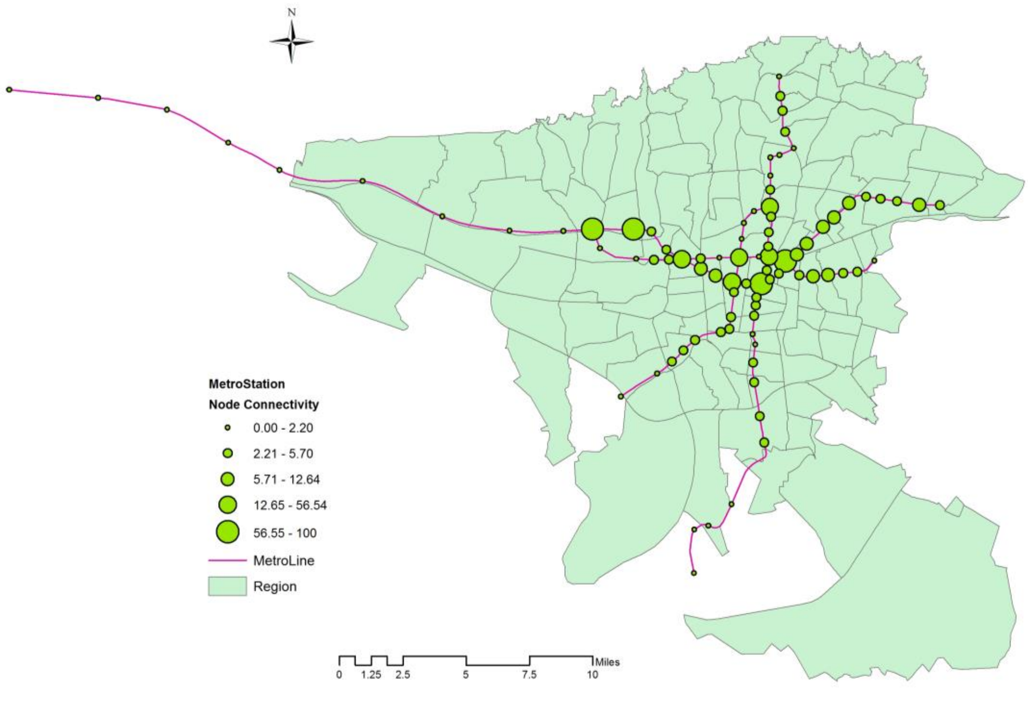

Fig. 5 Node connectivity for the metro network

5.2 LINE CONNECTIVITY MEASURE

In this study, the line connectivity index is applied to the transit network for the city of Tehran. This section provides both metro and bus modes.

Fig. 6 illustrates the line connectivity index for the bus and BRT networks. Because the transit line factors obtained (frequency, speed, capacity and other factors) for western and eastern regions are better than southern and northern regions, line connectivity for these regions (north and south) is higher than in western and eastern regions. The map clearly shows that there is a concentration of highly connected lines that are near regions 12 and 16 because the number of bus and BRT lines in these regions pales in comparison to other regions.

As can be seen from Fig. 7, the best line connectivity measure for the metro lines (87.26) is shown in dark brown (line 4). In contrast to line 4, the measure for line 3 (light yellow) is equal to 16.42, showing that it has the worst line connectivity.

