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RESEARCH PAPER

Urban Planning

Exploring the Dynamics of Spatial Structure Using an Interaction Pattern (The Case of Mashhad Metropolitan Region, Iran)

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Abstract

In recent decades, remarkable changes have occurred in the spatial structure of metropolitan regions, creating a discontinuous, scattered and polycentric development which have significant implications for commuting patterns. This study examines the dynamics of the spatial structure using an interaction pattern in Mashhad Metropolitan Region (MMR). Four dimensions-centrality and dominance, network cohesion, interaction strength and levels and hierarchy-were used to analyze people flows in 1999, 2007 and 2012, showing that the interaction between Mashhad and other cities in the MMR have increased over the time. The results show that the spatial structure of MMR is monocentric with traditional interaction patterns, in which Mashhad is the central node of the region and other cities are dispersed in MMR. Therefore, it is necessary to adopt an integrated approach to develop a polycentric metropolitan region in order to protect the environment and reinforce inter-city relationships, manage travel demand, reduce unnecessary trips, and restrict sprawl. These policies are led to more convergence and polycentric development.

Keywords: *Spatial structure, Interaction pattern, Mashhad metropolitan region, Passenger flows.*

1. INTRODUCTION

During the last decades, the spatial structure of metropolitan regions has remarkably changed [1-3,55]. Social-economic functions of past urban centres also changed and replaced by scattered and fragmented centres of employment, trade, and amusement [1], leading to the complexity of geographical scopes, expansion of spatial differentiation and development of connectivity in the region. On this basis, understanding new forms of the spatial changes is crucial in regional policies and strategies due to the great influence of spatial structure on inter-urban relations, economic interactions, and development of spatial justice and regional equity [4]. In recent years, the spatial structure of metropolitan regions is widely analyzed; This analysis can be categorized into four groups: 1) studies that use population data to analyze spatial structure [2, 5-7]; 2) Studies that use employment data to identify the spatial structure [3, 8-10]; 3) studies that use flows network to analyze spatial structure [11-14]; 4) studies that use one or varieties of data (population, employment, and or flows network) to analyze spatial structure in metropolitan regions [6,15].

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These groups of studies generally adopted two main approaches: atomistic and network approach [12]. An atomistic approach rooted in ideas of traditional geography school of urban systems by focusing on the concentration level of activities or functions in a specific area and based on intrinsic and local characteristics [16]. In this approach, the element of relation including linkage of parts is ignored in defining urban systems, and interaction of cities is conceptualized with hierarchical arrangements of space. Network approach focuses on relations and flows among cities and their position in outer areas of a complex network. Therefore, any change in components of the urban system can be associated with a change in its spatial configuration [12]. This approach identifies and defines status and role of nodes in urban systems regarding relations and intra-network flows; circulating flows among cities rather than to what is fixed within nodes [17-19]. Unlike the node-based atomistic approach, network approach provides a better understanding of spatial structure in metropolitan regions. Accordingly, the main prerequisite to gain a complete understanding of the spatial structure in metropolitan regions is provided by regarding a network approach to the changes of this phenomena. However, despite the fact that there is a strong body of literature in the field of spatial structure generally and there are many types of researches regarding network approach to study spatial changes specifically, the majority of these researches are focused on metropolitan regions in Europe, America and China [7]. However, the spatial changes in developing countries are not properly analyzed, showing that there is a lack of information on the way the spatial structure in metropolitan regions has transformed in these countries. For this reason, analyzing spatial changes in these countries is crucial in order to gain a complete understanding of differences between changes in terms of spatial structure in developed and developing countries. On this basis, the current study intends to analyze changes of spatial structure in Mashhad Metropolitan Region (MMR) using a network approach to explore the dynamics of spatial structure in metropolitan regions like MMR.

Demographic changes along with the rapid and unplanned growth of urban population in recent decades have led to incongruity in development of regions in Iran and increased the inequality among them, causing a great gap between main metropolitan regions (e.g. Tehran, Mashhad, Esfahan, Tabriz, etc.) and intermediate and small cities. To decentralize from metropolitan regions, regional plans were formulated, such as the formation of industrial poles in peripheral areas, tax exemptions for key industries constructed in peripheral areas, development of transportation system and infrastructure, and improvement of regional management. On this basis, the present study becomes necessary since it can significantly play a role in a better understanding of changes in the spatial structure of metropolitan regions.

Mashhad Metropolitan Region is the second biggest metropolitan region in Iran, with more than 3 million population. About 43% of the urban population and almost 50% of the surplus value of Khorasan Razavi Province concentrates in MMR. Analysis of population and economic activities show high concentration and imbalance of capital and population in Mashhad metropolis (the main centre of the region). Furthermore, the spatial development of MMR has concentrated over the east-west axis (Mashhad-Chenaran) unlike the other parts of the region. This process will create more economic, social and environmental consequences in MMR. Thus, the analysis of the spatial structure of the region is crucial in order to understand its dynamics. Despite the critical role of determining geographic, socioeconomic and institutional effects on the spatial structure of metropolitan regions, this study concentrates only on urban interaction, reflecting the outcomes of the mentioned factors in the context of metropolitan spatial structure.

On this basis, the aim of this study is to consider how passenger flows have changed the spatial structure of MMR over time?. Accordingly, the study is divided into five sections: the second section describes conceptual and theoretical issues related to the spatial structure of metropolitan regions. Section three briefly explains the methodology of the study including the study area, data collecting, effective indexes and analytical methods. Section four analyzes the spatial structure of MMR based on the flows of people. The final section discusses and concludes the results and also makes suggestions for future studies.

