Spatio-Temporal Pedestrian Accident Analysis to Improve Urban Pedestrian Safety: The case of the Eskişehir Motorway

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ABSTRACT

Determining pedestrian accident hotspots on road segments is a crucial part of the pedestrian safety assessment as it is used to prioritize problematic parts of a road network for in particularly planning and implementation strategies. Moreover, the spatial pattern of the pedestrian accidents may change over time due to several factors. In order to better understand pedestrian safety conditions, pedestrian accident patterns have to be analysed with regard to both space and time. This paper adapts such a spatio-temporal hotspot detection method for the analysis of pedestrian accidents. In this study, 189 traffic accidents involving pedestrians that resulted in injury or fatality on the Eskişehir Motorway (Turkey) between the years of 2005 and 2010 are mapped with their spatial and temporal information. Network-based Kernel Density Estimation is used to examine the hotspots of pedestrian accidents and their changes over the years. Then, the significances of the results are evaluated by using Network-based the Nearest Neighbor Distance and the K-function methods. The impact of land use change and taken measures are evaluated based on spatio-temporal hotspot analysis.

Key Words: *Spatial analysis, pedestrian accident, hotspot, kernel density estimation, Eskişehir*

1. INTRODUCTION

Land use planning is the key determinant factor in construction of the road network in urban areas. Therefore, the decisions taken in the planning process can result in a variety of problems related to the traffic and transportation [1, 2]. Transportation cost, traffic accident, urban sprawl, spatial fragmentation, air pollution and noise pollution can be considered as some of the main issues associated with this topic [3, 4].

Evaluating the social and economic impacts of urban residents, traffic accidents -especially pedestrian accidents- are one of the priority issues within them. More than 1.24 million people, 22 % of them pedestrians, die annually on the world's roads and 20 – 50 million people suffer from non-fatal injuries leaving devastating traumas on the life of others as well as on the communities [5]. The World Health Organization

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(WHO) predicts that the number of road traffic injuries will rise to become the fifth leading cause of deaths by 2030. It is also reported by the WHO that road traffic accidents are leading injury related cause of deaths among people aged 10 to 24 [5].

According to WHO 2013 report [5], middle-income countries, including Turkey have the highest annual traffic fatality rate with 20.1 per 100 000 population, whereas the rate in high-income countries is 8.7 per 100 000. Approximately 80% of road fatalities occur in the developing countries. This report documented that Turkey's rank is 64 out of 183 countries and traffic fatality rate is 12 per 100.000 populations in 2010 in Turkey, whereas the average of 28 European Union member countries was 7 in the same year [5]. Besides, in Turkey, an average of 3553 traffic accidents, with 10 fatalities on scene (20% of them pedestrians) and 734 injuries (12% of them pedestrians), happened daily in 2012 [6]. These statistics suggest that the issue of pedestrian accidents is one of the most important health and safety issues in Turkey.

Pedestrian accidents mostly occur on urban roads having both high pedestrian density and high traffic speed (i.e. motorways passing the city) in Turkey, similar to most of the developing and developed countries. Moreover, road design and land use can both increase and reduce pedestrian safety through land-use decisions and presence or absence of pedestrian facilities [7]. Additionally, to understand the factors causing pedestrian accidents and to improve the pedestrian safety, it is crucial to analyse pedestrian accident hotspots, and the effects of road design and land use on pedestrian accident hotspots.

Since traffic accidents have geo-coded (positional) data, many studies (e.g. [8 – 11]) have focused on the issue of road safety analysis using Geographic Information Systems (GIS). GIS allows one to visually represent traffic accidents and also spatially analyse them to identify the hotspots. One can use different methods to determine traffic accident hotspots by using GIS based spatial analysis techniques (e.g. [12-21]). Longley [22] stated that in order to allocate resources appropriately to increase road safety, it is important to identify accident hotspots correctly. However, once identified hotspots can differ over time due to changes in the physical environment or nature. In order to monitor such changes over time one can apply Hotspot Detection Methods (HDM) in a spatio-temporal manner, which provides analyst with comparison of various HDM results in different time intervals. Hotspot analyses [23-24] and spatio-temporal analyses [25] have been used for pedestrian accidents. Determining pedestrian accident hotspots on road segments in space and time provides one with better pedestrian safety assessment as it is used to prioritize problematic parts of a road network.