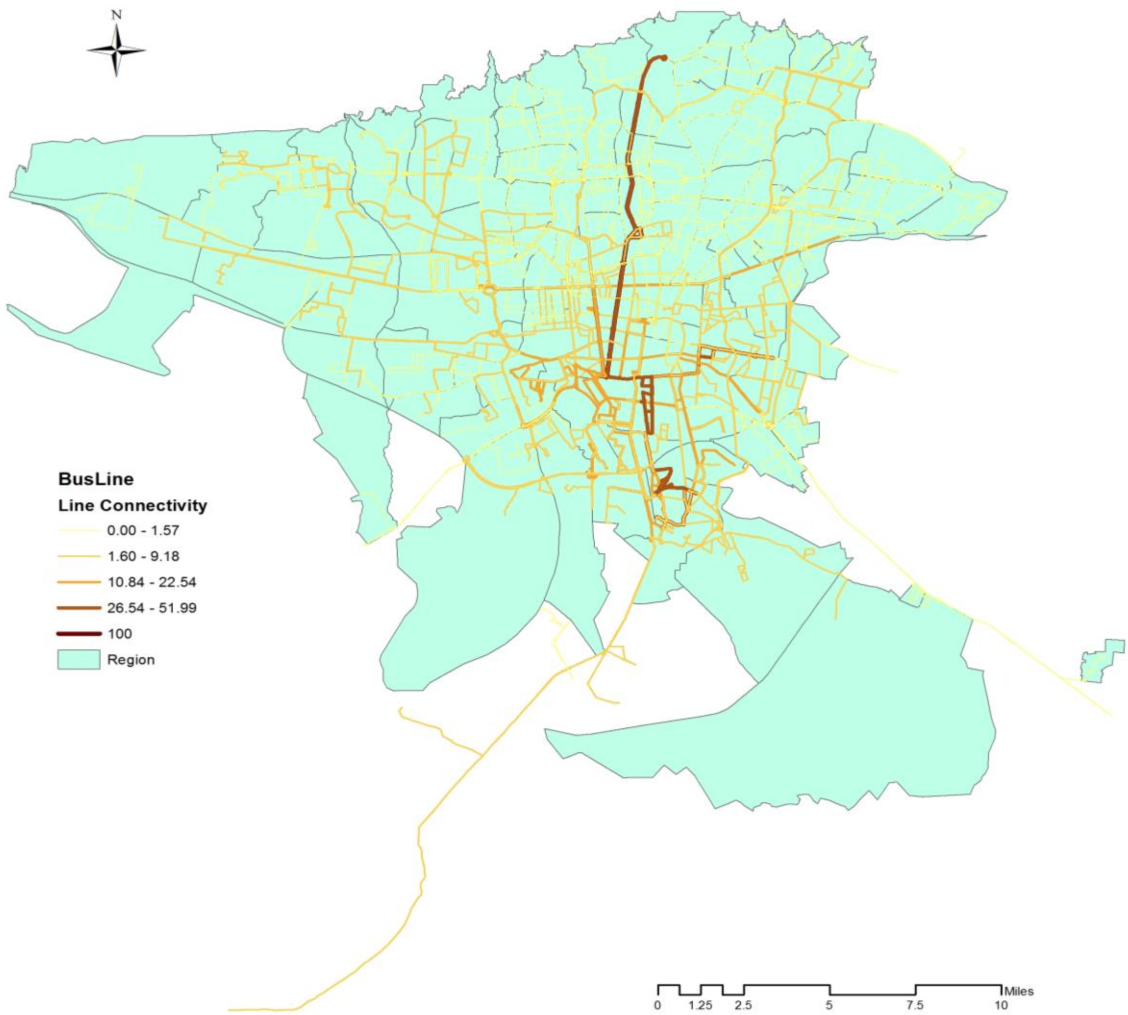

Fig. 6 Line connectivity for bus and BRT networks

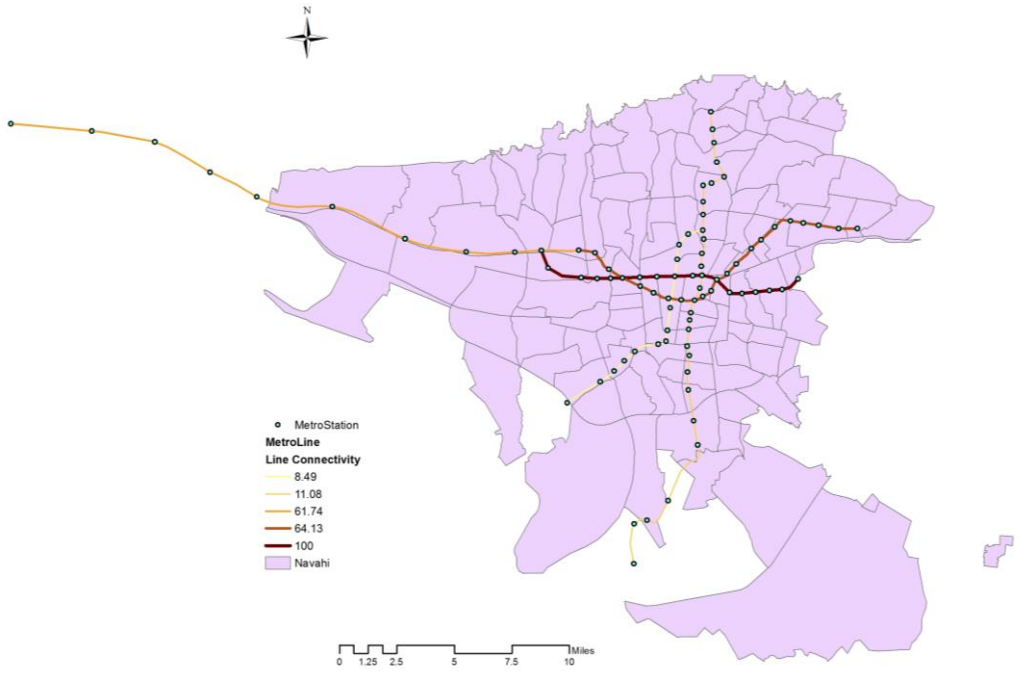

Fig. 7 Line connectivity for the metro network

5.3 REGIONAL CONNECTIVITY MEASURE

Transit connectivity was calculated for each zone within an analysis location. Fig. 8 shows the connectivity of each area for bus and BRT networks. In the figure, areas in dark green have high levels of connectivity under the definition offered in the earlier sections of this paper. As can be seen, areas in light green have very low connectivity. The map clearly shows that areas with major transit services are higher in connectivity. By comparing Fig. 8 with Figs. 5 and 7 it can be seen that due to the high node and line connectivity in bus and BRT networks, the overall connectivity in central areas (a high-performing network) is better than in other areas of Tehran.