2. LITERATURE REVIEW

Analysis of spatial structure in the context of metropolitan regions has achieved an important position in regional studies [3,12,20]. Before the 1960s, the main theme of the studies was Christaller’s (1933) “central place theory” which was focused on understanding the special characteristics of nodes in spatial structure [21-22]. During the 1960s, the system approach took the ground, considering cities as a collection of interlinked elements. In this period, Berry (1964) first introduced the functional concept of an urban system and defined the urban network as a group of interdependent cities. Pred (1977) developed Berry’s idea by studying inter-urban relationships in national and regional scales. He implied that the relationship between cities is not only vertical but also has a horizontal nature [12,20]. Neal (2011) believed that central place theory provides an incomplete understanding of the way cities acquire unique economic role [23]. In the 1990s, the paradigm shift in theories related to spatial structure changed the direction of the related researches; For instance, the studies of urban systems, at this time, were mostly based on flow analysis rather than hierarchical size-based approaches [19, 24-26]. In this period of time, Castells (1989) introduced “space of flows” as one of the key elements of global information network, noting that social and economic activities are organized in two diverse methods; 1) “space of places” where the spatial structure of a system is defined as specific attributes of nodes; and 2) “space of flows” where the nodal interactions and network relationships define the spatial form and structure of a system [27].

Accordingly, spatial structure is defined as population (or human settlements) and employment distribution and spatial flows connecting population (or human settlements) to employment centres in metropolitan regions [1,4,15]. Thus, analyzing spatial interactions is important in understanding spatial configuration [7, 28]. In other words, interaction in the literature of spatial structure reveals that the role of nodes is mostly affected by the nodal relations and functional flows [17, 29]. On this basis, new forms of human settlements such as suburbanization processes, over the last decades, has influenced the spatial structure of interaction patterns which formed new forms of spatial structure [30] with special characteristics such as centralized versus decentralized, monocentric versus polycentric [31]. Centralized-decentralized dimension refers to the extent to which population and employment are centralized in cities or decentralized over smaller suburban places. The monocentric-polycentric dimension reflects that urban population and employment are concentrated in a city or spread over multiple cities in the wider metropolitan region [32].

Spatial interactions impact journey-to-work flows and the formation of different types of spatial patterns. Burger and Meijers (2010) took commuting distance as an index to discuss different aspects of flows, believing that work-settlement separation cause more commuting in metropolitan regions. They identified three patterns of journey-to-work: traditional commuting (commuting from peripheral regions to principal city), exchange commuting (commuting from principal city to peripheral regions) and criss-cross commuting (commuting between different parts of the peripheral regions) Fig. 1. Low degree of exchange and criss-cross commuting is the characteristics of the monocentric metropolitan regions since the majority of commuters living in the peripheral regions travel to the principal city. In a polycentric metropolitan region, commuting is reciprocal. In a polycentric criss-cross pattern, different parts of the peripheral regions are more dominant since they attract commuters from other parts of the peripheral regions. In this case, the parts of the peripheral regions play as complementary to the principal city and gain increasing importance as centres within the metropolitan region. Commuting flows are decentralized as the number of workers who commute between the different parts of the peripheral regions and bypass the principal city increases; however, the degree of exchange commuting remains low. Finally, a decentralized polycentric metropolitan region is characterized by a multi-oriented commuting pattern in which there is no dominant centre. There is a large amount of criss-cross and exchange commuting in a polycentric decentralized pattern [33-35].

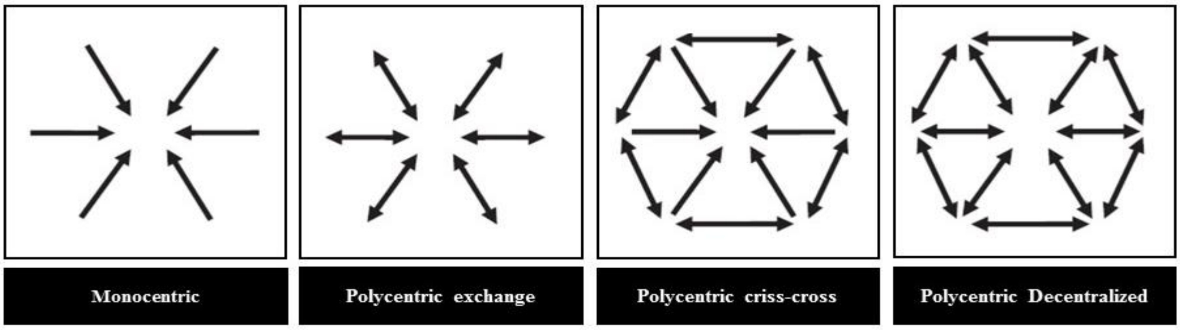

Fig. 1 Functional Typology of spatial structure patterns in metropolitan regions [33]

Bertaud characterized three different types of relationships Fig. 2. Type A represents the monocentric pattern, in which peripheral development is rare and dispersed. The workers residing in the suburb will usually have to commute to the principal city for work. Type C shows a fully polycentric pattern, in which development on the suburb is compact and, consequently, there are high local jobs-housing balance and high density. The workers residing in the suburb tend to find their job locations within or near the emerged sub-centres; thus, they travel within these subcenters or to another sub-centre. They less need to commute to the city core in this pattern than in the monocentric pattern. Therefore, the commuting trip length is short for the majority of the workers residing in the suburbs. Self-contained development on the suburb in the polycentric pattern would cause less congestion in the city core compared to the low levels of compact development on the suburb that can be found in the monocentric pattern. Between type A and type C, type B represents a transitional city which is developing from a monocentric to a polycentric pattern. In this type, suburban housing and industrial development are relatively less compact than in the polycentric pattern, and more than that in the monocentric pattern. Commuting flow is random but still has a strong tendency to move from peripheral to city core [36].

