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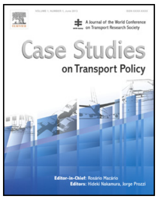

Designing the required changes in the bus network after performing limited traffic zone in Mashhad, Iran

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ABSTRACT

After performing Limited Traffic Zone (LTZ), an approach to limit the number of vehicles entering a zone or street in Mashhad, Iran, a change in the share of public transportation happens. In some routes, the share of public transportation decreases during peak hour because some users shift the time of their trips to other hours. Alternatively, the use of private cars on most routes shifts toward public transportation and as a result, these routes experience more demand. Supposing that the current system is based on current demand, after performing an LTZ, transit systems need to be modified based on new demand. This modification can be done in regards to route configuration, frequency and timetables. In this paper, a methodology is proposed to modify the bus transit system to determine required changes in the system. This method is easy to implement in large cities, especially cities that have seasonal demand changes and need to adjust their system with minimum changes in route configuration. The objective function of this method is based on covering the increased demand in the system. The methodology includes a GIS-based heuristic approach and is performed in Mashhad, Iran.

1. Introduction

Limited Traffic Zone (LTZ) is an approach to limit the number of vehicles entering a zone or street. This method of travel demand management (TDM) has been practiced in Mashhad for more than 10 years.

Studies show that around 20 million pilgrims visit the Holy Shrine of Imam Reza in the center of Mashhad each year. Most of these pilgrims come to Mashhad during summer (July to end of September) and two weeks at the beginning of spring (March 21 to April 4). Therefore, the majority of pilgrims visit a small zone in the city (Holy Shrine of Imam Reza) in a short period of time. Also, the daily travel demand is higher at noon and sunset since most prayers at the Holy Shrine are during these times of the day.

Summer and spring holidays are based on the solar calendar so they happen on the same dates each year. However, some religious dates that attract pilgrims to Mashhad are based on the lunar calendar and therefore, travel each year happens on different dates. Both these solar and lunar holidays are called special days. Of course in some years, lunar occasions fall on solar-based holidays, so the city experiences an extreme peak period.

To manage crowded traffic on these special days, the Mashhad Traffic and Transportation Organization (MTTO) decided to implement two LTZs: one for summer and spring holidays and another one for normal days on which lunar occasions may happen. Fig. 1 demonstrates the border of these two LTZs. During normal days, only the smaller LTZ operates while during special days, both of them operate with a different control scheme. On normal days, LTZ operates based on a license plate scheme. During odd days, only vehicles with plates ending with an odd number can enter this LTZ. The same applies to even days for even-numbered plates. On Fridays (formal weekend in Mashhad), all vehicles can enter the LTZ. On special days, LTZ operates based on zone pricing. Each vehicle that enters this LTZ is charged a fee and if it has the appropriate license plate for that day, it can also enter the inner LTZ. In order to determine the borders and restricted areas, an LTZ Comprehensive Study (LTZCS) was conducted by MTTO. The study also estimated the new demand of trips during special and normal days. This paper summarizes the findings of the public transit section of LTZCS.

The emphasis of this research is to modify the current bus system without introducing a new bus network. There are several reasons for keeping the current bus system and avoiding a new system that is significantly different from the current system. Introducing a new bus line usually does not have negative social effects, but removing or even partially changing it usually produces a lot of public complaints. Previous experience in Mashhad shows

