Spatial Factors Related to Traffic Crashes on Pedestrians in All Districts of Tehran

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Abstract

Background: A great proportion of deaths due to traffic crashes occur for pedestrians, both in developing and developed countries. **Objectives:** The aim of the present study was to determine the spatial factors related to the frequency of traffic crashes on pedestrians in districts of Tehran city. **Methods:** This was a cross-sectional study. All traffic crashes on pedestrians during 2013–2015 were included in this study. The data were extracted from different sources such as traffic police main office, Tehran municipal office, and Iran statistics center. Poisson and negative binomial regression models were used to analyze the role of environment and district on frequency of traffic crashes. Moreover, the likelihood-ratio test has been used for comparison between models, while assessment of goodness-of-fit has been reported using R^2, Akaike information criteria, and Bayesian information criteria. **Results:** Of 12,090 crashes, 11,895 (98.4%) had led to injuries, while 195 (1.6%) had led to deaths. The frequency of crashes varied substantially in different districts of Tehran. The incidence of injuries did not show any particular pattern, whereas the pattern of incidence of deaths was lower in central districts in comparison to higher incidence in marginal districts (e.g., north, south, west, and east of Tehran). The results of the final model showed a statistically significant association among various variables such as demographics, web of roads, rate of traveling, and land use with the outcome as number of crashes in geographic units. **Conclusions:** Frequency distribution of traffic crashes leading to injury and/or death is completely different in various districts of Tehran. Demographic as well as spatial characteristics also play an important role in determining this distribution. Regional planning, appropriate traffic management, control measures on spatial risk factors, and educational programs could substantially improve the safety of pedestrians in Tehran.

Keywords: Injuries, pedestrians, spatial analysis, traffic

Background

Traffic crashes result in 1.35 million annual deaths and cause injuries to tens of millions of people around the world.[1] Pedestrians are regarded as the most vulnerable users of roads. Substantial portion of fatal traffic crashes is attributable to pedestrians in the developed world. In 2013, 22% of all fatalities as a result of road traffic crashes in the European Union were associated with pedestrians.[2] In 2010, 4280 deaths and 70,000 injuries occurred among pedestrians in the United States due to traffic crashes.[3] Each year, there are 400 pedestrians killed by road traffic

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crashes in Canada, accounting for 13% of all traffic casualties.[4]

Proportion of deaths related to traffic crashes grows larger in dense cities. In Mumbai and Delhi, for example, pedestrians accounted for 78% and 53% of traffic fatalities, respectively.[5]

There has been an increase of inner and outer city traffic burden during recent years due to the increase of automobile manufacturing in Iran, whereas the passages have not been equivalently expanded. Therefore, a large proportion of traffic accidents can be attributable to spatial and environmental factors such as quality of roads and passages.[6]

According to traffic police main office, fatal traffic crashes on pedestrians account for 40% of total traffic deaths in Tehran city.[7]

Assessment of geographical frequency distribution and severity of pedestrian crashes have been considered important, leading to adaptation of geographical and statistical analytic methods worldwide.

Iran has experienced a growing traffic burden due to increased automobile manufactures, recently; however, the roads have not been developed accordingly. Due to the impact of spatial factors on traffic crashes and intensification of crashes by low capacity of roads, investigation of the effects of spatial factors on incidence of traffic crashes is indeed imperative. Results of such investigations could be used to control plans more appropriately and target the reduction of these effects.

Tehran, the capital city of Iran, with 612 kg^2 of area, is located in the north of the country. The population of Tehran according to 2016 census was 8,693,706,[8] while the number of stationary population is estimated to be 8,089,766 now. Tehran, which is the center of business and industry in Iran, is divided into 22 districts, 134 counties including Tajrish and Rey, and 560 traffic zones.[9] Daily, there are 15–19 million interurban travels which hamper traffic control strategies.[10] Construction of highways, development of public transportation systems, and different traffic legislations are part of such strategies. Development of subway roads was another strategy which was responsible for transport of 129 million passengers on 2011.[11] Tehran is ranked as the 25th populated city worldwide and is estimated to become more populated in 2030.[12]

Objectives

The aim of the present study was to determine the spatial factors related to the frequency of traffic crashes on pedestrians in districts of the city of Tehran.

