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Spatial analysis to identify high risk areas for traffic crashes resulting in death of pedestrians in Tehran

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Abstract

Background: More than 20% of deaths from traffic crashes are related to pedestrians. This figure in Tehran, the capital of Iran, reaches to 40%. This study aimed to determine the high-risk areas and spatially analyze the traffic crashes, causing death to pedestrians in Tehran.

Methods: Mapping was used to display the distribution of the crashes. Determining the distribution pattern of crashes and the hot spots/ low-risk areas were done, using Moran's I index and Getis-Ord G, respectively.

Results: A total of 198 crashes were studied; 92 of which, (46.4%) occurred in 2013 to 2014 and other 106 cases (63.6%) occurred in 2014 to 2015. The highest and the lowest frequency of crashes was related to January (26 cases) and June (10 cases), respectively. One hundred fifty- eight cases (79.8%) of crashes occurred in Tehran highways. Moran's index showed that the studied traffic crashes had a cluster distribution ($p<0.001$). Getis-Ord General G index indicated that the distribution of hot and cold spots of the studied crashes was statistically significant ($p<0.001$).

Conclusion: The majority of traffic crashes causing death to pedestrians occurred in highways located in the main entrances and exits of Tehran. Given the important role of environmental factors in the occurrence of traffic crashes related to pedestrians, identification of these factors requires more studies with casual inferences.

Keywords: Spatial Analysis, Road traffic injury, Pedestrians.

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Introduction

Road traffic injuries are responsible for the death of 1.23 million people around the world annually (1). In terms of Disability Adjusted Life Year (DALY) (1). Road traffic injuries ranked ninth in 1999, and are expected to rise to the third place by 2020 (2). These events account for 1-2% of Gross National Product (GDP) of different countries (3). In Iran, cost of road traffic injuries is 2.19% of GDP that is significantly higher than the global average (4).

More than 20% of deaths caused by traffic crashes belong to pedestrians. According to the estimates, about 273000 pedestrians around the world lost their lives due to traffic crashes in 2010 (5). In 2013, 22% of all fatalities as a result of road traffic crashes in the European Union(EU) were fatalities of pedestrians (6). Studies have shown that most traffic crashes related to pedestrians, particularly in high-income countries, occur in interurban streets and roads (7). For example, in the European Union countries, 70% of these crashes occur in cities, and this figure is 76% in the U.S. (8). Pe-

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destrians are associated with the highest contribution of deaths caused by traffic crashes in the world's densely populated cities. For instance, In Mumbai and Delhi, pedestrians accounted for 78% and 53% of traffic fatalities, respectively (9). This figure is 44% in San Francisco (10). According to the statistics of Tehran Traffic Police, more than 6,000 traffic crashes causing injury and more than 100 traffic crashes causing death annually occur in Tehran. In fact, more than 40% of deaths from traffic crashes in Tehran occur for pedestrians (11).

Given the importance of this issue, in the recent years, many studies have been conducted in different parts of the world, especially in densely populated cities, on the role of environmental and demographic factors in frequency, spatial distribution, and severity of traffic crashes related to pedestrians in urban areas, using different methods of spatial analysis and a variety of statistical models (12-21).

In the recent years, due to the increase in automobile production, traffic load has dramatically increased in urban and suburban streets and roads of Iran, while these transport infrastructures have not been developed qualitatively and quantitatively commensurate with car production. Since a major proportion of traffic crashes in Iran occur due to environmental factors, especially the quality of roads and streets and as the capacity of streets and roads, studying the urban and interurban roads and streets, particularly in densely populated cities with heavy traffic such as Tehran, in terms of the environmental factors involved in traffic crashes can be helpful to more accurately identify the environmental factors of such crashes and their contribution. The results of such studies can be used in better planning for reduction of this type of risk factors. Hence, this study aimed to determine the high-risk areas and spatially analyze the traffic crashes causing death to pedestrians in Tehran in 2013 and 2014. Tehran is the largest city and the capital of Iran, with an area of more than 612 square kilometers (22). It is the 25th most populous city in the world (23). Tehran is divided into 22 Districts, 370 Parishes, and 560 Traffic zones, with more than 535 km of highway and 445 arterial streets (24).