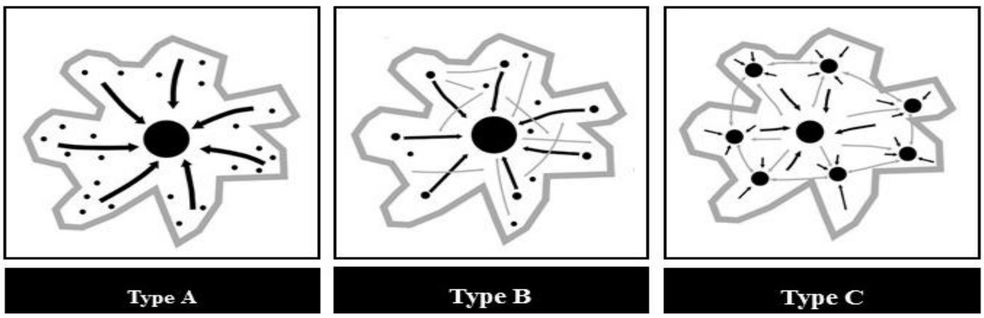

Fig. 2 Typology of interaction patterns in metropolitan regions [36]

As it was discussed in the former section, changes in the urban system and spatial structure literature led to changes in related researches; and urban systems were described based on network-based hierarchy instead of size-based hierarchy [24, 26]. For instance, Limtanakool et al (2007) categorized urban systems patterns from interaction view. They suggested a framework that includes the strength of interaction, symmetry, and network structure based upon a set of indexes offered. On this basis and using data of transportation in Europe, the pattern of interaction among functional urban regions has been studied [17]. In addition, Dadashpoor et al. (2017) developed a methodology for identifying various dimensions of the spatial configuration of urban systems in Iran based on three S-dimensions of spatial interaction of Limtanakool et al (2007). Through the provision of empirical evidence of different types of flows of people including air, bus and car flows, they used five dimensions of urban system's spatial configuration including centrality and dominance, network cohesion, network strength, network symmetry and communities and levels. Their findings show that although the spatial configurations of different flows are not the same, all of them have a meaningful distance with a polycentric urban system due to the primacy of the Tehran metropolis [12]. Ma and Timberlake (2008) in their research identified world cities of China. To do this, they analyzed both levels of world networks and national networks through air flow from 1995 to 2005. Three indexes including betweenness centrality, closeness centrality and levels and hierarchy were introduced and accordingly Shanghai metropolis was identified as a frontier metropolis in China and among world cities [37]. In another research, Zhen et al (2013), using world city network analysis methodology explained characteristics of the spatial development of an urban network in China; they used centrality and connections intensity indexes. The results of their findings show that productive service network bears positive influence on the development of an urban network in China [38]. Zhao et al., (2015) had a critical study of existing practice models related to inter-cities networks. This research focused on the development of regional corporation models by presenting a new method for approximating urban networks based on a spatial strategy of firms. Two algorithms of IWCNM and RCCM were developed and indexes of betweenness centrality and closeness centrality were used in two metropolitan regions of Yangtze River Delta and Pearl River Delta. Two main findings of this research are as follows: 1) unlike to common methods (such as the model of an interrelated network of cities), the new method creates regional and hierarchical networks which are more real; 2) the new method permits to use analyzing social networks to measure betweenness centrality and closeness centrality [39].

Studying world experiences denotes that methodology of measuring the spatial organization of urban systems based on analyzing inter-cities flows is a new one. It has been done in different geographical scales (from regional to world scale) and in accordance with different flows (air, routes, roads, information flows, and cellphone and social networks) [34]. But, few studies have been conducted in metropolitan regions and their spatial structure using flow data, especially in developing countries; this is among the differentiated point of this research.

3. THE STUDY AREA AND DATA PROCESSING

3.1. Study area: Mashhad metropolitan region (MMR)

Until a hundred years ago, Iran had a balanced urban system, which moved toward an imbalanced and heterogeneous system after land reforms (1962- 1972) and rural-urban migration. Spatially Iran has experienced imbalanced population distribution in different urban nodes as well as the imbalanced dispersion of these nodes over the territorial zone, leading to the formation of the hierarchical urban system with a dominance of great cities [6] such as Mashhad.

Mashhad as the capital of Khorasan Razavi province (in the northeast of Iran) is the second biggest metropolis of the country. The increase of population, migration, and low- income population in the centre and peripheral lands have influenced Mashhad metropolis during the last decades, intensifying interactions among Mashhad metropolis and peripheral areas. 9.6 per cent of the whole area of the province belongs to MMR, having a special political status due to its long borders with neighbouring countries such as Afghanistan and Turkmenistan.

Fig. 3 Location of MMR in Iran and Khorasan Razavi province

More than 94 per cent of the overall population of the MMR lives in Mashhad metropolis. Rich history and culture and the presence of Imam Reza holy shrine in this region provide a key role for this metropolis in national spatial development. In addition, the concentration of about 54 per cent of the population, 71 per cent of the urban population, more than 58 per cent of employees, about 52 per cent of firms, and more than 54 per cent of the added value of the province turned MMR to a unique region within the province. Two main north-to-south-axis of Mashhad-Ghouchan and Mashhad-Zahedan and also east-to-west-axis of Mashhad-Neyshabour-Tehran forms the main structure of the region's roads Fig. 3.