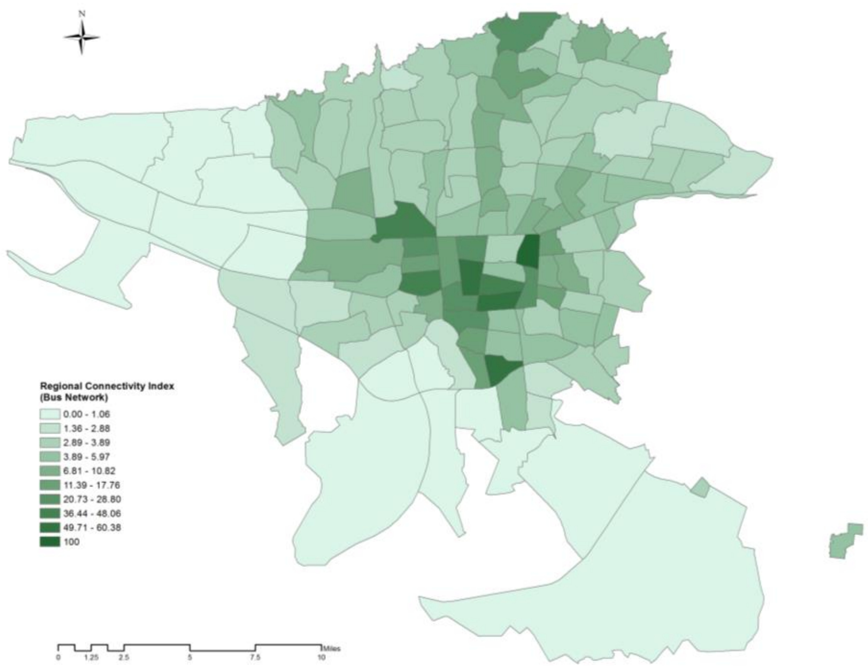

Fig. 8 Regional Connectivity for Bus and BRT Network

Fig. 9 plots the regional connectivity for the Tehran Metro network. As can be seen from Fig. 9, connected areas from North to South and East to West in the city of Tehran have better connectivity than other areas. According to Fig. 6 and 8 it can be seen that the Tehran Metro network just to be covered these areas. It is clear from Fig. 9 that the areas in dark green are better connected because the stations located in these areas connect two high-performing lines.

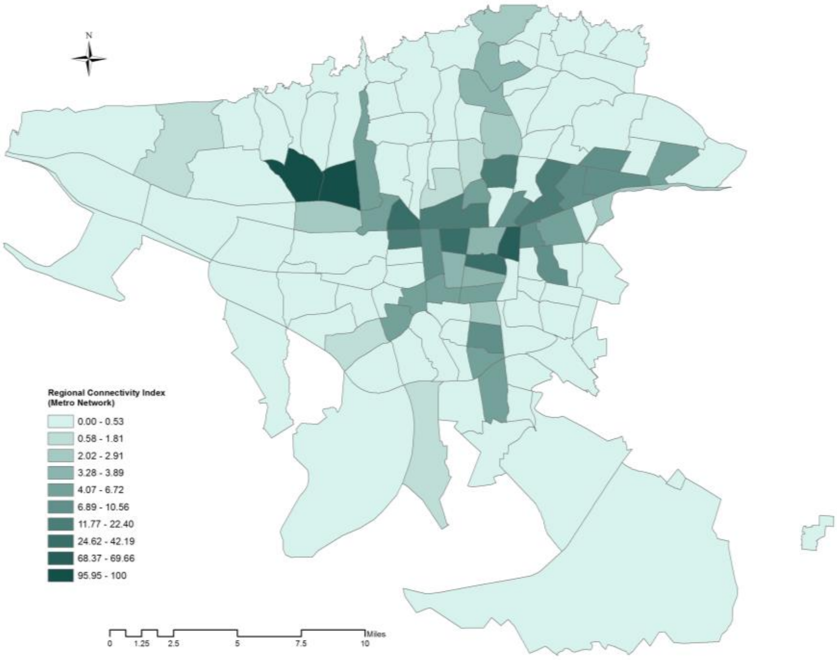

Fig. 9 Regional Connectivity for Metro Network

Finally, by combining the regional connectivity for metro and bus, we reached the total connectivity for each area. Fig. 10 displays total connectivity of public transit in Tehran areas. Based on Fig. 10, we find that areas where there are metro and bus with respect to other areas have better connectivity. Generally, Fig. 10 is a combination of Fig. 8 and Fig. 9.