Methods

This was a cross-sectional study. The data were extracted from the database of Tehran Traffic Police. Statistical analyses were performed by descriptive and inferential statistics in SPSS and Arc-GIS. Relative and absolute frequency were used to describe the quantitative data. Mapping was applied to display the distribution of crashes by spatial complications. Analytic surveys were conducted in the following steps: First, the exact location of traffic crashes causing death to pedestrians was extracted by reviewing the files of crashes in the database of Tehran Traffic Police. Second, according to the Universal Transverse Mercator (UTM), geographical coordinates of the traffic crashes locations with the accuracy of one to three meters were recorded and saved in a computer. The UTM system divides the Earth into 60 zones, each 6° of longitude in width and uses a secant transverse Mercator projection in each zone. These zones have been numbered 1 to 60. Each zone starts at 180° west and proceeds to 180° east. The central meridian is located at the center of each zone. . Coordinates are measured in metric units. The point of origin of each UTM zone is the intersection of the equator and the zone's central meridian.

Third, using Arc-GIS, different layers of geographic information were put on each other and mapping was extracted. Finally, Global Moran's index with Euclidean distance method was used to study and analyze the distribution pattern of traffic crashes related to pedestrians in terms of being either cluster or scattered. Moran's I index is the most common index used for measuring the spatial autocorrelation to determine how close are the objects compared to other close objects.

Autocorrelation refers to the relationship

between the remaining values across the regression line. A strong autocorrelation occurs when the values of a variable that are spatially close to each other are correlated. In other words, it is achieved when changes occur regularly. If the spatial objects or the values of variables related to them are randomly distributed in space, there must apparently be no relationship between them. Moran's index studies the distribution pattern of these spatial objects by considering the values of the studied variable in terms of being cluster or scattered. If the value of Moran's index is equal to +1 or near +1, it implies a complete cluster pattern or existence of autocorrelation. If this value is zero, it means that the pattern is random or multipolar accumulation.

Finally, if Moran's index is equal to -1 or near -1, it shows that the crashes follow a scattered pattern. Hot Spots Analysis: For this analysis, Global Getis-Ord G index with Euclidean distance method was calculated for each feature. Z-score of this index shows that to what extent the studies feature has been distributed cluster-like, which may be statistically significant. In this study, this index was used to display the areas with high, low or moderate frequency of traffic crashes associated with pedestrians. Getis-Ord G index values were interpreted based on comparing the observed values and the expected values. If the observed values of Getis-Ord G index in an area are more than the expected values, that area is considered among the hot spots, and if the observed values are less than the expected values, that area is considered among the cold spots.

Results

One hundred ninety-eight incidents were studied; 92 of which, (46.4%) occurred in April 2013 to March 2014 and other 106 cases (63.6%) occurred in April 2014 to March 2015. The highest and the lowest frequency of crashes belonged to January (26 cases) and June (10 cases). Figure 1 demonstrates the trend of the traffic crashes causing death to pedestrians in 2013-2015 in Tehran.

Overall, 158 cases (79.8%) of crashes have occurred in Tehran highways. Azadegan highway, which stretches from Northwest to Southeast of Tehran, had the highest frequency of crashes (25 cases). During the study period, fatal road traffic injuries that caused the death of pedestrians oc-