This paper adapts a spatio-temporal hotspot detection method for the analysis of pedestrian accidents. In this study, 189 traffic accidents involving pedestrians that resulted in injury or fatality on the Eskişehir Motorway

(Turkey) between the years of 2005 and 2010 are mapped with their spatial and temporal information. Network-based Kernel Density Estimation (KDE) is used to examine the hotspots of pedestrian accidents and their changes over the years. Then, the significance of the results is evaluated by using Network-based Nearest Neighbor Distance (NND) and the K-function methods. The impact of land use change and taken measures are evaluated based on spatio-temporal hotspot analysis.

2. METHODOLOGY

In Turkey, the main data source for producing road traffic accident maps is accident location data obtained from Global Positioning System (GPS) devices. Since 2003, a traffic accident database stores all information about traffic accidents with fatalities or injuries by means of the Traffic Information System (TIS) in the districts of traffic police agencies. The data contains information about date, time, kilometer of the road segment where the traffic accident took place, type of the traffic accident, number of vehicles involved in the traffic accident, code of the highway, coordinates of the traffic accident, age, sex and alcohol consumption of the driver, weather conditions, lighting conditions, vehicle type, and number of persons injured/killed.

Annually, data of approximately 100.000 traffic accidents are collected. This data is then analyzed using GIS to produce accident maps. In this study, 189 pedestrian accidents with fatality or injury on the Eskişehir Motorway between the years of 2005 -2010 are mapped and analyzed.

Firstly, data of 189 fatal or injurious pedestrian accidents where queried from the traffic information database. The queried data was then reviewed and verified using the traffic accident reports in order to eliminate erroneous information. It was found that 16 % of the queried data contained some errors. These errors were corrected by using the accident reports, resulting in 100% accurate accident data for the analysis. At the same time the route, the Eskişehir Motorway, were digitized and connection points of the route were numbered in GIS. Secondly, a traffic accident point map was created using traffic accident coordinates data as the second step (Figure 1). Thirdly, dense accident locations (referred to as hotspots) were determined using the network-based KDE- via SANET toolset in ArcGIS 9.3/ArcMap for 2 dimensional (D) view (Figure 3 and 4) and ArcGIS 9.3/ArcScene for 3-D view (Figure 3 and 7). Fourthly, the significance of the hot spots for each year were tested with network-based NND (Nearest Neighbour Distance) (Figure 5) and K-function (Figure 6)- via SANET toolset in ArcGIS 9.3/ArcMap. Finally, the spatial and temporal changes in the pedestrian accident patterns are evaluated and some exemplary pedestrian safety strategies are developed.

3. SPATIO-TEMPORAL HOT SPOT ANALYSIS

Eskişehir is a fast growing middle-sized metropolitan city in Turkey and supplies a suitable backdrop for a

developing country context. It is situated in the north-western part of the Mid-Anatolian region of Turkey. The Eskişehir Motorway runs between the provinces of Ankara, Bursa, and Kütahya with sections passing the city center of these provinces. The route is circa 39 km long and the average rate of pedestrian accidents with fatality or injury is approximately 14% of the total number of accidents with fatality or injury on this route. Locations of pedestrian accidents with fatality or injury on the Eskişehir Motorway between the years of 2005 - 2010 are mapped in Figure 1.

Figure 1: Location of Pedestrian Accidents on Eskişehir Motorway: 2005-2010.

The network based KDE analysis is performed for every year between the years of 2005 -2010. Then the significance of the detected hotspots is tested by using network-based NND and K-function methods.

3.1. Network-Based KDE Method

It is important to assess the robustness of the hotspots using when they are identified temporally. Hence assessing the significance of detected hotspots should be performed. In HDM the distance between accident locations is used. One can measure this distance in two ways. While in Planar HDM the Euclidian distance (birds flight) is used, in the network based HDM the actual distance on the road network is used. Using the

Euclidian distance can be misleading, since two points that are close in terms of birds flight can be far away on the road network.