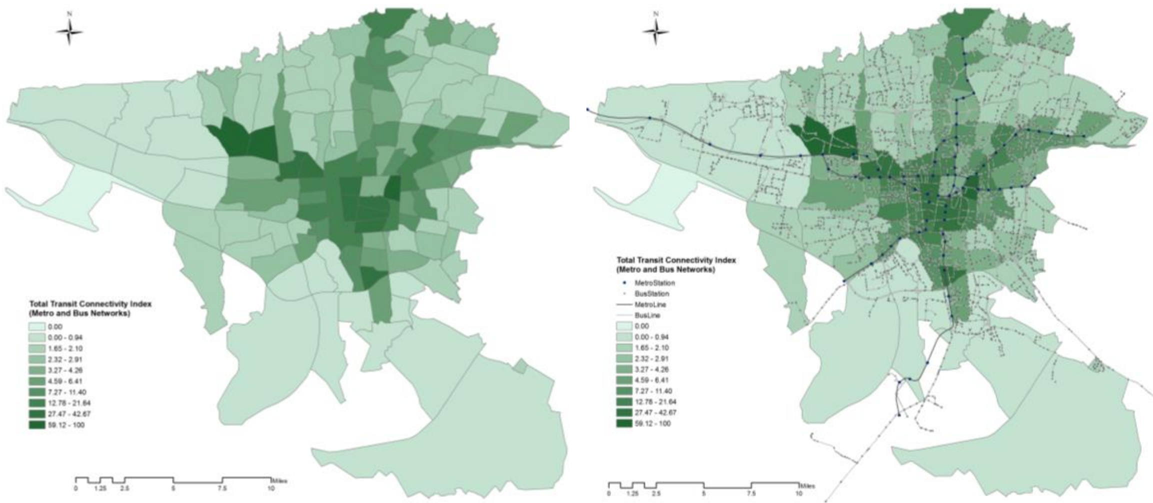

Fig. 10 Total regional connectivity for multi-modal transit network (Metro and Bus)

In Fig. 10, dark green areas have the highest connectivity. One of these areas includes the Sadeghiyeh Metro Station. Sadeghiyeh lies at the junction of Tehran Metro Line 2 and Tehran Metro Line 5, lines which have high connectivity. It is located in the vicinity of the Mohammad Ali Jenah Expressway and Tehran-Karaj Freeway at the western end of Line 2 and eastern end of Line 5. The next station in Line 2 is Tarasht and the next station in Line 5 is Ekbatan. It also has a wide parking area and is considered the most crowded Tehran metro station. Additionally, this station is covered by bus mode.

The results suggest how future investments in rail and bus should be prioritized. The metro has a major role to play in enhancing network performance and, if combined with bus and BRT modes, can provide the areas concerned with high connectivity.

6 DISCUSSION AND CONCLUSION

Recognition of public transit connectivity (supply side) and potential need for this service (demand side) in each municipality area and their distribution are important to transportation planners, because of the crucial role of the public transit system in mass displacement of people and its compliance with sustainable development and social equity (Kaplan et al., 2014). Studies and researches conducted on Tehran indicate a uniform attitude across the public about transit use in the two neighborhoods from one area. The most apparent difference concerns the negative effect of poor accessibility on public transit: the main reason for not using public transportation is "Little accessibility to stations, long distance between the stations" (Masoumi, 2013).

In this regard, this paper examined the public transit connectivity index, which was generated from graph theory as indicated in previous researches. The connectivity index was determined in three steps in the multimodal transit network of Tehran: node connectivity, line connectivity and regional connectivity. The concept of connectivity defined as the level of service such as transit frequency, speed, line distance and capacity is particularly widely used in public transit analysis. The transit network in the city of Tehran includes three modes: BRT, Bus and Metro. The connectivity index is applied by urban form with differences among geographical, land use, highway and trip pattern characteristics between regions.

By calculating nodes and lines connectivity for each area, as well as comparing this index through the population and employment in each area, areas with poor access to services were identified. For areas with low connectivity measures, new lines can be designed to improve connectivity of these areas. Connectivity measures can also be used for identification and improvement of poorly connected areas, Transit-Oriented Development and sustainable development, Based on the weaknesses of the regions/areas in using of public transit services and the severity of this issue, priority of transit projects should be prioritized to be conducted in regions with poorer connectivity.

In this study, Tehran's municipality districts were examined in terms of public transit connectivity, whose results were also exhibited on maps, by integrating the methodology with GIS.

Several policies can be obtained by interpreting and scrutinizing the results as follows:

- In poor areas, urban planners can design bus or/and metro stations with high performance to facilitate comfortable transfers to provide access to crucial services.
- Although there may be many transit stations in an area, connectivity power for this area may be low because of the low level of service for these stations. One of the factors is fleet frequency passing through these stations (waiting time at stations). On the other hand, passengers are usually restless and find delayed buses a big problem; city governments should encourage bus agencies to increase fleet frequency to decrease waiting times.