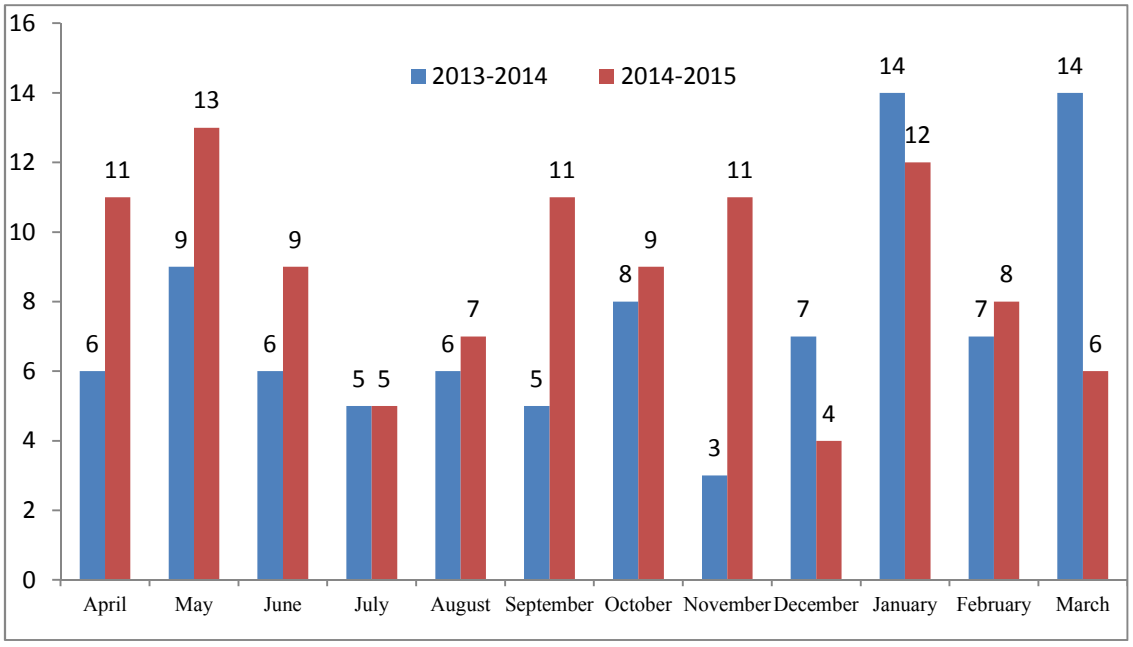

Fig. 1. Distribution of Fatal Crashes Associated with Pedestrians in Tehran by Different Months: 2013-2015

curred most frequently in traffic zones located in the West, East and South of Tehran. Figure 2 depicts the distribution of studied crashes in Tehran and their position to highways, and urban to interurban bus terminals.

Among the 22 districts of Tehran, districts located in the South, East, and Northwest of Tehran, as well as districts located in the Center of the city, have shown the highest and the lowest frequency of traffic crashes, respectively. Figure 3 displays the distribution of studied crashes in the 22 districts of Tehran in 2013 and 2014.

Result revealed that the density of events in the areas with dominant transportation, industrial and military land use was higher than the areas with dominant residential land use (Fig. 4). During the study period,