Methods

This is an ecological study on casualties of traffic crashes on pedestrians during 2013–2015 in spatial units. Different data sources such as traffic police main office, Tehran municipal office, and Iran statistics center had been used. The dependent variable (outcome) was the rate of injuries or deaths in any district. The definitions of independent variables are provided in Table 1.[9]

Statistical analysis was done using computer software such as SPSS Version 2 0, (SPSS Inc., Chicago, Ill., USA), STATA Version 12, (College station, Texas 77845, USA) and ArcGIS 10.2.2, (ESRI Redlands, USA). Descriptive statistics (e.g., mean, standard deviation [SD], and range) as well as maps were used to describe the distribution of crashes. Regression models including negative binomial (NB) regression and generalized Poisson regression were used for analysis of the effects of spatial and regional factors on frequency of traffic crashes on pedestrians. Unit of analysis was every district of Tehran metropolitan.

Given the statistically significant difference of overdispersion index with 0 in nonfatal crashes ($P < 0.001$), the use of NB regression model was justified, while nonsignificant difference in fatal events ($P = 0.5$) justified the use of generalized Poisson regression model.

We used maximum likelihood methods for estimation of regression coefficients and likelihood-ratio tests for comparisons of the models. We also assessed the goodness-of-fit models using Akaike information criteria and Bayesian information criteria.[13,14]

First, if the P value of variables was < 0.2 in the univariate analysis, they were included in the model. Then, various models were compared to determine which one was the best in terms of goodness-of-fit.

Results

Among 12,090 crashes being studied, 11,895 (98.4%) nonfatal and 195 (1.6%) fatal crashes were reported. The frequency distribution of nonfatal and fatal crashes was quite different in Tehran city. The absolute number of fatal crashes ranged between the lowest in central districts with one case per districts coded 11 and 12 and the highest with 27 cases in district coded 2 and 22 cases in district coded 4 [Figure 1].

On the other hand, the incidence of nonfatal crashes did not follow any particular pattern. However, this number was higher in central districts compared to marginal ones. For instance, the district coded 6 with 1092 cases and the district coded 5 (located in the north-west) with 1018 cases had the highest number of cases, followed by districts coded 2 and 12 with more than 750 cases, while districts coded 17 and 22 had the lowest number of cases [Figure 2].

Furthermore, the incidence rate of injury and fatal crashes was quite different in Tehran city. The incidence rate of fatal crashes ranged between the lowest in central districts and the highest in southern districts. In contrast, the incidence rate of injury crashes ranged between the lowest in marginal areas of Tehran, especially in the southern and eastern districts, and the highest in central districts [Figure 3].

There were 3 different categories of variables, namely population and exposure, web of roads, and traveling and land use, which were included to investigate their relationship with traffic crashes on pedestrians in all 22 districts of Tehran.

Table 1: Definition of independent variables

Variable	Definition
Population density	The population divided by area on km^2 for of each geographical unit
Percentage of illiteracy	The percentage of illiterate people over 6 years of age
Percentage of employees at work	The number of employees divided by the total population of each geographical unit (i). Estimation is based on base-year statistics and mathematical modeling. The number of employees/50 residents with the assumption of at least one employee in any geographical unit can be obtained using the following formula $EMPE_i^t = Max\left\{EMPE_i^t\left(1+r_{em}^t\right), P_i^t / 50\right\}$ Where EMPE is the number of employees in year *t*, and $r_{em}{}^t$ is the rate of employees' growth in the year *t*
Percentage of students at residence	The proportion of students in any geographical unit (i). Estimation is based on base-year statistics and mathematical modeling. With the assumption of 1% annual population growth, it can be estimated using the following formula $STU_i^t = STU_i^o\left(1+0.01\right)^{t-o}$ Where STU^t is the number of students in year *t*, and STU^o is the number of the students in base year
Number of green spaces/km^2	Estimated by the number of green spaces divided by the area of each geographical unit
Level of development	Indicates the level of development of urban areas. Calculation is based on 7 items, namely education, housing, employment, biologic environment, access to information, Facility and infrastructures
Length of highways/length of all roads (km)	They are designed to facilitate transportation and are among the highest rank of urban roads. Highways are in higher level of speed and movement and have no local access points. Crossroads are usually interchange and are separated by physical objects
Length of arterial roads (km)	The main objective is to facilitate the movements within urban movement network. They comprise 75% of total vehicle kilometers passed through this network
Travel attraction	Estimation is based on mathematical modeling with socioeconomic variables. The number of travel attraction in each geographical unit, for instance, is calculated using TA_i=1.620EMPE$_i$+2.420SHOP$_i$+62694DB$_i$ Where EMPE$_i$ and SHOP$_i$ are the number of employees and shops in the area zone i, respectively, and DB$_i$ is the covariate of Tehran Bazaar (traffic zone 1)
Per capita ownership of private cars	Obtained from the results of comprehensive transportation studies in different years. Various economical and mathematical indices have been used for intervals between these studies. It is estimated by $CO^t = CO^b + \frac{0.0016\Delta t^{2.0999}}{1+1.3912e^{0.0928\Delta t}}$ Where CO_b and CO_t are per capita ownership of private cars in base year and in year *t*, respectively, and Δt is the difference of years
Lack of parking space/km^2	Estimated using the number of private cars stopped in any particular area for any reason except commute. The most common method of estimation is based on times passed for occupational and nonoccupational commutes which involved private cars
Land used	Includes the area of each geographical unit used for different utilizations. Land use is estimated in total or partial. The most important of them in spatial studies included: residential, administrative, business, educational, industrial, and service