Analyzing urban system of MMR using rank-size rule revealed that the hierarchy of cities in MMR has a great difference deviation. Settlements with low population have far more deviation compared to the settlements with high population. The analysis of the 13-year period indicated a considerable difference of principal city with other cities in MMR with regard to the excessive concentration of population in Mashhad metropolis. The population of Mashhad increased about 3000000 in the latter period (2007-2012), while the population of Chenaran changed about 6000. As Table 1 indicates, Mashhad as the primate city was 57 times more populated than Chenaran (the second city) and 76 times more populated than Fariman.

Table 1 Population analysis of MMR based on the rank-size rule

	1996			2007			2012		
	Population	**Rank**	**Population-based on the rank-size model**	**Population**	**Rank**	**Population-based on the rank-size model**	**Population**	**Rank**	**Population-based on the rank-size model**
Mashhad	1887405	1	1887405	2427316	1	2427316	2766258	1	2766258
Chenaran	32064	59	943703	42004	58	1213658	48567	57	1383129
Fariman	26966	70	629135	33254	73	809105	36550	76	922086
Molk Abad	-	-	-	1383	1755	242732	1487	1860	276626

3.2. Data processing

Although interaction among urban regions could emerge in different types of flows such as people, goods, information, capital, etc., we focused on passenger flow among different nodes in the region since physical flows have an important role in the real interaction of people than other types of flows [26], and they are still effective in the configuration of urban systems [40].

Required data were obtained from the Provincial Transportation and Terminal Department of Khorasan Razavi. The study covered only origin-destination (O-D) flows in bus mode since only Terminals' data were available. The study area included all cities with operating terminals in Mashhad metropolitan region (excluding Torghabeh and Shandiz[1]) for 1999, 2007 and 2012. The calculation had been conducted for Mashhad, Chenaran, Fariman and Molk Abad; the data were combined with one entry for Mashhad which had multiple terminals; for other three cities, only one terminal was included for collecting the data. In other words, each node in this study represents a city instead of a terminal. Table 2 summarizes the number of trips and the passenger volume from 1999 to 2012.

Table 2 Number of trips and passenger volume in 4 main cities of MMR (1999-2012)[2]

Name	**1999**		**2007**		**2012**	
	No. of trips	**Passenger volume**	**No. of trips**	**Passenger volume**	**No. of trips**	**Passenger volume**
Mashhad	342312	6603125	467572	7757786	579652	8694791
Chenaran	39100	621638	53812	761314	68996	898549
Fariman	10795	333537	15535	413492	29877	702114
Molk Abad	3683	72955	8044	100706	12067	294430

Unavailability of data based on the purpose of travel (working, immigrate, etc.) and mode of travel (by bus, car, etc.) was one of the main limitations of this study. However, analyzing the spatial structure of Mashhad metropolitan region regarding various purposes of trips can be an important part of the process of understanding the spatial structure of metropolitan regions.

To analyze data, first, flow matrixes were designed in Excel and converted to Ucinet file. Then, different variables were calculated in Ucinet. Afterwards, a variable which was in the same group of indexes was summed up and normalized from 0 to 100. Finally, in order to visualize the files, they were imported in ArcGIS and the maps were exported from ArcGIS.

4. METHODS

Different indexes have been used in previous literature to analyse spatial interactions based on network approach, such as network cohesion [41], degree centrality [24,39,40,42-43], interaction strength [17,44], symmetry [17,44], and levels and hierarchy [39,45].

The present study used the methodology of Limtanakool et al. [17] and its development by Dadashpoor et al. [12], employing four dimensions of centrality and dominance, network cohesion, interaction strength and levels, and hierarchy. We tried to achieve this by focusing on passenger's commuting between urban areas in Mashhad metropolitan region. Network symmetry index was omitted from the study since the volume of the incoming flows was equal to the outgoing one in this case. Table 3 introduces the mathematical relations of dimensions and variables to analyze the dynamics of the spatial structure of MMR.

Table 3. Mathematical relations of dimensions and variables [12][3]

Dimensions	Variables	Equations
Centrality and dominance	Degree centrality	$C = \frac{\sum_j (k_i max - k_i)}{Max \sum_j (k_i max - k_i)}$
Network cohesion	Network Density	$D = \frac{\sum_j a_{ij}}{(n-1)n}$
	Network Entropy	$EI = -\sum_{i=1}^{L} \frac{(z_I)\ln(z_I)}{\ln(I)}$
Interaction Strength	Relative Strength of interaction	$RSI_{ij} = \frac{t_{ij}}{\sum_{i=1}^{I}\sum_{j=1}^{J} t_{ij}}$
Levels and hierarchy	Additive Algorithm	$\delta_{int}(C) = \frac{\neq internal\ edges\ of\ C}{\frac{n_c(n_c-1)}{2}}$ $\delta_{ext}(C) = \frac{\neq inter-cluster\ edges\ of\ C}{n_c(n - n_c)}$