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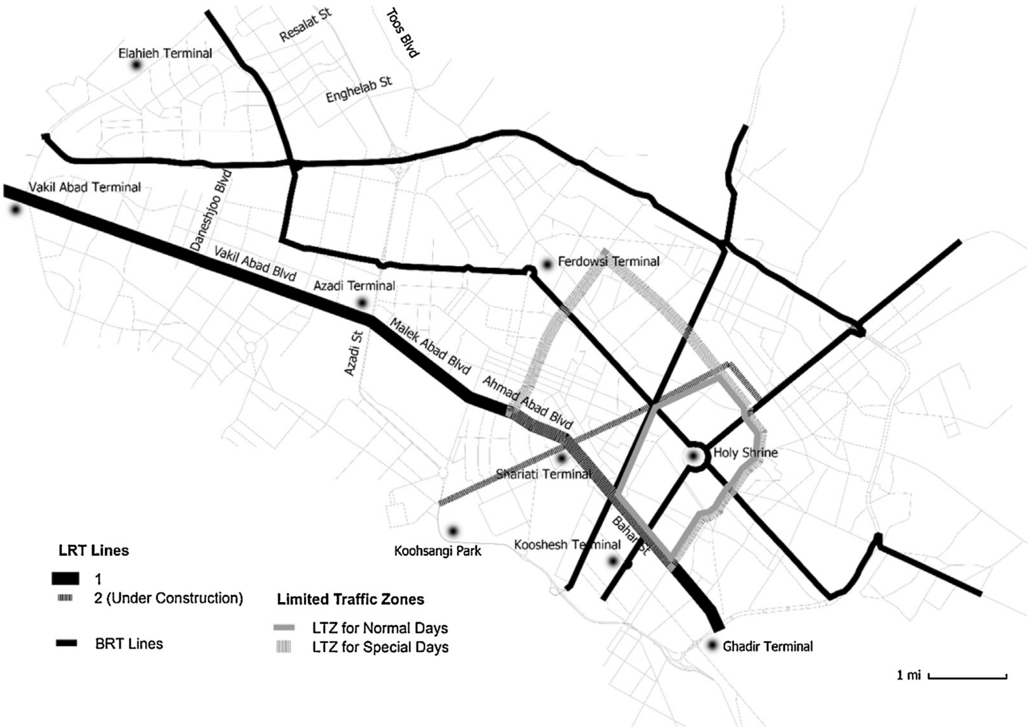

Fig. 1. Mashhad Street, LRT, and BRT networks.

that in some cases, it could generate protests. Another reason is the practical difficulties. A bus system takes years to form, including the habits on both the side of operators and users. Most cities start their bus system with a few lines and as the population of the city increases, more lines are added. Changing a network, or even a line, requires a lot of energy and cost in the system. LTZ produces considerable friction in changing the habits in a city, it does not seem wise to create more friction by changing the current bus network altogether.

This paper is organized as follows. The next section provides a literature review. Methodology to design required changes in the bus network after performing limited traffic zone is provided in Section 3. The case study section and its results are presented at the end.

2. Literature review

Various methods cast restrictions on vehicles entering roadways in an effort to manage traffic congestion and demand, including Area Licensing Scheme (ALS), Traffic Restricted Area and Congestion Charging Zone. Much research has been conducted on traffic restriction measures in different cities. In Athens, vehicle entry was regulated according to the last digit of the license plate of the vehicle, such that each vehicle is banned on alternate days Monday to Friday. Some studies show up to 50 percent reductions in traffic with this scheme (Argyrakos, 1986; Matsoukis, 1985). More recently, Grange and Troncoso (2011) and Han et al. (2010) also have investigated the effect of these restrictions on urban transport flows. However, some other studies such as Behbehani et al. (1984) in Singapore, and Harrison (1986) in Hong Kong indicate that road user fees can work more effectively to reduce private car usage only if fees are set significantly high. Olszewski et al. (1995) and Olszewski and Xie (2005) developed models for the Singapore CBD (Central Business District) with the aim of providing an analytical framework for the evaluation of traffic management measures for Singapore Restricted Zone. Also Jones and Hervik (1992) have summarized other methods for restraining car traffic in European cities and assessing the potential of a road pricing measure as a demand management tool in the future.

Another interesting method to reduce entrance of vehicles in some zones is called road diet. In this method, capacity can be restricted through reallocating part of the carriageway to bus lanes, which limits the space for private cars. This kind of restriction can also be done by transit signal priority that allows bus lanes to bypass the traffic signals and as a result, imposes delays on other vehicles. Some early studies proposing this method were Cracknell et al. (1975) for London, Vincent Layfield (1977) for Nottingham, and Small (1983). Later, Huang (2000) evaluated the transit fares and highway tolls and Basso et al. (2011) analyzed dedicated bus lanes in addition to congestion pricing and transit subsidies. Various research such as Watters et al. (2006) and Li et al. (2009) have also been done to reduce traffic congestion using public transportation priority systems.