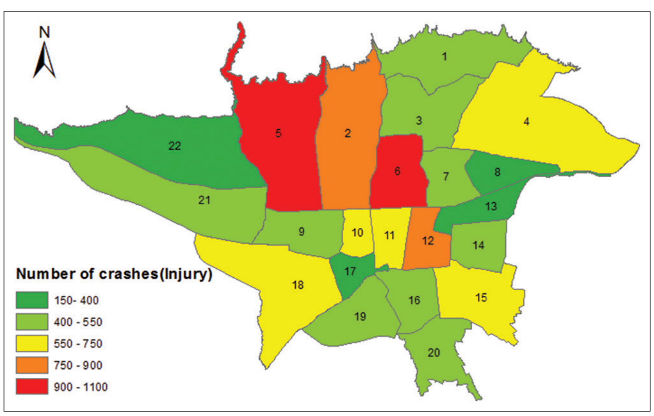

Figure 1: Frequency of injuries of pedestrian-related crashes in districts of Tehran 2013–2015

Table 2 demonstrates the descriptive characteristics (mean, SD, minimum, and maximum) of the independent variables.

According to final NB regression model, frequency of nonfatal crashes on pedestrians had a significant association with population density, percentage of illiteracy, percentage of employees at workplace, percentage of students at residential place, length of arterial roads to length of all roads, lack of parking space, educational land used to total area, and total land used to total area.

In addition, population density, percentage of illiteracy, percentage of employees at workplace, percentage of students at residential place, length of arterial roads to length of all roads, and educational land used to total area indicated a positive association, whereas lack of parking space and total land used to total area indicated a negative association with outcome variable [Table 3].

According to final generalized Poisson regression model, frequency of fatal crashes on pedestrians had a significant association with percentage of employees at workplace, length

Table 2: Descriptive statistics of independent variables

Variable	Mean	SD	Minimum	Maximum
Exposure variables				
Population density/km^2	16,649.65	8582.95	1935.27	34,419.99
Percentage of illiteracy	0.06	0.03	0.03	0.13
Percentage of employee at work	0.15	0.20	0.03	0.90
Percentage of student at residence	0.04	0.01	0.02	0.09
Number of parks/km^2	1.58	1.03	0.90	5.07
Level of development	60.56	15.16	0.49	100
Road network and travel variables				
Length of highways (km)	9.30	10.31	0	44.1
Length of highways/length of all roads	0.32	0.27	0	1.06
Length of arterial roads (km)	20.191	16.5127	0	66.9
Length of arterial roads/length of all roads	0.81	0.66	0	2.57
Travel attraction	17,598.70	16,662.74	756.21	77,086.51
Per capita ownership of private cars	0.35	0.12	0.22	0.68
Lack of parking space/km^2	714.23	606.23	17.91	2189.31
Land used variables				
Total land used (m^2)	18,110,265.99	10,711,801.38	6,105,032.00	40,071,922.43
Total land used/total area	0.70	0.15	0.41	1.22
Residential land used (m^2)	8,092,634.30	4,682,181.05	2,064,359.29	20,349,977.83
Residential land use/total area	0.34	0.14	0.10	0.59
Commercial land used (m^2)	521,975.89	495,398.14	139,707.57	2,290,825.67
Commercial land use/total area	0.02	0.01	0.002	0.05
Educational land used (m^2)	314,472.91	157,872.33	61,060.83	591,062.92
Educational land used/total area	0.01	0.009	0.0009	0.04
Industry land used (m^2)	702,163.82	1,489,559.39	31,036.29	6,940,509.14
Industry land used/total area	0.02	0.03	0.001	0.13
Transportation and storage land used (m^2)	497,527.33	827,650.53	41,485.63	3,243,042.38
Transportation and storage land used/total area	0.01	0.03	0.001	0.15