Okabe et al. [26] reviewed the planar hot spot detection method on network space and improved the network-based HDM by designing the SANET tool to analyze spatial phenomena that occur on networks. Figure 2 illustrates this difference. Using the same bandwidth distance, planar HDM finds four accidents as a cluster while the network-based HDM only finds two. In this study the more robust network-based HDM is selected.
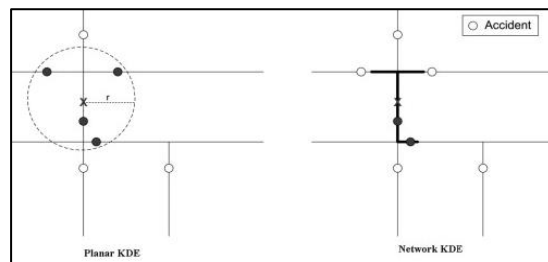

Figure 2: Difference of planar HDM and network-based HDM [13].

In a network-based KDE method, bandwidth and cell size are two important variables. They must be determined according to the size of the case study area and the number of events to detect dense segments properly. After testing several bandwidth and cell size alternatives for KDE maps, it is found that 700 meters of bandwidth and 40 meters of cell size are the most appropriate parameters for KDE. Moreover, KDE maps are illustrated in 3-D surface views by using ArcScene and Google Earth in order to better visualize the hot spots. Figure 3 illustrates both the 2-D and 3-D view of hotspots for the year 2010 as an example.
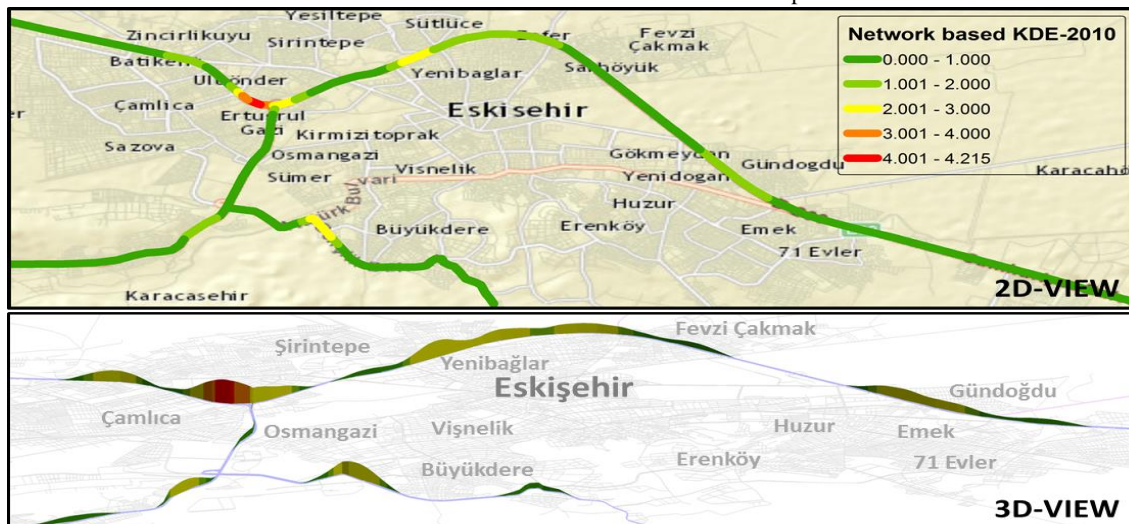

Figure 3: 2-D and 3-D view of hotspots according to network-based KDE in 2010.

The number of accidents on the route that resulted in fatality or injury between the years 2005 and 2010 have been 31, 26, 40, 27, 33, and 32 respectively, adding up to the total of 189 accidents in our study. Figure 4