Palma and Lindsey (2011) review the methods and technologies for congestion pricing of roads. Liu et al. (2012) developed a simple equilibrium model for a linear mono-centric city to investigate the effects of both restriction measures and pricing on morning commuters' travel cost and modal choice behavior and found that a Pareto-improving rationing and pricing scheme might be obtained as a combination of the rationing degree and the toll associated with rationing. Wang et al. (2010) analyzed the effect of road rationing on the original traffic assignment model. Shi et al. (2014) introduced an optimization method for alternate traffic restriction (ATR) schemes in terms of both their restriction districts and the proportion of restricted automobiles. Under ATR, a certain proportion of automobiles are prohibited from entering predetermined ATR districts during specific time periods. Other methods can be summarized as credit-based congestion pricing (Kara and Kalmanje, 2005), vehicle quota systems (Chin and Smith, 1997; Seik, 1998), and travel credit systems (Yang and Wang, 2011).

Most of the research is focused on restriction of private vehicles to manage congestion in an area. Usually in these studies, the effect

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of these measures on public transportation is not in their scope. However, there are some studies that investigate the effect of demand fluctuations and take it into account for public transit network design. Though the scope of these studies is not designing or modifying public transportation based on changes that happen after LTZ, one aspect of LTZ that has been studied is change in demand. Usually this topic is discussed under seasonal demand variation. Amiripour et al. (2011, 2014) considered seasonal demand variation into bus network design problems and proposed two solution methods. The methods were applied on a case study in the city of Mashhad. Also, Lee and Vuchic (2005) and Fan and Machemehl (2006) have designed transit network considering variable demand. Cats and Jenelius (2015) proposed a methodology for evaluating the effectiveness of a strategic increase in capacity on alternative public transportation network links to mitigate the impact of unexpected network disruptions.

After performing LTZ, the pattern and number of trips changes. As a result, many private car users either change time and/or path of trips, or mostly shift toward public transportation. In the majority of cities, LTZ is performed during peak hours and, in many cases, only during peak seasons. In all cases when LTZ is performed, the demand of transportation system changes and subsequently, the current public transportation fails to match the new demand. Developing a public transportation network that best matches supply and demand is a challenging issue but will eventually lead to a more successful LTZ. Though bus network is extremely sensitive to passenger demand, two surveys done by Kepaptsoglou and Karlaftis (2009) and Guihaire and Hao (2008) show that bus networks have usually been designed for one single demand scenario in all surveyed methods and as a result, demand changes are ignored. These methods usually consider only the demand matrix for one day of the year and apply it year round. Such a network is appropriate in cities with consistent demand all year.

To our knowledge, though some attributes of LTZ like congestion pricing are widely studied, the effect of LTZ on public transportation (especially on bus network and modifying it based on changes due to LTZ) is a neglected topic in literature. The objective of the current study is to develop a method that can modify the current bus network with minimum changes of routes after performing the LTZ in Mashhad, Iran.

3. Methodology

The methodology proposed in this paper (Fig. 2) was applied to Mashhad, Iran. This method is a GIS-based heuristic approach. The reason for selecting GIS is that macroscopic models, especially VISUM, can export their output to GIS maps. On GIS maps, the additional demand caused by LTZ, street network, bus network, and bus terminal locations, can be shown and easily changed using GIS tools.

The demand of the bus transit system increases in some areas because of restrictions on private cars. However, there are areas where bus demand decreases. This demand reduction is due to changing the time of some trips. The additional demand of the system can be calculated by subtracting the demand of the system after performing the restricted area, from the demand of the system before performing the restricted area, as shown in Eqs. (1) and (2).

$$\delta_i^{a,n} = P_i^{a,n} - P_i^{b,n} \tag{1}$$

$$\delta_i^{a,s} = P_i^{a,s} - P_i^{b,n} \tag{2}$$

$\delta_i^{a,n}$: Additional demand after performing LTZ in normal days at link i

$\delta_i^{a,s}$: Additional demand after performing LTZ in special days at link i

P: Public transportation demand

i: Subscript indicating link number

a: Superscript indicating after performing LTZ period

b: Superscript indicating before performing LTZ period

n: Superscript indicating normal days

s: Superscript indicating special days

Additional fleet size of line k is calculated by:

$$N_k^{a,n} = \left[\frac{2 \times \delta_{i,max}^{a,n} \times l_k}{C \times v_k^{a,n}}\right]^+ \tag{3}$$

$$N_k^{a,s} = \left[\frac{2 \times \delta_{i,max}^{a,s} \times l_k}{C \times v_k^{a,s}}\right]^+ \tag{4}$$

$\delta_{i,max}$: Maximum additional demand along the route k

N_k: Additional required fleet size on route k

$v_k^{a,s}$: Average cycle speed on route k (km/h)

l_k: Length of route k (km)