- *Centrality and Dominance* measure the relative importance of a node within a network. In this study, degree centrality is used to analyze the importance of a node in terms of the direct link to other nodes, accessibility to other nods, and its intermediary between others [46].
- *Degree centrality* is the number of edges shared with others; thus, indicates the importance of the node in a network [47].
- *Network cohesion* examines the level of unity and integration of different types of network flows and their quality of distribution along with the nodes [43]. Network cohesion operates at the network level and is topologically obtained from 2 variables: 1) network density; 2) network entropy.
- • *Network Density* measures the number of existing arcs to the maximum number of possible arcs in the network [47]. An obtained value closer to 1 indicates more links with a fixed number of vertices [49].
- • *Network Entropy* measures the distribution of network interactions of flows [12,50].
- *Interaction Strength* measures the resistance of interactions and relations [45].
- *Levels and Hierarchy* examines the network's social configuration in a continuous spectrum from separate to fully clustered [46]. Theoretically, the number of clusters can be a range from 1 to n (number of network vertices); a higher number indicates a more complex multi-level hierarchy with a more dispersed structure in the networks [12]. By contrast, the simpler two-level hierarchical organization usually occurs in concentrated, monopolar, and incoherent networks Fig. 4 [51].

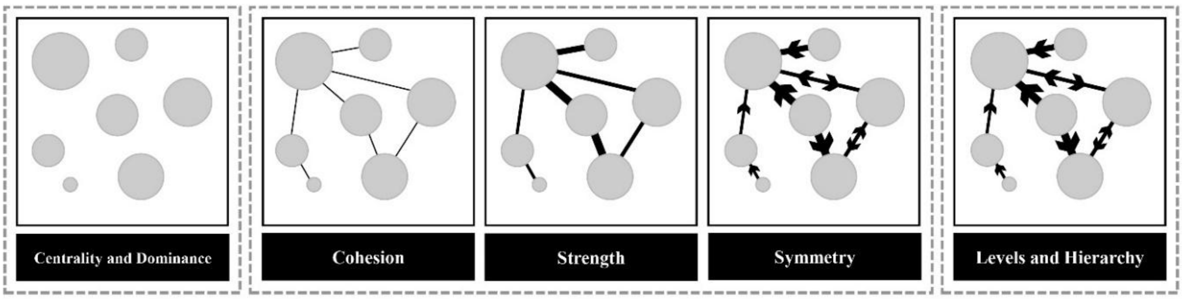

Fig. 4 Dimensions of the spatial configuration of an urban system [12]

5. RESULTS

Node-oriented attributes do not necessarily express the status of cities in urban systems; cities are eligible for different status according to their functions and role in the network of flows. In this section, structural characteristics of transportation network will be examined to investigate dynamics of spatial structure in MMR, based on data obtained from Provincial transportation and Terminal Department of Khorasan Razavi for 4 cities of Mashhad, Fariman, Chenaran, Molk Abad, which are the most important cities in urban hierarchy of the region compared to other cities. Data covered average daily trips from Mashhad to Chenaran, Fariman, and Molk Abad in years 1999, 2007, and 2012; the outcome of these data was a 4*4 matrix.

Network centrality and dominance dimension are calculated based on centrality degree. Descriptive statistics of centrality degree revealed a significant increase in these variables. In order to gain a complete understanding of the centrality and dominance dimension, the data were normalized. Being significant in 1999, centrality and dominance dimension had a considerable increase of 20.06 per cent from 2007 to 2012 Table 4. Based on the results, despite the significant increase in the volume of passengers in all the cities, this dimension decreased considerably in Chenaran, Fariman and Molk Abad since the number of incoming passengers decreased, while, the number of incoming passengers to Mashhad metropolis considerably grew in the given period, leading to the formation of the more monocentric spatial pattern Fig. 5.

Table 4 Centrality and Dominance dimension in MMR in 1999, 2007 and 2012

	1999	2007	2012
Degree centrality	48.59	50.78	66.74
Centrality and Dominance*(0-100)	48.59	50.78	66.74

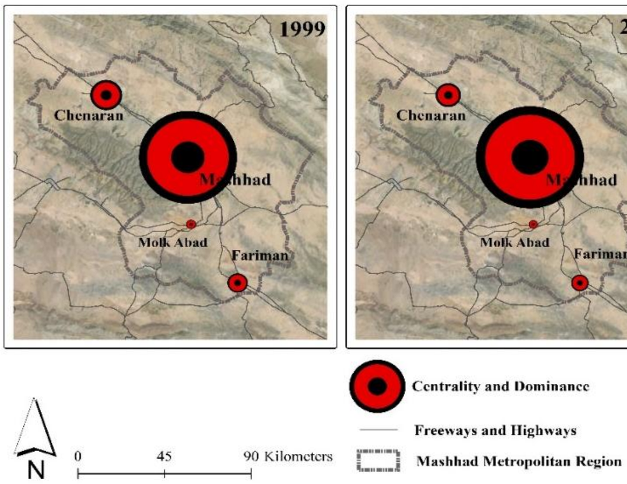

Fig. 5 Changes in centrality and dominance dimension from 1999 to 2012

Network cohesion dimension reveals the intensity of centrality in a network. For doing this dimension, two indexes of density and Entropy were used. The results showed that the density of the network was 0.33 for all three periods, which points to the low density of the network from a typological point of view. Entropy index of the network expresses the extent, spread, and invariable distribution of interactions. The number of 1 for this index indicates the completely networked structure and the number of 0 represents a network with completely monocentric structure. The calculated number for this dimension indicates that the cohesion has decreased over the period, showing a more monocentric pattern during 1999- 2012 Table 5.