SD: Standard deviation

Table 3: Pedestrian injury crashes final negative binomial model for districts in Tehran

Covariates	Coefficient	*P*	95% CI	
			Lower	Upper
Population density	35.97602	0.000	17.60849	54.34355
Percentage of illiteracy	7.516251	0.014	1.498323	13.53418
Percentage of employee at work	2.066946	0.000	1.128292	3.0056
Percentage of student at residence	26.57876	0.005	7.908569	45.24895
Length of arterial roads/length of all roads	0.8291373	0.000	0.5431729	1.115102
Number of parks/km^2	0.0180292	0.833	−0.1490922	0.185150
Lack of parking space/km^2	−0.001343	0.000	−0.0017966	−0.00088
Per capita ownership of private cars	−0.2475988	0.895	−3.939786	3.444588
Level of development	0.0044274	0.593	−0.0117918	0.020646
Total land used/total area	−2.428004	0.000	−3.24784	−1.608168
Commercial land used/total area	−1.398744	0.761	−10.41669	7.619203
Educational land used/total area	17.05775	0.047	0.2471037	33.86839
Constant	5.136367	0.000	4.138921	6.133813
Fitting criteria				
Ln alpha	−3.633329		−4.265754	−3.000903
Alpha	0.0264281		0.0140413	0.0497421
Likelihood-ratio test of alpha				
AIC	12.96	0.000		
BIC	232.48			

CI: Confidence interval, AIC: Akaike information criteria, BIC: Bayesian information criteria of highways to length of all roads, length of arterial roads to length of all roads, educational land use, industrial land use, and transportation as well as depository land use.

In addition, length of highways to length of all roads, length of arterial roads/length of all roads, educational land use, and industrial land use indicated a positive association, whereas percentage of employees at work and transportation as well as depository land use indicated a negative association with outcome variable [Table 4].

Discussion

According to Figure 1, marginal districts including north-west, east, south, and south-east of Tehran were among the high-risk areas for fatal crashes on pedestrians.

Figure 2 showed that districts coded 6 in the center and 5 in the north-west had the highest number of nonfatal crashes with more than 500 events annually. Being the center and ranked as the 4th dense district (10,240 habitants in square kilometers) in Tehran, district coded 6 has experienced much severe nonfatal traffic crashes that could be explained by the huge burden of transportation and commuters (952,984 commutes daily)[9] and smaller area compared to district coded 5.

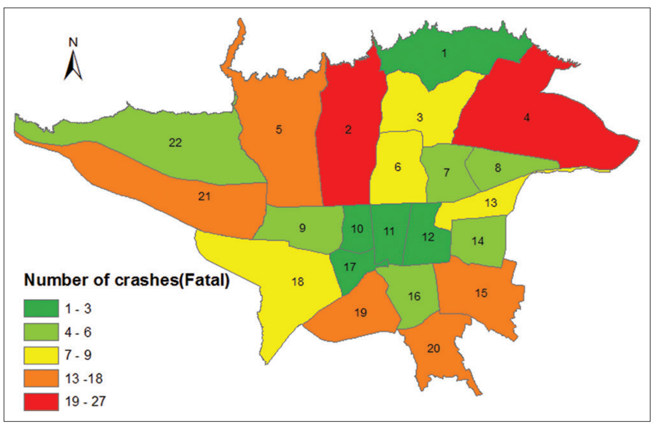

Figure 2: Frequency of fatal pedestrian-related crashes in districts of Tehran 2013–2015

Overall, there were different patterns of fatal and nonfatal traffic crashes in 22 districts of Tehran during 2013–2015. The present study revealed a significant negative association between population and employees' densities with fatal traffic crashes. In other words, fatal crashes occurred less commonly in districts with low population densities and lower percentage of employees at work. On the other hand, the frequency of nonfatal traffic crashes was significantly positively related to population characteristics such as population density, percentage of illiteracy, percentage of employees at work, and percentage of students at residence. It can be stated that nonfatal traffic crashes occurred more frequently in districts with high population density and higher percentage of employees at work.