shows the 2D-view of the hotspots for each year, detected using the network-based KDE analyzing all 189 accidents.
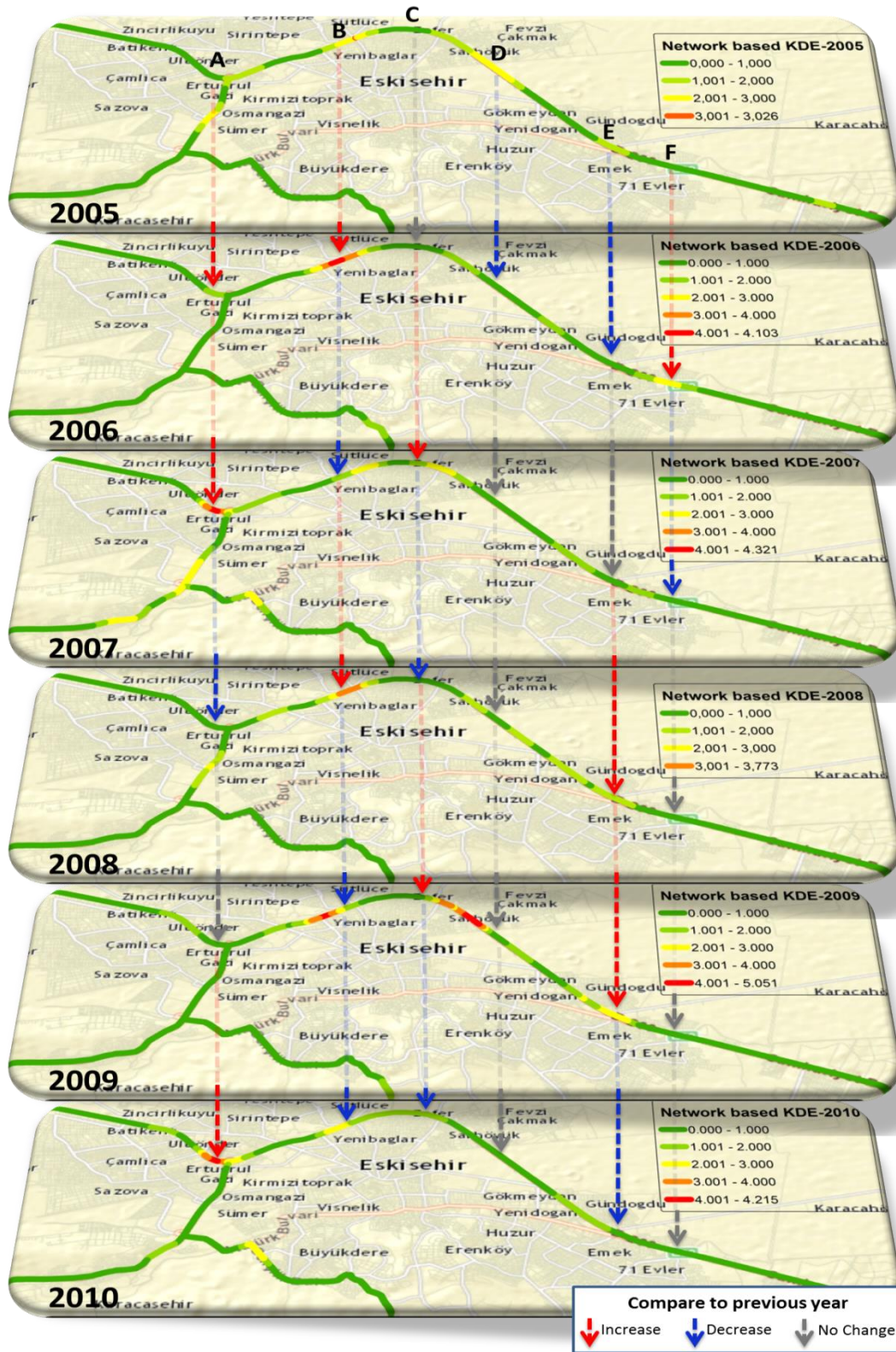
Figure 4: 2 D-view of the hotspots according to network-based KDE in years.

3.2. Significance of the Detected Hotspots

After a hotspot is detected by the network-based KDE, its significance must be evaluated. The Nearest-Neighbor-Distance (NND) and the K-function methods are used for this purpose.

In the NND method, the null hypothesis is based on random distribution and the measured distances of accidents to their nearest neighbors are tested against it. The detected hotspot is considered significant if the null hypothesis is rejected, thus the average nearest neighbor distance is significantly smaller than the expected distance in a random point pattern. The NND method is applied in this study using the Monte Carlo simulation, while 999 iterations and a cluster interval of 50 meters were found to be suitable for the case study.

The K-function considers not only the shortest distance but also the shortest distance for different distance lags, giving a more detailed investigation over the distance distribution [27, 28]. Here, the average number of points in each distance is calculated for each distance lag and is tested against a chosen number of random point patterns.