Table 5 Network cohesion dimension in MMR in 1999, 2007 and 2012

	1999		2007		2012	
	Obtained No.	**Normalized**	**Obtained No.**	**Normalized**	**Obtained No.**	**Normalized**
Network density	0.33	33	0.33	33	0.33	33
Network entropy	0.35	35	0.24	24	0.16	16
Network cohesion Index* (0-100)	**34%**		**28.5%**		**24.5%**	

* Network Cohesion dimension = (Normalized network density+ Normalized network entropy)/2

Relative Interaction strength dimension is measured by the relative strength of the interaction. The list of achieved quantities for this dimension is presented in Table 6. According to this Table, interaction strength in Mashhad-Chenaran increased steadily while the increase was significant in Mashhad-Fariman and Mashhad-Molk Abad especially during 2007 and 2012.

Table 6 Interaction strength of passengers flows from 1999 to 2012

		1999			2007			2012		
		In	Out	**Interaction Strength* (0-100)**	In	Out	**Interaction strength (0-100)**	In	Out	**Interaction strength (0-100)**
Mashhad	**Chenaran**	0.56	0.38	**47.07**	0.66	0.32	**49.07**	0.78	0.26	**51.67**
Mashhad	**Fariman**	0.35	0.15	**25.26**	0.40	0.13	**26.65**	0.65	0.10	**40.38**
Mashhad	**Molk Abad**	0.09	0.02	**5.52**	0.11	0.02	**6.49**	0.29	0.05	**16.93**

*Interaction strength= ((in + out) strength / 2) *100

In Fig. 6, cities are illustrated in accordance with interaction strength: Mashhad stands on the first position in both incoming and outgoing flows; Chenaran and Fariman stand on the second and third positions, respectively. Another interesting point is that the incoming number of flows to Mashhad generally was much more than the outgoing ones. In addition, although the number of incoming flows between Mashhad and Chenaran increased steadily during the given period, the two other cities experienced considerable growth in the number of outgoing flows.

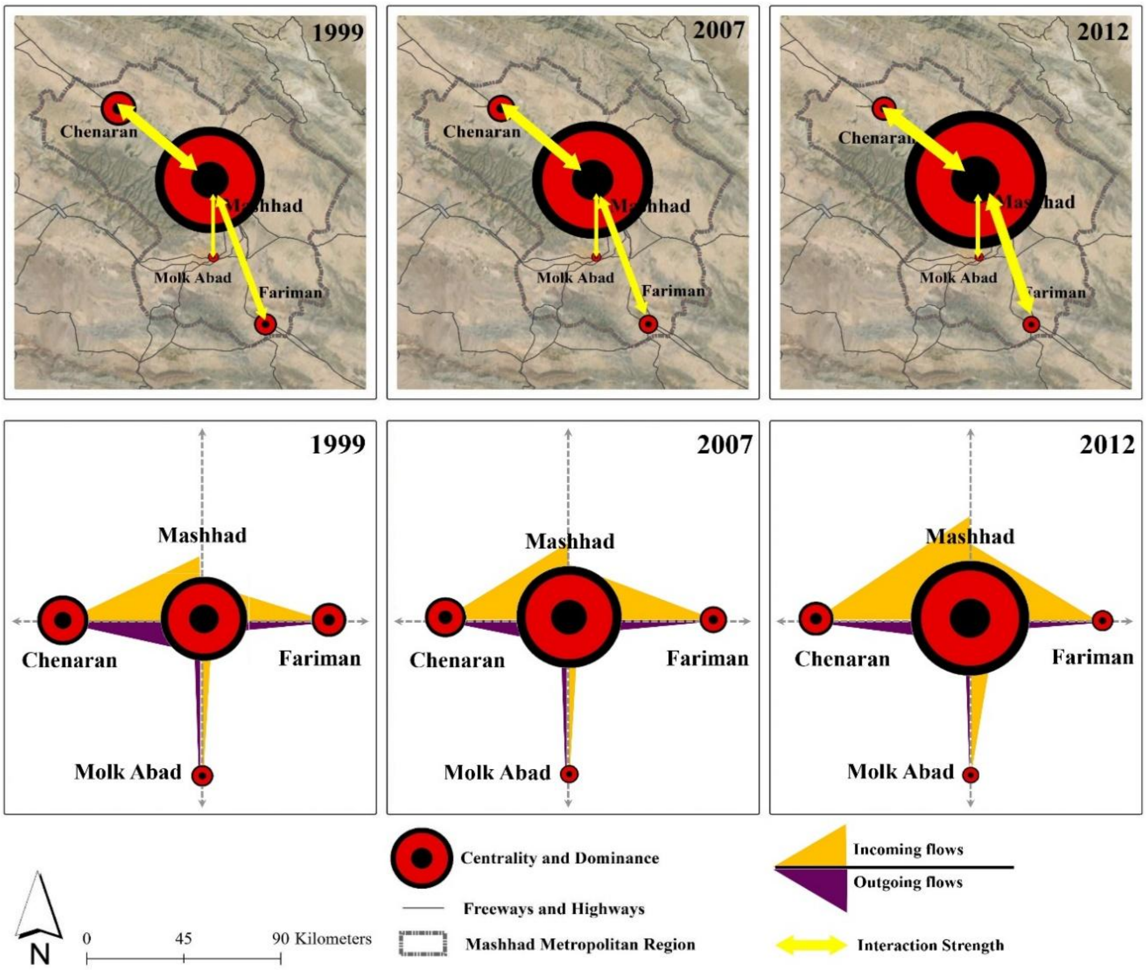

Fig. 6 Incoming and outgoing flows in MMR

Levels and hierarchy dimension reveals information on the linkages among cities, meaning that cities with stronger connections form an integrated functional region Fig. 7. Intensification in incoming passengers to Mashhad metropolis and reduction of Chenaran to a peripheral city revealed that the role of Mashhad as a primate city in MMR affected the passenger's flow and changed the relationships of peripheral cities in MMR.