C: Capacity of each bus (Persons)

The plus sign in these equations means that the value of the fleet size must be rounded to the next integer. Note that because the values of these equations are rounded up, the actual demand that N_k can cover is more than the demand that is used in these equations. Using Eqs. (3) and (4), the following equations give the actual total demand that is covered by an additional fleet of line k and can be subtracted from all links along the route k:

$$\delta_k^{a,n} = \frac{N_k^{a,n} \times v_k^{a,n} \times C}{2 \times l_k} \tag{5}$$

$$\delta_k^{a,s} = \frac{N_k^{a,s} \times v_k^{a,s} \times C}{2 \times l_k} \tag{6}$$

δ_k: Additional demand along the route k

Because the additional required fleet size (N_k) is rounded to the next higher integer, δ_k is greater than or equal to $\delta_{i,max}$.

If more than one bus line passes in a section of a street, then the demand is divided between them based on the inverse ratio of their length. The process of assigning fleets to lines starts from the terminal station towards LTZ because generally, most of the lines end at or close to LTZ and additional demand is more concentrated at this area. If the fleet is assigned the other way around, it results in considerable empty buses at the other end of the lines.

Short turn of a line (imagine Line A) is another line which some of the first or last stops have been removed from the original Line A and the rest of short turn is parallel to it. In Mashhad usually short turns are named with a slash and a number after the original line's name (A/1). The criteria for making a short turn is that at least the first five stops of a line do not have demand, otherwise it is better to increase the fleet from the first stop of the original line. In addition to the demand criteria for making a short turn, the feasibility of turning the first stop of a short turn to a bus terminal must be considered.

One very important consideration is that current lines usually have empty seats at the beginning side of the line that is further from LTZ. Therefore, if a line has additional demand only at theses sections, whether the existing fleet of the line can cover the additional demand or not should be checked. This can be done by making a GIS map of the present demand and lines and calculating the surplus seats at these sections.

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4. Case study

Mashhad currently has 118 urban bus lines and its fleet size is 1711. Suburban lines are not considered in this study. The average length of urban lines is 12.41 km, average headway is 9 min, and average cycle speed is 19 km/h. In LTZCS, demands for special and normal days were estimated using VISUM and were exported to ArcMap. Our demand is based on this study. To cover increased demand, most of the changes were made on the frequency. For routes where changing the frequency is not sufficient, short turn routes also can be added to current lines. In our case study region, there are some areas that experience up to 5458 persons per hour (pph) in additional demand on normal days and 5596 (pph) on special days. Figs. 3 and 4 show the additional demand after performing LTZ for normal and special days, respectively.

After calculating the additional demand, at first, line changes are designed for special days ($\delta^{a,s}$). An analysis was performed to discover if the passenger-km would be affected and by how much when $\delta^{a,s}$ is reduced to a certain threshold. Based on the analysis in Arc GIS environment, it was concluded that if only 85 percent of demand is used in the design, the effect of this reduction on uncovered passenger-km with the design load factor is insignificant, but it reduces the fleet size significantly. This analysis shows that only less than two percent of passenger-km in the streets is not covered considering the capacity of 65 persons per bus while fleet size is reduced by 15 percent. This is mainly because walking can cover short distance trips. Considering 85 percent of demand