Several studies including Cottrill and Thakuriah,[15] Sebert Kuhlmann *et al.* in Denver city, Colorado,[16] Siddiqui *et al.* in Florida,[17] Ukkusuri *et al.* in New York,[18] and McArthur *et al.* in Michigan[19] have found a significant relationship between population density and frequency of traffic crashes on pedestrians. Although the direction of their findings was the opposite of what we have found in fatal crashes, increment in number and severity of crashes in marginal districts can be explained by the fact that lower population density and percentage of employees at work decrease the traffic burden in roads and consequently lead to increase the pace of traffic. Other explanations related to cultural and safety equipment differences between Tehran compared to American cities.

The proportion of length of highways to total roads which is an important component of transportation had a positive significant relationship with the frequency of fatal crashes. In other words, the incidence of fatal crashes was higher in areas with higher highway densities. Speedy motor vehicles

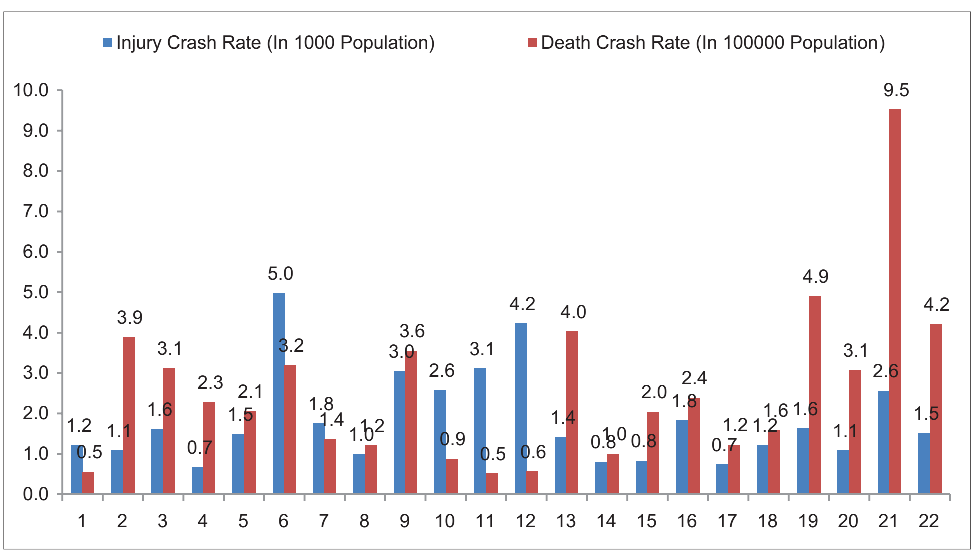

Figure 3: Incidence of injury and fatal pedestrian-related crashes in districts of Tehran 2013–2015

Table 4: Pedestrian fatal crashes final generalized Poisson model for districts in Tehran

Covariates	Coefficient	*P*	95% CI	
			Lower	Upper
Population density	−172.279	0.061	−352.7823	8.224313
Percentage of illiterates	51.07947	0.067	−3.499457	105.6584
Percentage of employees at work	−16.99633	0.000	−25.88309	−8.10956
Length of highways/length of all roads	20.02158	0.000	13.72369	26.31946
Length of arterial roads/length of all roads	0.3455357	0.000	0.187152	0.503919
Residential land used	−3.39e-07	0.198	−8.56e-07	1.77e-07
Commercial land used	−6.96e-06	0.061	−0.0000142	3.22e-07
Educational land used	0.0000166	0.007	4.64e-06	0.000028
Industry land used	3.33e-06	0.028	3.66e-07	6.30e-06
Transportation and storage land used	−4.57e-06	0.002	−7.52e-06	−1.61e-06
Constant	−1.464534	0.622	−7.287207	4.358138
AIC		5.42		
BIC		−18.34		

CI: Confidence interval, AIC: Akaike information criteria, BIC: Bayesian information criteria

in such roads can possibly cause more severe and fatal crashes on pedestrians. In addition, in area level, frequency of nonfatal crashes had a significant positive relationship with transportation variables such as length of arterial roads and a negative relationship with the lack of parking and per capita ownership of private cars.