Sarker et al. (2014) demonstrated that the connectivity measure can assess effectiveness and efficiency of a transit system to prioritize the nodes/links in a transit system. Therefore, the use of a connectivity measure can help urban managers increase efficiency of Tehran's multimodal public transit network (especially the metro network). Additionally, Litman (2015 and 2016) defined efficiency as not being able non-drivers to access education, employment, shopping and recreation. Different factors can affect accessibility such as travel speed and affordability, the quality of transport options, transport network connectivity, land use accessibility, and mobility substitutes such as telecommunications and delivery services. From this perspective, transport systems are most efficient if they increase road network connectivity, support efficient modes, and encourage more accessible land use. This justifies integrated planning that increases transport network connectivity and supports more accessible and multi-modal community development. Based on the results of connectivity calculations in section 5, regional connectivity shows that transit connectivity for suburban areas is very weak. Thereupon, despite of the many transit stations located in this areas, they are highly inefficient. As a result, transit node (station) connectivity can be considered one of the appropriate opportunities for sustainable development and enhancement in urban quality in these areas. In Tehran, this issue is very important in terms of socio-economic inequality and spatial gap between the north, south, east and west of the city. According to the development of public transit systems such as the metro in Tehran, awareness of the efficiency of transit connectivity (especially, node connectivity) on the quality of surrounding environment in the direction of urban planning is essential. The connectivity indices can be used to identify areas with unsuitable infrastructure and to help decision makers for prioritizing areas in development planning and design of urban transit systems. In addition, transit network modeling to develop connectivity indices with other transit factors and the relation between connectivity measures and TOD indices can be evaluated in future research.

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IMAGE SOURCES

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Fig. 2: author.

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Fig. 10: author.

Fig. 11: author.

The cover page: Tehran Municipality, http://tehran.ir

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MODELLING THE SHIFTS IN ACTIVITY CENTRES ALONG THE SUBWAY STATIONS

THE CASE STUDY OF METROPOLITAN TEHRAN

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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.

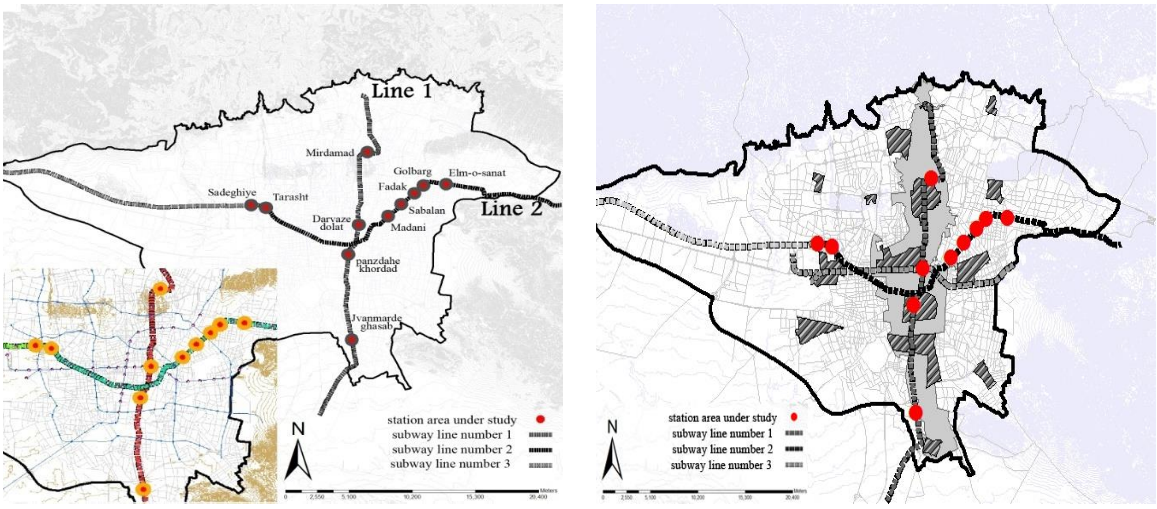

Fig.1 Network of Tehran's subway system and the stations in the case study (on the left) and Location of subway stations in relation to central zones (on the right)

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.

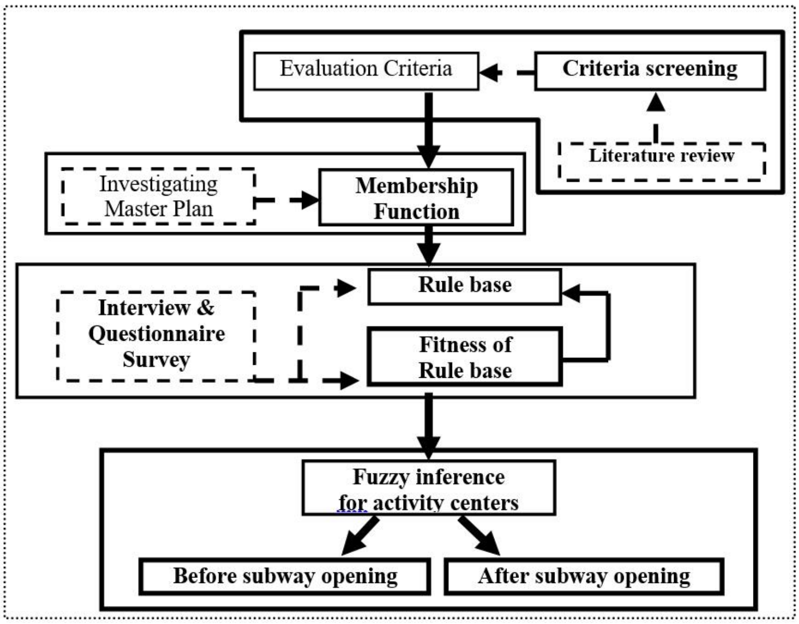

Fig. 2 The study process

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:

$$x = \frac{B_{ij} - \min}{\max - \min} \quad (1)$$

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:

$$\mu_A(x): X \rightarrow [0\ 1] \quad (2)$$

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.