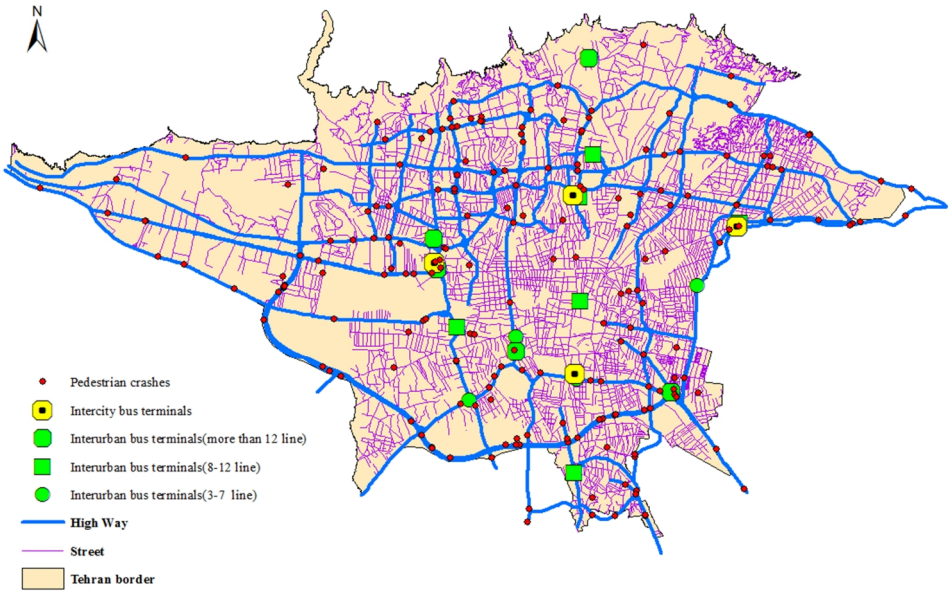

Fig. 2. Mapping of Fatal Crashes Associated with Pedestrians in Tehran and their Position Relative to Highways and Urban and Interurban Passenger Terminals: 2013-2015

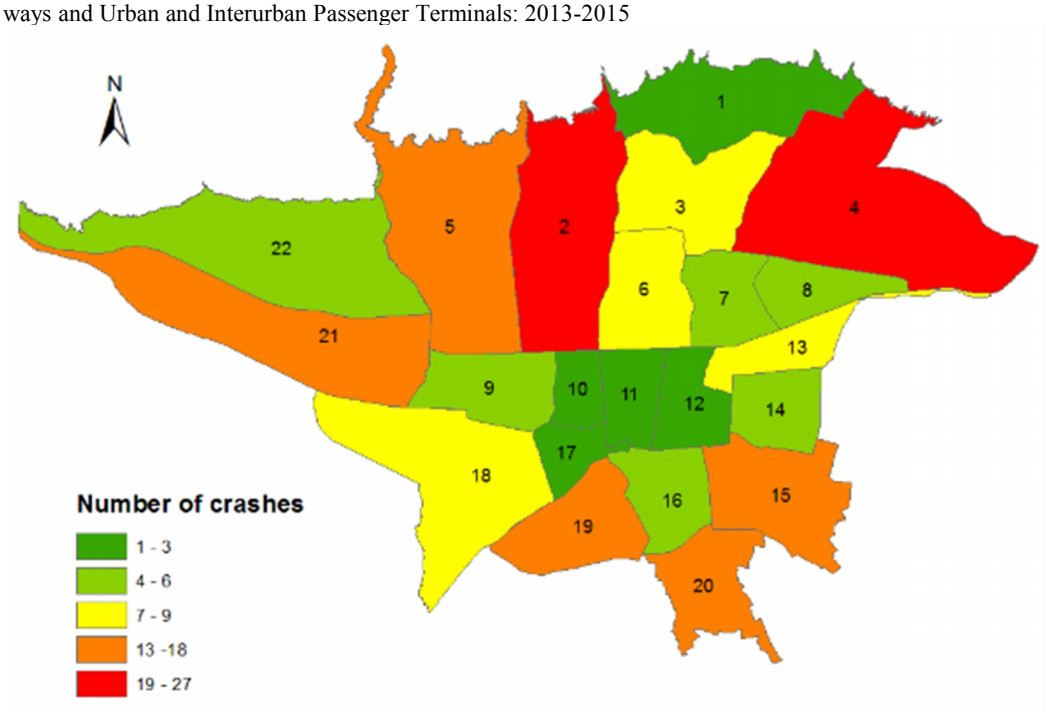

Fig. 3. Mapping of Fatal Crashes Associated with Pedestrians in the 22 districts of Tehran in 2013-2015