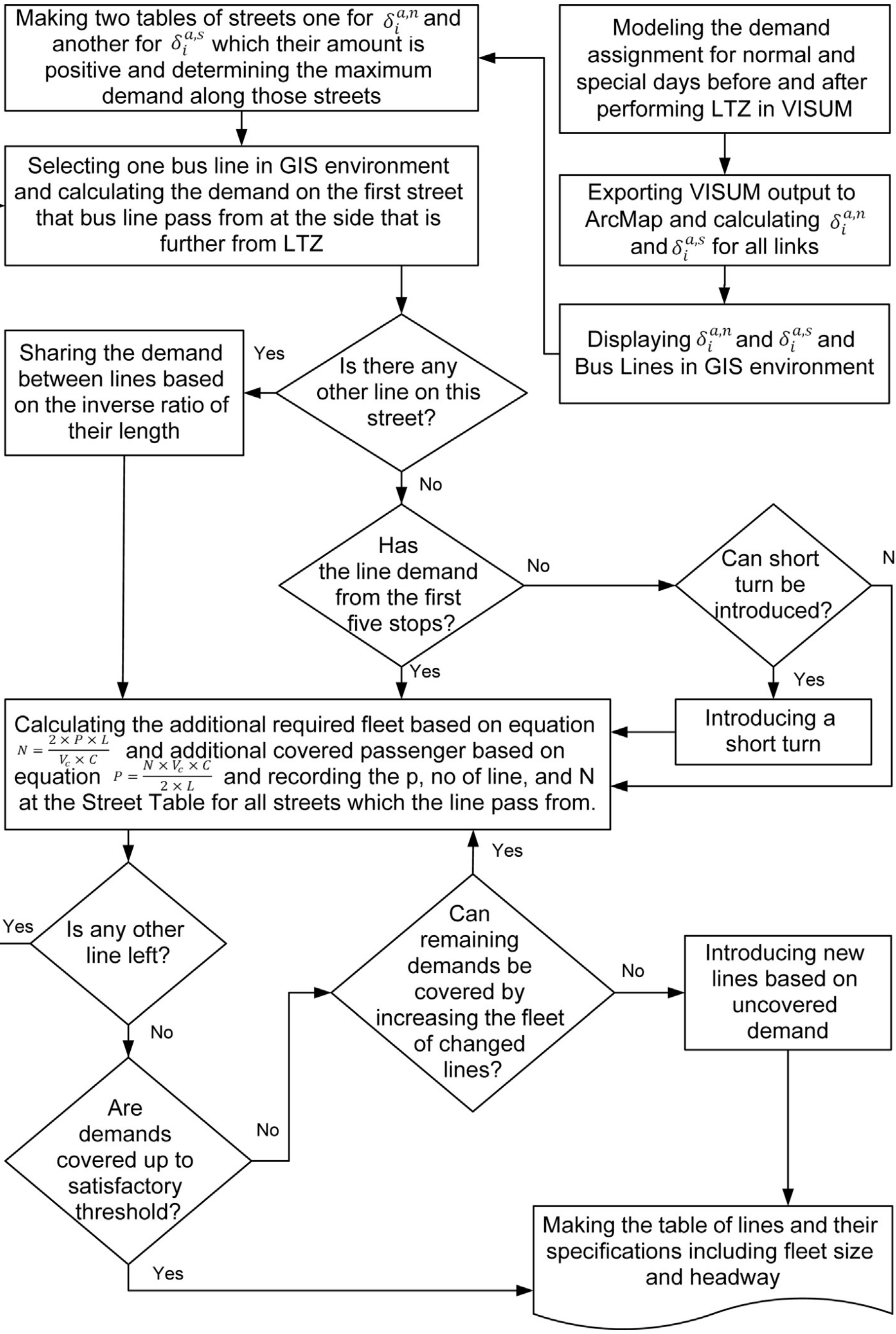

Fig. 2. Methodology flowchart applied to urban bus lines in Mashhad, Iran.

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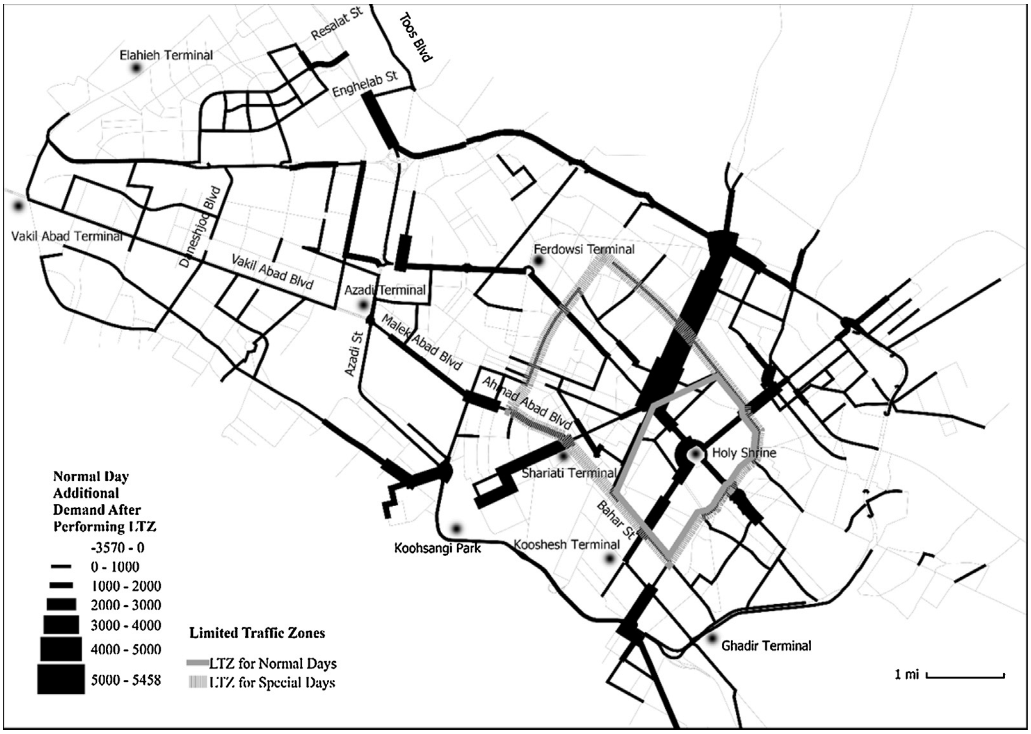