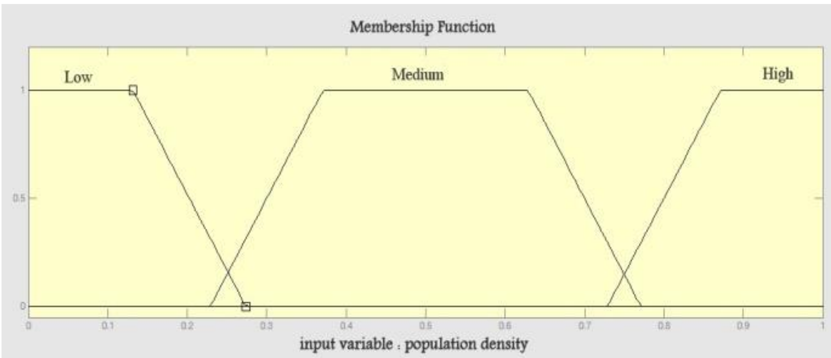

Fig. 3 Membership of output linguistic variables

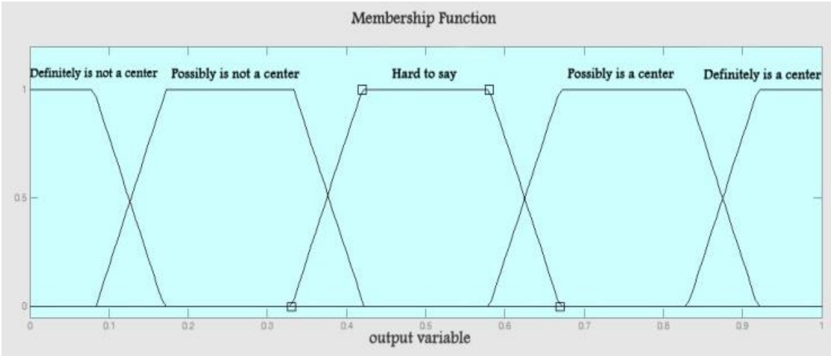

Fig. 4 Membership of inputs linguistic

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		
IF	High	AND	Low	AND	Low	THEN	Possibly is not a center
	Medium		Low		High		
	Low		Low		High		
	Medium		Low		Medium		
	Medium		Low		Low		
IF	Low	AND	Medium	AND	Low	THEN	Definitely is not a center
	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.

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

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.

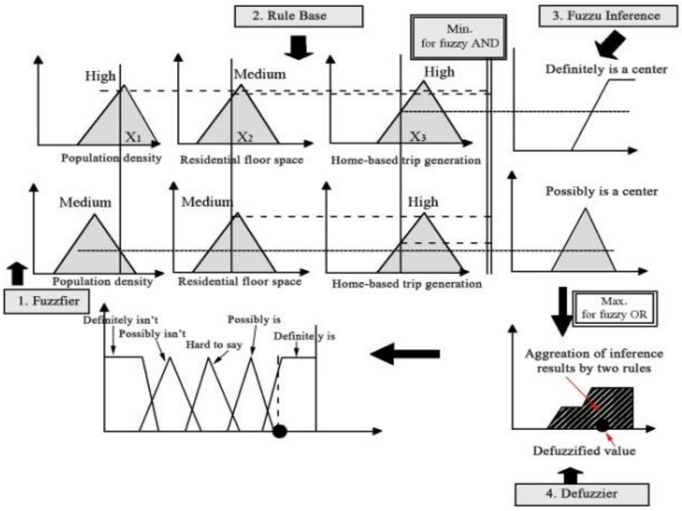

Fig. 5 The Mamdani fuzzy inference system illustrated by inference on the residential center

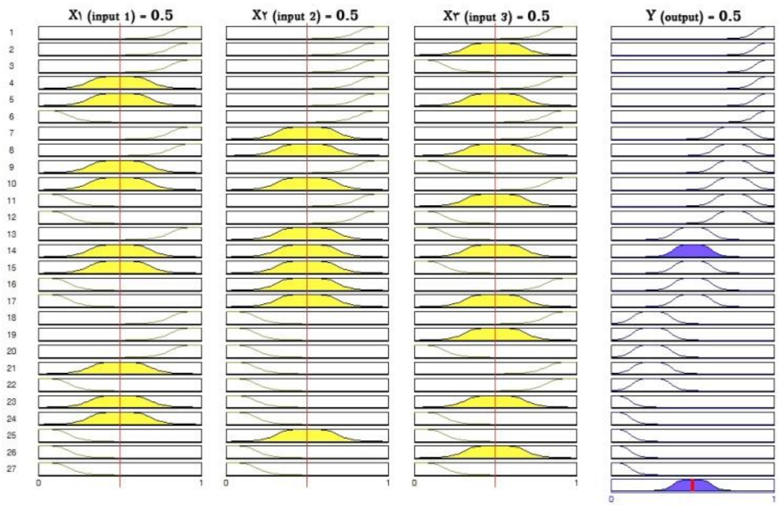

Fig. 6 Inputs (Xi) and output (Y) of the fuzzy inference

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:

$$\text{Fitness} = Ns/N \tag{4}$$

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.