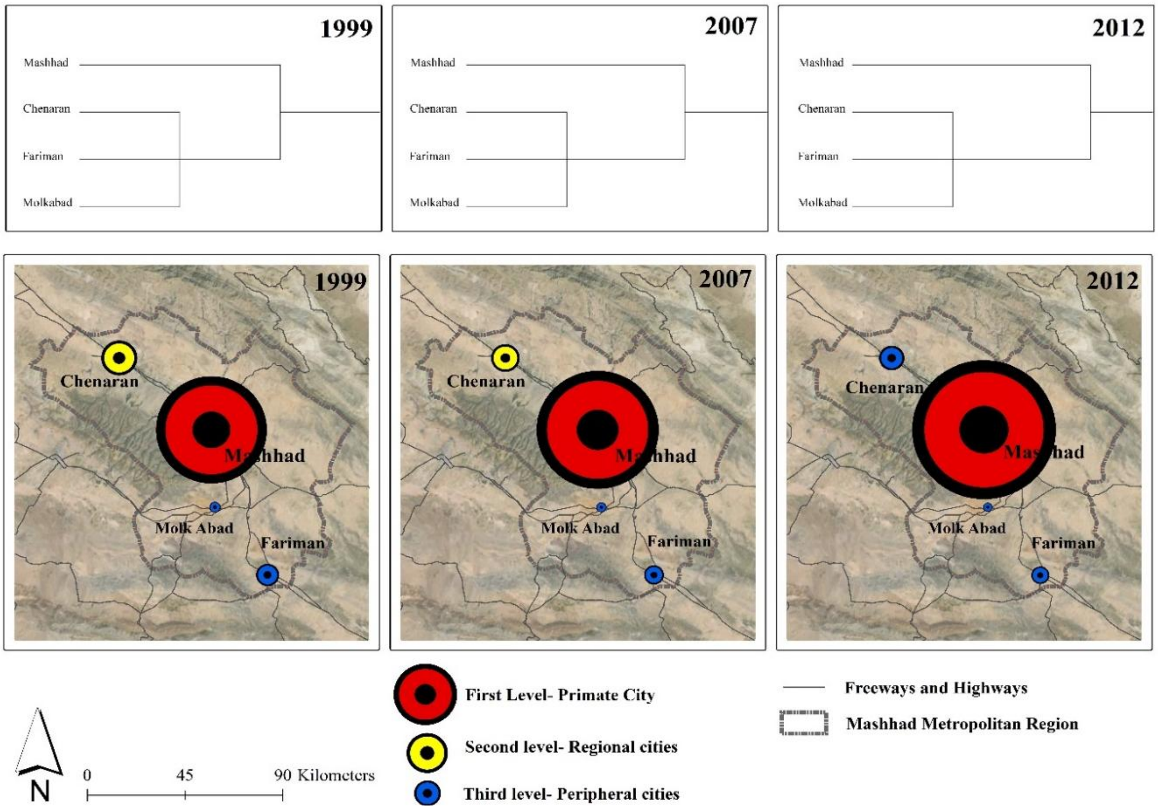

Fig. 7 Functional levels in MMR from 1999 to 2012

Having determined the functional levels of flows in MMR, the urban system was categorized to recognize the hierarchy of flows in the MMR. On this basis, Mashhad played a primate role while Chenaran changed from a regional in 2007 to a peripheral city in 2012. The other two cities' role (Fariman and Molk Abad) did not change over the given period Table 7.

Table 7 Functional Regions in MMR in 1999, 2007 and 2012

		1999		2007		2012	
Level	**Functional Regions**	**Cities**	**Central City**	**Cities**	**Central City**	**Cities**	**Central City**
1	Central	Mashhad, Chenaran	Mashhad	Mashhad, Chenaran	Mashhad	Mashhad	**Mashhad**
2	Peripheral	Fariman, Molk Abad	-	Fariman, Molk Abad	-	Chenaran, Fariman, Molk Abad	-

6. DISCUSSION

The aim of this study was to explore the dynamics of spatial structure in MMR based on interaction patterns, using four dimensions of centrality and dominance, network cohesion, interaction strength and levels, and hierarchy, referring to passenger's interaction volume among 4 cities in MMR. Centrality and dominance dimension revealed the increase of centrality over the given period; the role of Mashhad metropolis in the interaction pattern of MMR grew, unlike the three other cities. Another interesting point was that network cohesion decreased from 1999 to 2012, confirming the results of centrality dimension about the growth of a monocentric pattern in MMR. Furthermore, the results of interaction strength indicated that despite the increased relationships among Mashhad and three other cities of MMR, this growth was in favour of Mashhad metropolis since the incoming flows to Mashhad increased considerably unlike the outgoing ones decreased significantly from 1999 to 2007. However, despite the development policies that focused on the polycentric development of MMR, the spatial pattern of this region tended towards a monocentric pattern with the centrality of Mashhad. Based on hierarchy and levels dimension, Mashhad became the primate city of MMR in 1999 while Chenaran was a regional city in the region and the other two cities were identified as peripheral cities. The results of network analysis in 2007 were near to the results in 1999. Although the passenger's flow between Mashhad and Chenaran increased in 2012, the role of Chenaran in the spatial structure of MMR changed from a regional (second level) to peripheral city (third level).