A confidence interval of 95% is used for both methods in order to determine the statistical significance. Figure 5 shows the result of the NND method, while Figure 6 shows the result of the K-function method. Figures 5 and 6 indicate that similar results are obtained from both methods. Utilizing these two methods at the same time gives the analyst the possibility to double check the significance. A detected hotspot is only considered significant, if both methods reject the null hypothesis of random distribution. If one of the methods gives a negative result, a more investigative approach can be used. Using the traffic conflict technique [29, 30] to inspect such areas on the spot may give better results.
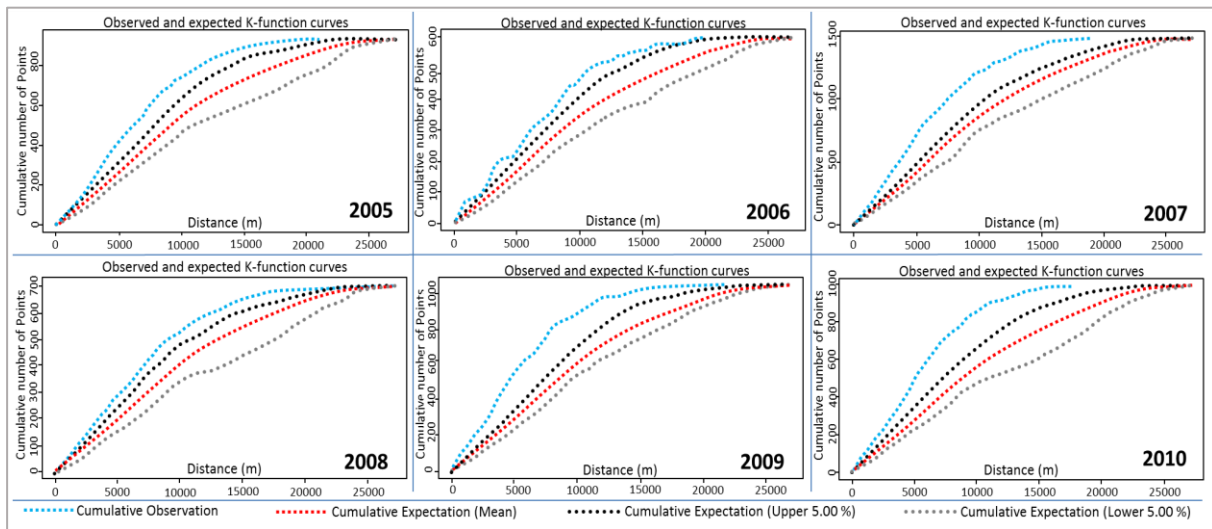

Figure 5: Significance of the detected hotspots according to network-based K-function in years.
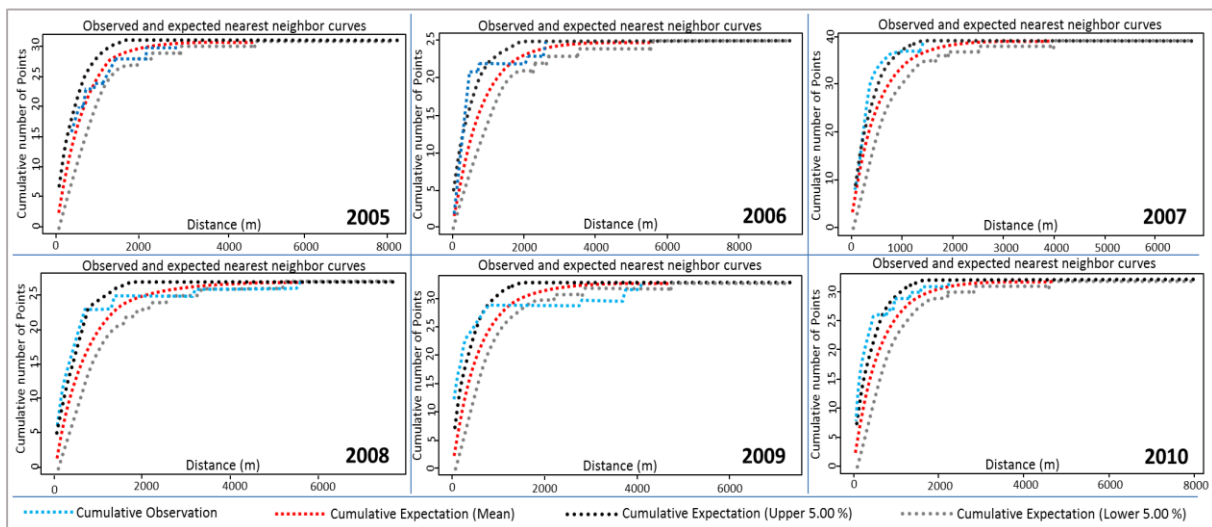

Figure 6: Significance of the detected hotspots according to network-based NND in years.