In other words, the incidence of nonfatal crashes was much higher in areas with more arterial roads. This finding is consistent with findings of several other studies, for example, Hashimoto in Florida,[20] Cloutier *et al.* in Canada,[21] and Green *et al.* in England.[22] Therefore, unsafe arterial roads can be considered as one of the reasons for increasing the incidence of nonfatal traffic crashes on pedestrians. Therefore, improving safety of arterial roads is necessary.

Distribution of fatal crashes had a significant relationship with land use variables such as educational, industrial, transportation, and depository land use in a way that the incidence of fatal crashes was higher in areas with high density of industrial and educational centers. High traffic rate of heavy automobiles through these areas could be one possible explanation for this phenomenon.

Distribution of nonfatal crashes was also related to land use variables such as total land use and educational utilization. The incidence of such crashes was higher in educational areas, which implied unsafe commutes for students.

It is worth mentioning that one of the effective reasons in traffic crashes on pedestrians is land use as shown by Yao and Loo in Hong Kong,[23] Ukkusuri *et al*. in New York,[18] Wier *et al*. in the United States.[24] Therefore, incorporation of safety measures in development designs for reconstruction of old city structures is important.

Our results showed that increased level of development and the number of parks within 22 districts of Tehran was related to increased incidence of nonfatal crashes. However, this relation is not significant, particularly, more developed areas could be concomitant with ignorance of pedestrians' safety during development process, and the increase in numbers of parks could uptake more passengers through their leisure times. Hence, improving safety of pedestrians around parks could possibly prevent such crashes.

The present study had some limitations. Fatal traffic crashes are defined as any death related to motor vehicles within 1 month after the crash. For the purpose of this study, we used traffic police data which did not cover fatal crashes within the defined period of 1 month. Because of lack of unregistered geographical coordinates at the time of a crash, police officers use spot maps and approximate geographic coordinates to register the crash. Accordingly, the real place of crash could be slightly different from what was registered. Few cases with unreliable police-registered spots compelled us to make a contact with the casualty to get more accurate information. Nonetheless, determination of the accurate place of crash could still be misleading. Poisson modeling for our interesting outcome, crashes injury, was another limitation of the study because this model is pertinent for rare data.

It is possible to change spatial objects over time. To resolve this problem, we used the latest information of traffic police, and estimation was undertaken using geographical and time layers.

One of the strengths of our study was the systematic use of Tehran traffic police data to determine the influence of spatial factors on the distribution of fatal and nonfatal traffic crashes on pedestrians.

There are only a few studies investigating spatial factors on the crashes on pedestrians in Iran using geographic information system and NB and generalized Poisson regression models. In this study, we used geographical information system to characterize high-risk areas of traffic crashes, while regression models were used to determine effective factors influencing frequency distribution of those crashes. This study showed that depending on the availability of reliable information, regression models are a suitable choice for determining influential factors and using the findings to target preventive measures. According to our findings, for pedestrians, marginal districts such as north, east, south, and south-west of Tehran (coded as 5, 4, 3, 15, 19, 20, and 21) are among the high-risk areas for fatal crashes, while central and north-west districts of Tehran (coded as 5 and 6) are among high-risk districts for nonfatal crashes. Frequency of fatal and nonfatal crashes on pedestrians is related to different spatial factors, especially population density, percentage of students, length of highways and arterial roads, and land use. More suitable designation of preventive programs for safety of citizens and decrease of traffic crashes are highly recommended. It is imperative to assess these factors more carefully and adapt applicable approaches to modify them if possible. It should be noted that some effective interventions such as designing safer infrastructure, improving the safety features of vehicles, speed restriction in crowded places, improving postcrash care for victims of road crashes, setting and enforcing laws relating to key risks, and raising public awareness can be used to reduce traffic crashes.

Conclusion

According to the results, there are various high risk districts for pedestrians fatal crashes in Tehran. North, east, south and south west are among the high risk areas for fatal crashes, while central and north west districts are among high risk districts for nonfatal crashes. Demographic and spatial characteristics play an important role in different distribution of traffic crashes leading to injury and/or death. It concluded that regional planning, appropriate traffic management, control measures on spatial risk factors, and educational programs could substantially improve the safety of pedestrians in Tehran.

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Conflicts of interest

There are no conflicts of interest.

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