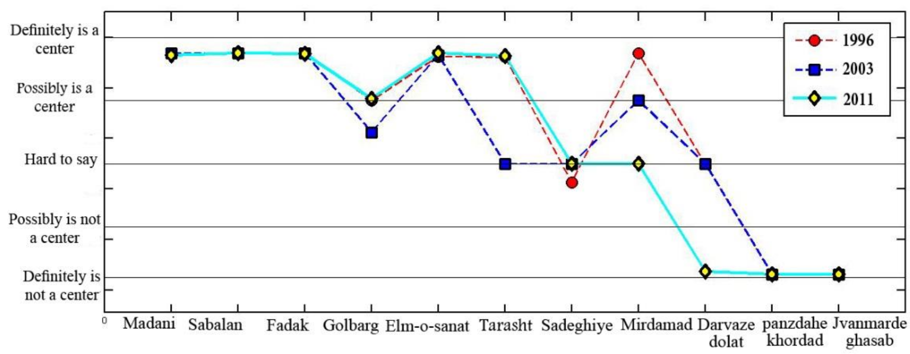

Fig. 7 Inference conclusions of residential activity

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.

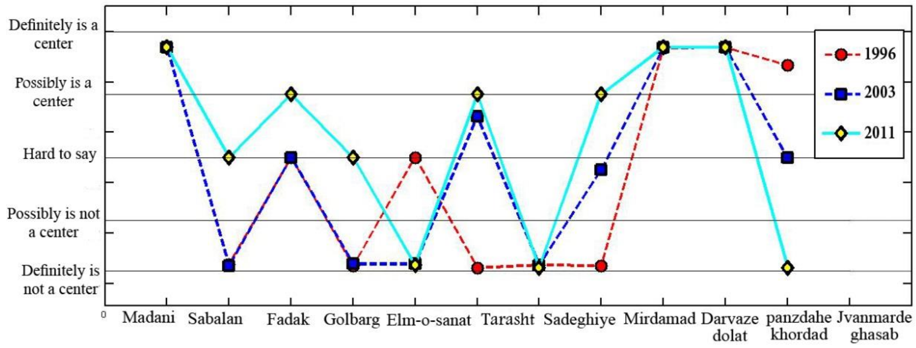

Fig. 8 Inference conclusions of employment activity

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).

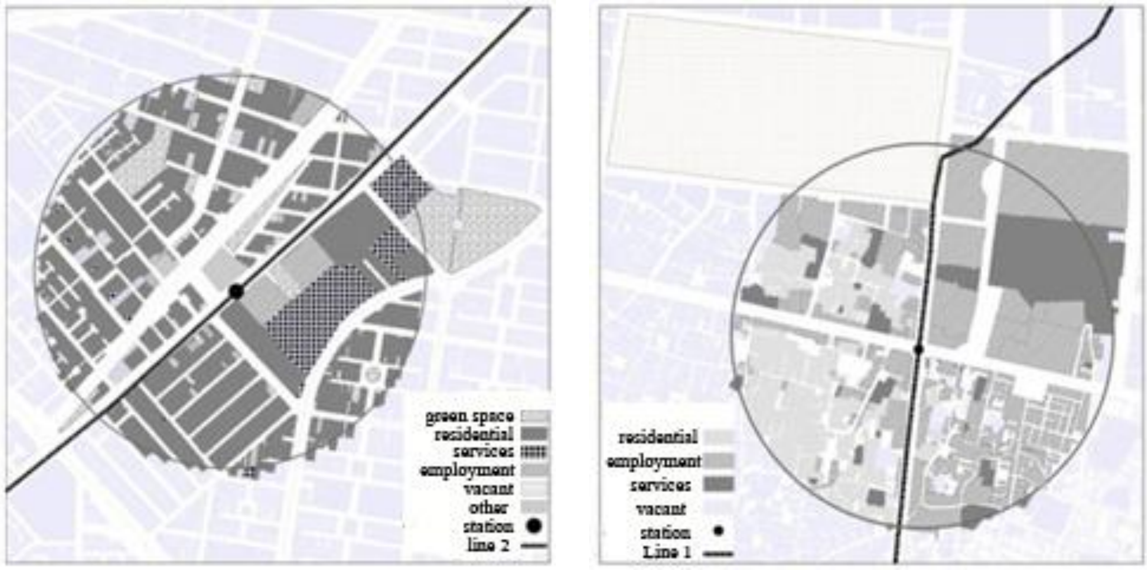

Fig. 9 Fadak station area as a residential center (on the left) and Panzdah-e-Khordad station area as an employment center (on the right)

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.