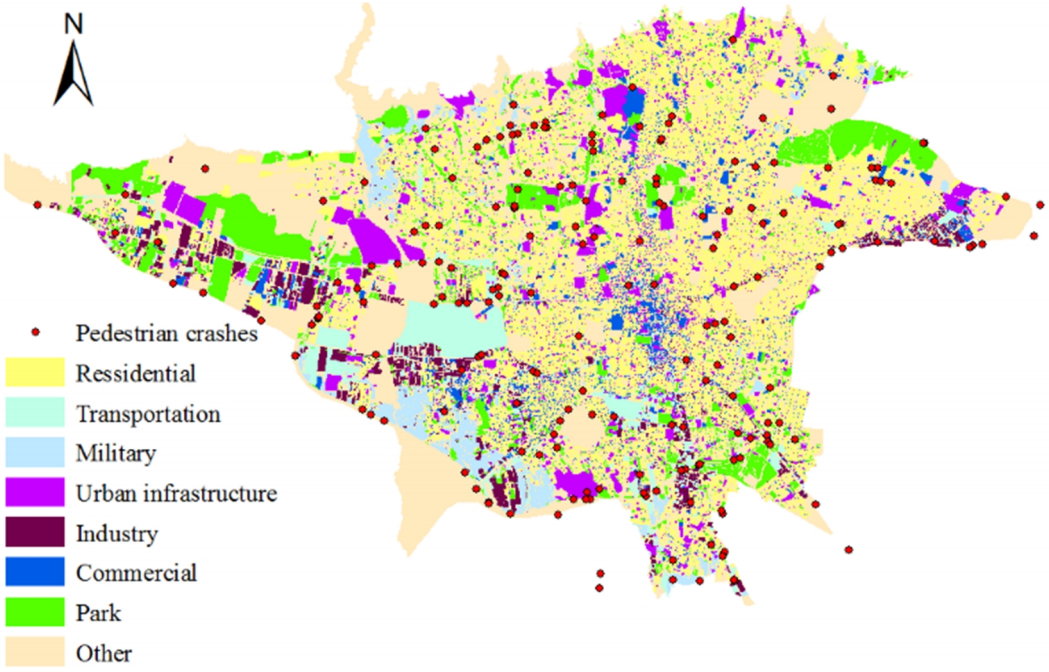

Fig. 4. Mapping of Fatal Crashes Associated with Pedestrians in Tehran and their Position Relative to Land Use in 2013-2015