The most considerable point in MMR was the excessive concentration in Mashhad and the formation of satellite settlements in the region, which was resulted from the effective role of Mashhad metropolis to attract flows in MMR due to the factors such as appropriate distance with other cities, locating in geographical center of the region, physical expansion, proximity of cities with Mashhad, overwhelming population of Mashhad as a district's capital and high economic value of the city. In other words, different kinds of links (such as economic, demographic, services, etc.) between Mashhad metropolis and other cities in the region formed a heterogeneous system, in which passengers preferred to go to the centre for the sake of facilities despite the cost of travel.

The tendency of flows to form a functional zone in Mashhad-Chenaran axis needs further studies. The study of Burger et al shows that functional linkages in metropolitan regions have complicated patterns due to complicating macro-level system [25, 33]. One of the main reasons for this is a concentration of industrial-activity zones around Mashhad-Chenaran axis. Furthermore, Mashhad metropolis has a tendency to develop in this direction. Comparison of the obtained results with similar studies could also be useful. For instance, the result of research on the metropolitan region of Hangzhou in China indicates the development of the region towards poly-centricity [52]. The comparison of the results with the findings by Sun et al. in Beijing metropolitan region indicates that this region unlike to Mashhad tends toward dispersion [7]. In addition, another study by Dadashpoor et al [54] suggests that Tehran metropolitan region is moving toward a polycentric pattern, the result which differs from the findings of this study.

7. CONCLUSION

Based on the statistical results and analysis of the indexes in former sections, it can be concluded that the spatial structure of MMR was monocentric which is adaptable to the spatial pattern introduced Type A presented by Bertaud (2001). The increase of incoming passengers to Mashhad metropolis was not comparable to the other cities in MMR although passenger flow of peripheral cities increased from 1999 to 2012. Excessive concentration in Mashhad metropolis made the other cities to be satellite nodes in the peripheral region of the main centre (Mashhad). Easy accessibility to employment centres in the principal city can explain the configuration of this kind of spatial pattern. One of the main factors that provided easy access to Mashhad and formed a monocentric pattern in this region is road network which is formed in such a way that all the paths connect to the centre of the region. Thus, the spatial structure of MMR can be defined by monocentric-centralized model [32] with traditional interaction patterns [33], interaction from peripheral cities to the principal city – Mashhad is the central node of the region and other cities are dispersed in MMR. These results are comparable to the results of Dadashpoor & Jahanzad who predicted the significant increase of population imbalance in MMR in the next 25 years [53] and contrary to the results obtained by Dadashpoor and Alidadi [54] in Tehran metropolitan region. The continuation of current trends may have devastating socio-economic consequences such as polarity and attraction of the region's investments in favour of Mashhad metropolis, which may result in hyper-compression on infrastructures in Mashhad.

To prevent these consequences, it is necessary to think about solutions: from a substantial view, it is required to 1) provide an integrated regional development framework in order to determine strategies and policies to protect the environment; 2) have interdependency of peripheral cities and rural regions; 3) strengthen cities to form homogeneous regions; 4) manage travel demands; 5) diminish unnecessary trips; 6) reinforce inter-city interaction in the metropolitan region; and 7) restrict sprawl. From a procedural view, it is crucial to define an institutional structure to facilitate the above-mentioned strategies; thus, we need to adopt an integrated and trans-sectoral approach through integrating political boundaries and transferring decision-making authority to a united planning committee in the region. These policies will result in a more convergence and polycentric pattern.

This study focused on an interaction pattern of spatial structure based on passenger's flows by bus; however, further studies are required to examine other spatial characteristics of MMR and to gain a comprehensive understanding of spatial transformation in MMR. These studies can be categorized into two main types: First, functional studies which examine interaction patterns using other transport modes such as goods, capital and information flow, applying the methodology conducted in this study. Second, studies that examine morphological attributes such as population, employment, land use, and etc. which can provide a better understanding of the spatial structure of the region.

APPENDIX A

Table A Guide for mathematic equations

(Existing link in the network) I-1,2,3,…L	**I**
number of vertices in the network	**n**
The ratio of flows from the link *i* to link j in the network	$\boldsymbol{z_I}$
The directed link from *i* to *j* (out from I and into j)	$\boldsymbol{a_{ij}}$
The volume of links from vertex *i* to j (out from I and into j)	$\boldsymbol{s_{ij}}$
Linear centrality degree of vertex *I* divided on the number of outgoing flows from vertex I	$\boldsymbol{k_i}$
The sum of vertex weight situated in vertex adjacency *i*	$\boldsymbol{c_i^I}$
Adjacency matrix for a given graph if vertex *i* is connected to vertex k: $A_{ik} = 1$ otherwise $A_{ik} = 0$	**A**
The intra-cluster density in the subgraph C	$\boldsymbol{\delta_{int}(c)}$
Number of links existing below graph C	$\boldsymbol{internal\ edges\ of\ C}$
Number of vertexes below graph C	$\boldsymbol{n_c}$

The inter-cluster density in the subgraph C	$\delta_{ext}(C)$
Number of links between vertexes below graph C and other vertexes of existing in the graph	$inter - cluster\ edges\ of\ C$

NOTE

1. Torghabeh and Shandiz have been excluded from the calculations, due to the unavailability of O-D data.
2. Source: Statistical yearbook of Provincial Transportation and Terminal Department of Khorasan Razavi.
3. The guideline of Table 3 is given in Table A. Appendix.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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