Fig. 3. Additional demand of bus transit system in normal days after performing LTZ, $\delta^{a,n}$.

for design is a policy decision and can be changed depending on the budget.

On special days, in addition to increasing the fleet of lines, 17 short turn and two new lines also were introduced to cover $\delta^{a,s}$ demand. Table 1 shows a part of the design details. This table includes the name of streets, Maximum Load Section (MLS) along of each street, the lines that pass from each street, added fleet to the lines and the number of passengers that this additional fleet

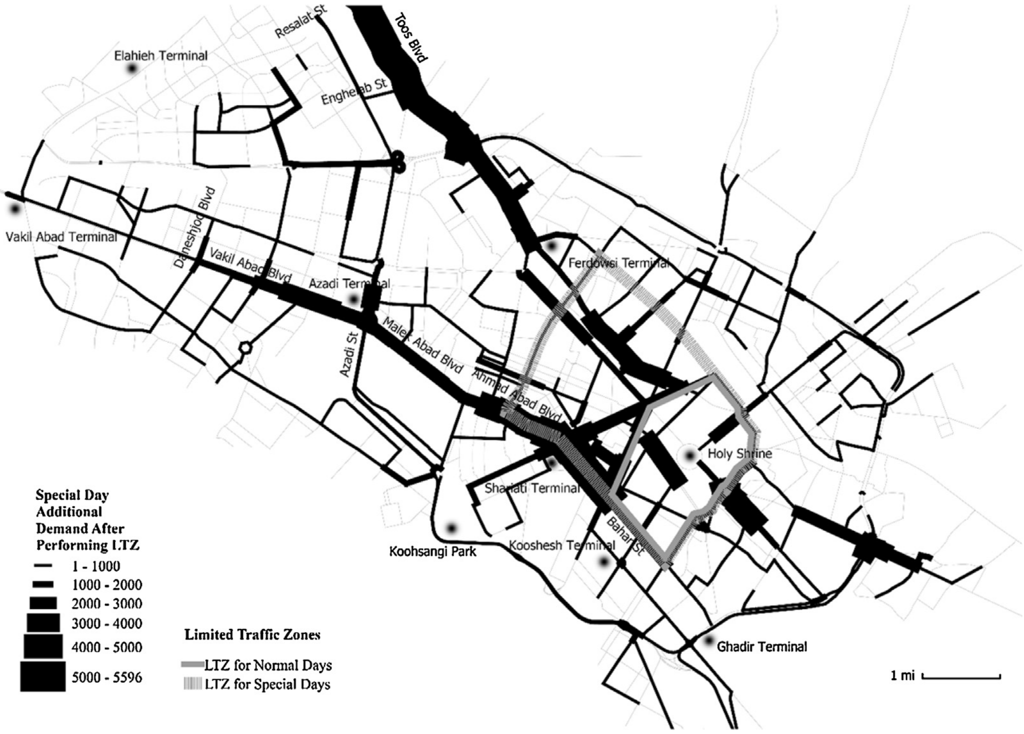

Fig. 4. Additional demand of bus transit system in special days after performing LTZ, $\delta^{a,s}$.

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Table 1
Line Changes along the streets for special days (sample).