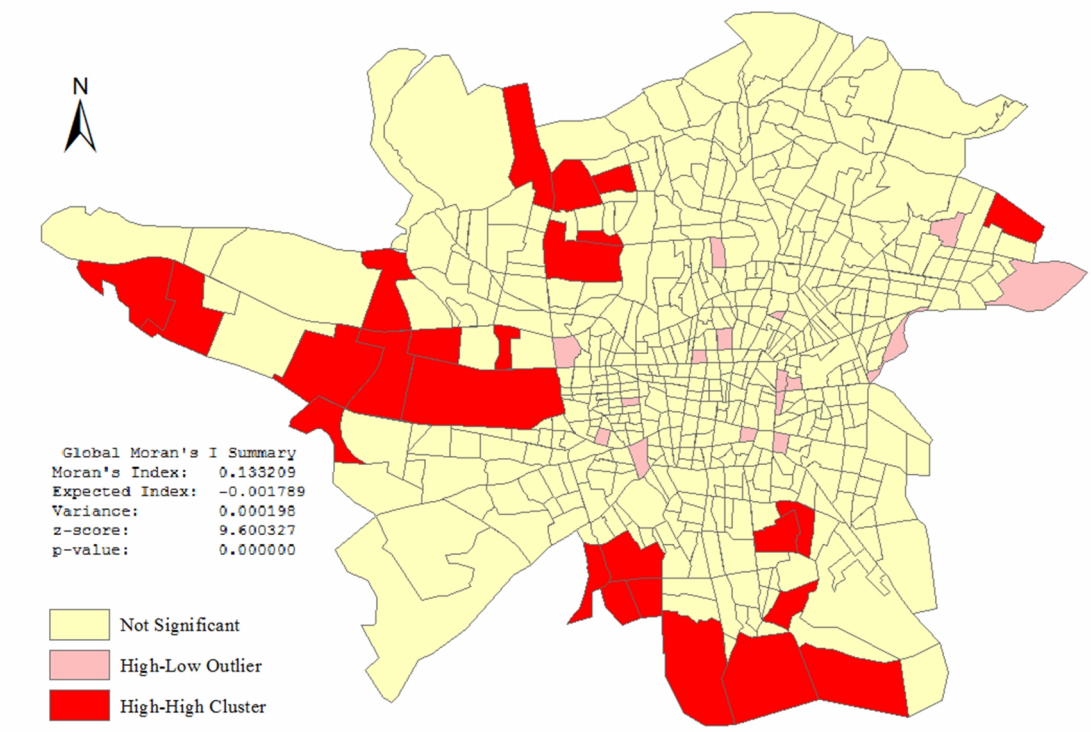

Fig. 5. Distribution Pattern of Fatal Crashes Associated with Pedestrians in Tehran by Traffic Areas in 2013-2015

fatal road traffic injuries that caused the death of pedestrians occurred most frequently in traffic zones located in the West, East and South of Tehran.

Figure 5 depicts the distribution pattern of traffic crashes causing death to pedestrians in traffic zones. Moran's I index value showed that the studied crashes had a cluster-like distribution ($p<0.001$).

The hot spots in Tehran in terms of traffic crashes causing death to pedestrians included the western, southern, northern, partly eastern suburbs, and cold spots were mainly located in the central areas of Teh-