4. RESULTS

The results derived from the spatio-temporal accident analysis show that the hotspots determined for this case study area vary in time and space. Figure 4-6 show these changes for the five year period. We examined the hotspots and the reasons that may have caused the changes over time. Based on the analyses the following main conclusions are derived.

One of the most crucial changes that we observed is the emergence of a hotspot at location A in the year 2006-2007 (Figure 4). The inspection of this area led to the result, that the newly built mall in this area was the main reason. The roads were not adapted to handle the increased amount of pedestrians attracted to the mall. Hence a statistically significant and persistent hotspot may be expected in the long run, which requires implementation of pedestrian safety measures. Changing of the pedestrian accident numbers is easily recognizable in the 3-d view near the building of the shopping mall (Figure 7).

Figure 7: Effects of building shopping mall on pedestrian accidents.

On the positive side, the building of overpass footbridges at B in 2009, C in 2010 and E in 2010 reduced the value of pedestrian accidents compared to previous years by 50, 27 and 70 percent, respectively and thus eliminated the hotspots (Figure 4). Another positive example is the middle refuges and fences to force pedestrians to cross the roads on specified points. These measures resulted in decreasing the accident numbers at D in 2006 and F in 2007 (Figure 4).

Overall we found that the improvement of pedestrian safety on city passing in Turkey is achieved by physically separating pedestrians from other road participants. In the developed countries, on the other hand, approaches are more pedestrian centred and thus the traffic flow and traffic speed is adapted to protect the pedestrians [31]. A similar finding presented itself for city passing sections, such as the Eskişehir Motorway inspected in this study. While in developed countries the flow and speed of the motorway is adapted for the needs of the urban roads, in Turkey, on the other hand, the goal seems to maximize the flow at high speeds. For this purpose, lanes are widened, the numbers of lanes are maximized and storied intersections are built causing decrease in pedestrian safety.

As the number of pedestrian crossings is unknown for the considered case, assessment of reduction in accident risk cannot be made. Further research will be performed by the authors on this subject, especially on the differences between developed countries and developing countries like Turkey.

5. CONCLUSION

In this study we adopted a spatio-temporal network based HDM to analyse fatal and injury accidents of pedestrians. On the examined Eskişehir Motorway in Turkey, the detected hotspots were found to be significant. As for the results regarding pedestrian safety, the following conclusions are derived:

✓ It is seen that the pedestrian accident density pattern is changed dramatically for various prevention measures and time periods. Hence, any change on a road section vicinity should be evaluated in space and time for effective evaluation of pedestrian safety. Moreover, it is obvious that visualizing spatial analysis in 3D provides better insight into the dynamics of hotspots.

✓ Shopping malls increase the number of pedestrians significantly and therefore increase the accident risk around them, if the surrounding environment is not adapted accordingly.

✓ Measures like middle fences or overpass footbridges that separate pedestrians from the motorized traffic, reduces the number of accidents.

✓ In determining the priority locations for taking pedestrian safety measures like overpass footbridges, paving, reflective materials, horizontal and vertical caution signs, use of pavement, calming the traffic, use of pavement with higher coefficient of friction, building guardrails, highlighting lines, the results of spatio-temporal analyses

with resultant hot spots performed for various parameters can provide guidelines for initial assessments.

We were able to observe the positive and negative effects of changes in the vicinity of the hotspots. Hence, we conclude that such spatio-temporal analysis is important to examine and evaluate safety measures as well as the risk assessment of new construction plans. We highly encourage other traffic safety researchers to consider the temporal aspect in their studies.

Lastly, this study gives useful information on land use and transportation planning policies. The analysis was implemented by using the 2005-2010 data on the Eskişehir Motorway (Turkey). Today in Turkey, pedestrian accidents are still an important urban issue [6], and also interventions of urban built environment are proceeding [32]. Therefore, our findings are quite important for planning studies. Also, these findings will be assessable to various neighbourhoods or cities in Turkey, especially motorways passing the city. Taking all of these into account, it is expected that future research on this topic would support the findings.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

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