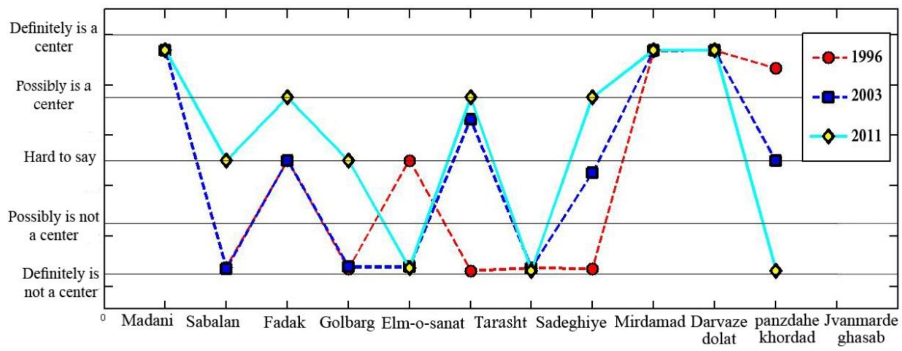

Fig. 10 Inference conclusions of services activity

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).

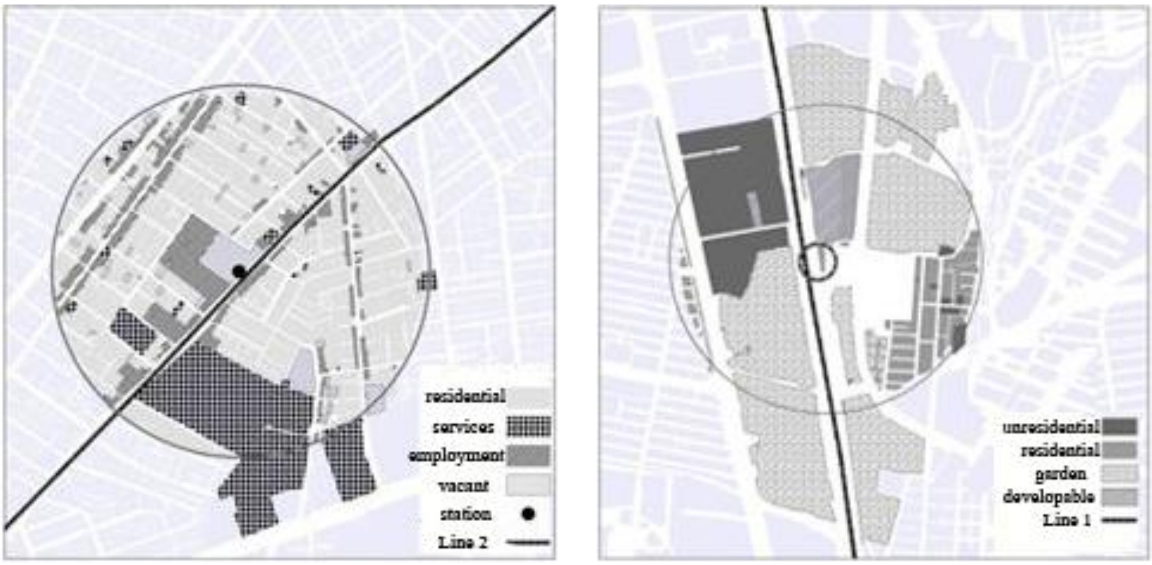

Fig. 11 Javanmard-e-Ghasab as a station with development constraints (on the left) and Shahid Madani station area as a services center (on the right)

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.

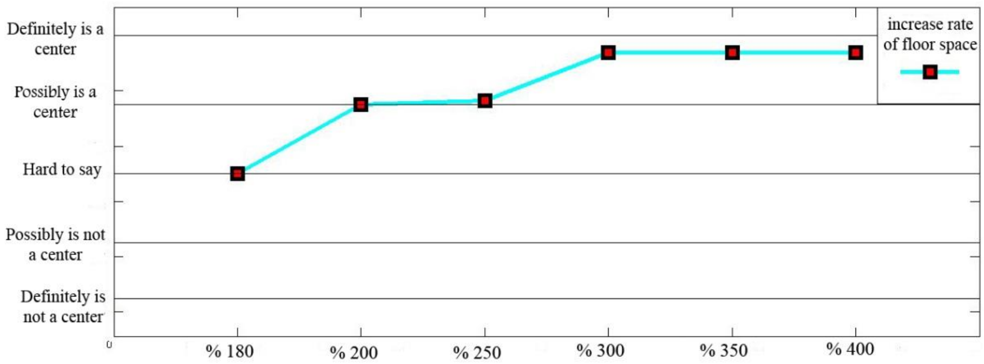

Fig. 12 Strategy analysis of employment activity for *Shahid-Madani* station area

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.

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