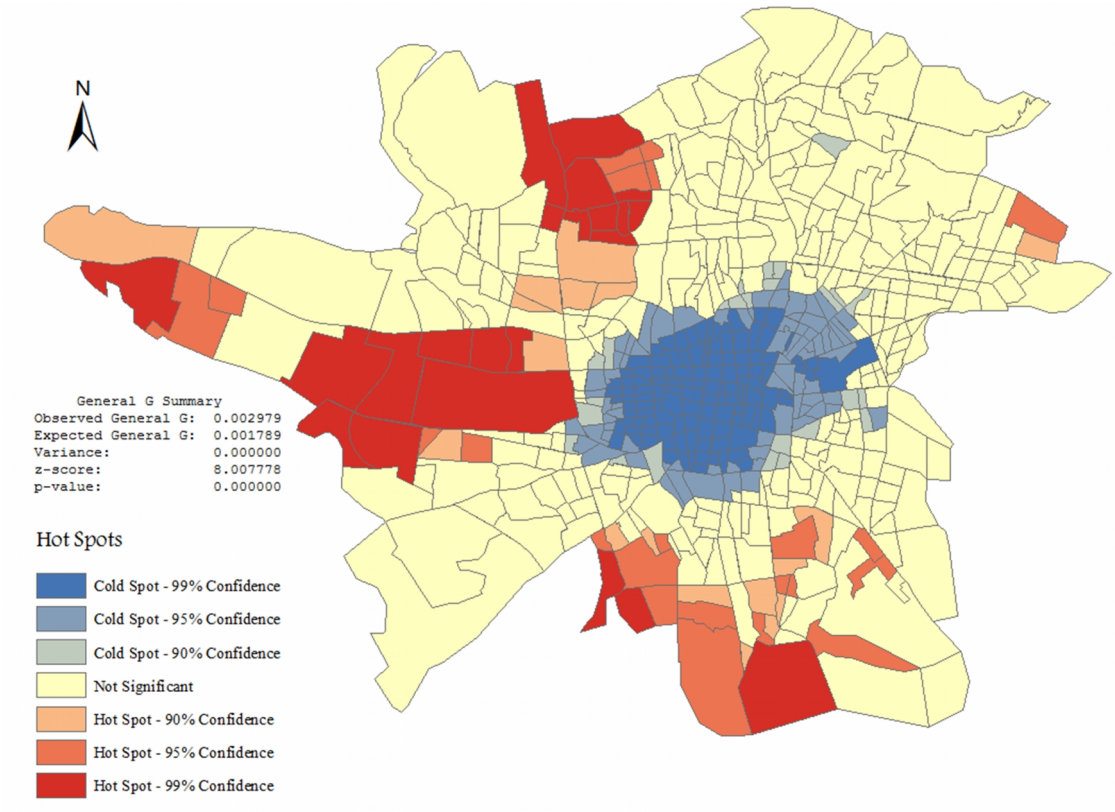

Fig. 6. Low and High-Risk Traffic Areas in Terms of Frequency of Fatal Crashes Associated with Pedestrians in Tehran in 2013-2015

ran (Fig. 6). Getis-Ord General G index showed that the distribution of hot and cold spots of the studied crashes was statistically significant ($p<0.001$).

Discussion

The results of this study revealed that occurrence of the traffic crashes causing death among pedestrians in Tehran during different months of 2013 and 2014 does not follow a specific and fixed trend. For instance, the highest and the lowest frequencies of studied crashes in 2013 have been recorded in January-February and October, respectively, while the highest and the lowest frequencies belonged to May and December, respectively. However, it can be generally concluded that the number of crashes in this period during the summer months (especially June and August) is fewer than the winter months (especially January and March). Since some studies have shown that the frequency of traffic crashes associated with pedestrians increases with increased pedestrian volume (10,25,26), these seasonal differences can be attributed to changes in pedestrian volume. Since some studies such as those conducted by Clouti-er, Cottrill, Green, Miranda-Moreno, McArthur et.al found that the number of schools or students is associated with the frequency of traffic crashes associated with pedestrians in urban areas (17,26-29), school holidays and reduced traffic of students in June and August can be one of the reasons for the reduced frequency of such crashes during these months. Therefore, better organization of students' traffic and promotion of the safety of the streets near schools can be considered as one of the strategies for reducing the deaths from traffic crashes related to pedestrians in Tehran.

This study showed that about 80% of the studied crashes have occurred in highways and freeways. Highways located at the main western and southern entrances and exits of Tehran such Azadegan Highway (from Northwest to Southeast of Tehran)

and Karaj Special Road, which connects Karaj to 36 km West of Tehran had the highest share of such crashes. These results are consistent with the findings of studies conducted by Wier et.al in San Francisco and Mueler et al. in Washington that showed that frequency of traffic crashes associated with pedestrians is higher in highways and freeways (15, 30). Since traffic load in the western and southern highways of Tehran is higher than other areas and there is an intense congestion of different means of transport in some of these areas, one reason for the high frequency of fatal crashes in these areas would be the high traffic load and congestion of different means of transportation. Therefore, the reasons of this problem need to be identified by conducting more studies. In addition, the necessary measures should be taken to reduce the rate of traffic crashes through organizing the passage of vehicles and pedestrians and separating the passage of light and heavy means of transportation in the western and southern highways of Tehran.

Distribution of studied crashes in terms of proximity to or remoteness from the West (Azadi) and South (Khazaneh) terminals showed that the density of traffic crash was relatively high at the end of the roads leading to Azadi Passenger Terminal such as Tehran-Karaj Freeway, Karaj Special Road, Afsarieh Bridge, and the eastern part of Azadegan Highway. Thus, one of the reasons for the high frequency of traffic crashes causing death to pedestrians in South and West of Tehran is the location of Azadi and Khazaneh Passenger terminals in these areas. On the other hand, distribution of the studied crashes in terms of proximity to or remoteness from urban passenger terminals does not follow a specific pattern and the frequency of traffic crashes associated with pedestrians is very low near these passenger terminals, especially those far from interurban passenger terminals. Therefore, it can be concluded that the streets and roads around the urban passenger terminals are of low risk in terms of traffic crashes associated with pedestrians.