Street Name	Max Demand along the Street	Line Changes along the Street					
Malek Abad Blvd.	2791	Line No.	38/1	P2			
		Added Fleet (veh)	13	59			
		Added Capacity (prs/hr)	929	5086			
Ahmad Abad Blvd.	5276	Line No.	15	S26	38/1	P2	92
		Added Fleet (veh)	3	2	13	59	1
		Added Capacity (prs/hr)	103	263	929	5086	134
Enghelab St.	5596	Line No.	86	P2			
		Added Fleet (veh)	5	59			
		Added Capacity (prs/hr)	540	5086			
Bahar St.	2748	Line No.	66	P2			
		Added Fleet (veh)	4	59			
		Added Capacity (prs/hr)	316	5086			
Vakil Abad Blvd (from Daneshjoo Blvd to Azadi St.)	3186	Line No.	S14	S15/1	15/1	94	94/1
		Added Fleet (veh)	2	2	9	8	4
		Added Capacity (prs/hr)	238	208	432	833	455
Toos Blvd	5256	Line No.	P1				
		Added Fleet (veh)	57				
		Added Capacity (prs/hr)	5213				

can cover. Long streets are divided into two or more sections from the points that other lines enter or exit the street. A similar table also was made for normal days.

On some streets, such as Toos Blvd. (north-west at Fig. 4), the demand is so high that the increase of fleet at these streets to cover all demand results in an unreasonable number of buses because lines continue to other streets with much lower demand. In these cases, new lines were proposed that, considering their terminals, almost only cover the high demand section.

For $\delta^{a,s}$ demand, 448 buses with 65 passengers per vehicle and cycle speed of 19 km/h are required. Table 2 shows a part of line specifications for special days. For $\delta^{a,n}$ demand (normal days after performing LTZ), there are two options: (1) the required fleet size for these days can be calculated $\delta^{a,s}$. With this scenario, special and normal days have different systems; (2) a robust system can be designed so that it can handle both normal and special days. Therefore, in this method, more buses are required but the system does not need to be changed after normal or special days. In some transit agencies, because of practical difficulties and also social effects that changes to headways may cause, the second method is more favorable. To make a robust system in the second method, a simplistic way is to choose the maximum number of additional fleet for each line from the special and normal designs. This makes a very low efficient system with considerable unusable capacity. Another method to make a robust system is to find the links where their $\delta^{a,n}$ demand is more than $\delta^{a,s}$ demand:

$$\delta_i^{a,n'} = \delta_i^{a,n} - \delta_i^{a,s}$$

$\delta_i^{a,n'}$: Additional demand of normal days compared to special days after LTZ

Then, design the system for only the $\delta_i^{a,n'}$ demand and merge this design with the special days design. By merging these two designs together, we have a system that is able to handle both normal and special days with a total number of 575 buses with 65 persons per bus. A table similar to Table 2 is made to show the specification of this design. These tables also show specifications of short turns and new lines.

5. Summary and conclusion

Results of assignment in VISUM and analysis in GIS show many corridors experience a much higher bus transit demand after performing the two LTZs in Mashhad. In this paper, the authors proposed a method to modify required changes in bus networks after performing the LTZs. The implemented methodology includes a GIS-based heuristic approach that can use empty seats of present buses in lines that have an additional demand at their beginning and mostly modifies the lines either by increasing the frequencies or introducing short turns. However, when a corridor has a significant high demand, a new line is designed for only this section to avoid producing significant empty seat-km in the network. The result of this study shows that in order to have a successful LTZ, the city of Mashhad needs to invest and expand the bus network fleet considerably. A total of 575 buses are required, which means that the current bus network fleet should be increased by 19 percent.

Table 2
Required changes for special days after performing LTZ (sample).

Line No.	Origin	Destination	Line Length (km)	Present Fleet Size	Additional Fleet for Special Days
1	Ghadir Terminal	Vakil Abad Terminal	21.2	31	0
11	Vakil Abad Terminal	Ferdowsi Terminal	12.4	16	2
12	Vakil Abad Terminal	Holy Shrine	19.5	37	1
14.1	Elahieh Terminal	Azadi Terminal	19.8	21	4
14	Kooshesh Terminal	Azadi Terminal	17.2	16	0
Proposed Line 1	Toos Blvd from Resalat St.	Ferdowsi Terminal	8.2	0	57
Short Turn of Line 38	Koohsangi Park	Shariati Terminal	5.5	0	8

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Due to its simplicity, this method can also be applied to temporal sporting events or festivals that are only a few days. Bus networks of a city can be modified for each event to reduce traffic congestion in or around the event centers.

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