Comparison of the 22 districts of Tehran in terms of the frequency of fatal crashes involving pedestrians shows that the highest frequency of this type of crashes has occurred in District 2, which accounts for 13.6% of the total cases, while this district covers only 8% of the total area of Tehran. Given that most crashes in District 2 have happened on highways, the relative high length of highways could be mentioned as one of the reasons for the higher frequency of traffic crashes associated with pedestrians in District 2 of Tehran. Highways in this district, with a length of about 61 km, account for about 11% of all highways of Tehran.

Results of this study revealed that high-risk traffic areas in terms of crashes causing death to pedestrians during the studied years are mostly located in the West and South of Tehran. High value of Moran's I index indicated the distribution of crashes by the 560 traffic areas of Tehran followed a cluster-like pattern. In other words, the location of occurrence of these crashes in Tehran did not follow a random distribution. In addition, findings demonstrated that the hot spots of the studied crashes were mostly located in the West and South of Tehran, while the cold spots were mainly focused in the central parts of the city. Since Getis-Ord General G index showed that the distribution of hot and cold spots of the studied crashes is statistically significant, it can be stated that some certain factors were involved in non-random distribution traffic crashes causing death to pedestrians in Tehran and high frequency of these crashes in high-risk areas. Due to the environmental and structural differences between the high-risk and low risk areas, which are mainly located in the center of Tehran, environmental factors can have a great role in this issue. Similar studies in other parts of the world, including the studies conducted by Slaughter et.al in New York, Anderson in London, Taquechel et.al in Atlanta, Wang and Kockelman in Texas, Siddiqui et.al in Florida and Kuhlmann et.al in Colorado, have also shown that envi-

ronmental factors are highly involved in non-random distribution of traffic crashes related to pedestrians (12,14,16,31-33).

It seems that one of the factors determining the distribution of the studied crashes in Tehran, which is the higher frequency of crashes in the suburban areas than the central part of the city, is the difference between drivers and pedestrians in terms of traffic culture. The drivers and pedestrians in central parts of the city have higher education levels and respect traffic regulations more than those in the suburban areas. Higher traffic load on the outskirts of the city compared to the downtown was another reason for this issue. Enforcement of regulation of traffic limits and alternative passage of vehicles with even or odd license plates in the central parts of Tehran causes the central parts of the city to have a lighter traffic load than the margins of Tehran.

This was one of the few studies in Iran that has used the files drawn by police experts for conducting an applied research to determine the high-risk areas in a metropolis. Using these files, we recorded the geographical coordinates of the location of crashes and we prepared a map to determine the distribution pattern of traffic crashes causing death to pedestrians and their position relative to other spatial objects.

This study was conducted using only the data of crashes registered by Tehran Traffic Police. Comparison of the statistics provided by the police and Forensic Medicine Organization showed that the actual number of fatal crashes in Tehran is more than those mentioned in the database of Tehran Traffic Police and the information related to some crashes causing death does not exist in this database. Therefore, it is not possible to acquire information on their location of occurrence through the police files.

In such studies, it is better that the relevancy of the death of the injured by traffic crashes to these crashes be defined based on the time of death after crash. This time in different countries varies between 6 days to one month, and in Iran, this time has been defined to be one month. However, due to the lack of consistency between the data provided by Tehran Traffic Police and Forensic Medicine Organization, relevancy of the death of the injured by traffic crashes to these crashes in this study was determined based on the data extracted from data based on Tehran Traffic Police.

Conclusion

Various districts of Tehran, excluding central districts, are considered high-risk areas. Therefore, the majority of traffic crashes causing death to pedestrians have occurred on highways located at the main entrance; that is, districts located in south, east and northwest of Tehran. Hence, highways are the most dangerous places for pedestrians in Tehran. Significant cluster-like distribution of crashes by the 560 traffic zones of Tehran and existence of hot spots in terms of the studied crashes in the Western and Southern parts of Tehran indicates the decisive role of environmental factors in occurrence of traffic crashes causing death to pedestrians. Thus, further studies are required to identify these factors. Moreover, it is necessary to organize the pedestrians' traffic in high-risk areas.

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