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IDENTIFYING CRITICAL ROAD SEGMENTS AFFECTING TRAFFIC ACCIDENTS WITH GEOSPATIAL ANALYSIS IN KOCAELI CITY

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ABSTRACT

Since urban road accidents in Kocaeli is a severe problem and it is anticipated that accidents can be interrelated to road infrastructure characteristics. This study aimed to explore risky road segments related to urban road accidents using GIS analysis and conduct field surveys on these areas to define their possibly poor geometric design parameters. The study revealed some possible accident prone locations using spatial density maps for the period of 2015 in Kocaeli city. A risky road segment (i.e. DSİ Junction) was found to have serious deficiencies in terms of driving safety due to the sharp reverse curb.

Keywords: GIS, Accident, Road, Infrastructure, Spatial Analysis.

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INTRODUCTION

Road accidents are esteemed as a consequence of the contemporary transportation systems. The effect of traffic accidents in terms of damages and loss of lives is a social and community health challenge. Urban road safety has always been of major concern to Turkey. Identifying the vulnerable locations of roads or hotspots is important for proper allocation and planning of resources for safety improvements. Naturally, dangerous road segments can be defined as places with higher accident risk than other similar locations (Elvik, 2007; Cantillo et al. 2016). The identification of these locations is an crucial component of the highway safety management. The problem of urban road accidents in Kocaeli, one of the most industrialized city of Turkey, is remarkable and has a significant magnitude. During 2015 there were a total of 2785 road traffic accidents in Kocaeli. Therefore, it is very important to examine this issue technically, which examines the relationship between urban traffic accidents and the variables pertain to road infrastructure. When approaching traffic accidents using quantitative statistical techniques, commonly used indicators can hide the determinant variables of the problem. Numerous studies have been conducted to explore the occurrence of traffic accidents from different perspectives. The analyzes dealt with the psychological, behavioral and socio-economic components of traffic users, as well as legal perspectives and technical characteristics of road infrastructure (Flahaut, 2004). Geo-spatial data analysis can be viewed as it is one of the most important tool for traffic accident analysis. GIS-aided spatial data assures experts with a wide variety of information about risky locations, hotspots and critical patterns (Liang, 2005; Erdogan et al.,, 2008; Mohammed et al., 2023; Le et al., 2020; Jima and Sipos, 2022; Ma et al., 2021). By specifying road accident hotspots with GIS approach a more robust comprehension can be acquired with regard to indicators of casual effects.

Road design parameters and geometric standards have a significant effect on the road safety and poor condition of geometric parameters significantly increases the crash rate. Curve radii, superelevation, gradient, lanes and median, access points, shoulder width and curve widening are some of the major design elements. Most of the design parameters are determined by design speed of the highway (Hong and Oguchie, 2005). In particular, curve geometric features are functions of the speed. Horizontal and vertical curbs have to be designed according to speed and in accordance with current standards. Inadequate curbs are the potential black spots on the road. While vertical curves have to consider sight distance, it is vital to reduce the centrifugal force effect on horizontal curves. Thus, in this study, the horizontal curve geometry at the black point where the accident rate is high was examined.

Several methods have been proposed over the years to identify hazardous road segments. This article aims to identify these critical sections using GIS methods and then explore the relationship between road accidents and transport infrastructure design variables in Kocaeli city after identifying these segments. Since urban road accidents are considered to be a serious problem in Kocaeli and that accidents may be related to possibly poor road infrastructure characteristics, some accident-prone sections in this province are identified especially with spatial analysis tools.

The study aimed to reveal potential accident-prone locations in Kocaeli province for 2015. After these sections were determined by GIS-based spatial analysis methods (density analysis, etc.), the road geometry was measured on the ground in order to determine in detail the properties of possible poor geometric sections of the roads. The analyzes we have done so far aim to reveal the geometric properties of high-rate accident locations in the city and then the areas that are insufficient in terms of safety on highways.

1. MATERIAL AND METHODS

Traffic safety at a roadway is mainly affected by human factors, environmental factors and vehicle characteristics. However, there are other factors such as highway design and design associated geometry (Mungnimit, 2001; Bener, 2005). Therefore, the development of safety problems on roads can be achieved by further improvement in the various geometric design parameters. In developing countries, accident information is mainly recorded for drivers who caused the accident, regardless of the true cause of the accident. Hence, neither the roadway geometry nor the environment is considered as a cause for accidents, simply because there is an ambiguity of the accident's cause for the authorities. As widely known highway geometry should be designed for vehicle traffic safety and efficiency. For example, the minimum radius of horizontal curve is defined with design speed, superelevation and side slip friction factor. The authors suggest that all of the design standard values should have a unique safety factor to keep consistent traffic safety. Studies showed that horizontal curves typically have more crash rates than tangent sections (AASHTO, 2004; Obaidat and Ramadan, 2012). In fact, the use of composite curves (e.g. spiral curves, simple circular curves) could help to mitigate some of the safety problems associated with horizontal curves by providing a smoother and safer path for drivers from tangent to curve position. It is usually beneficial to design horizontal alignments with combinations of maximum curve radii and minimum deflection angles since crash rates tend to increase with the reduced sight distance associated with either a reduced curve radius or an increased deflection angle or curvature. As it is known, roads with insufficient visibility, weak geometry, without turning lanes, and intersections and interchanges that are poorly arranged lead to greater risks for traffic users (TRIP, 2009). Therefore, this paper will focus on identifying hazardous locations in Kocaeli district from the infrastructure perspective (Figure 1) and the correlation of accident characteristics with geometrical elements of the roads. The spatial characteristics of road crashes in the city will be analyzed by spatial analysis tools.

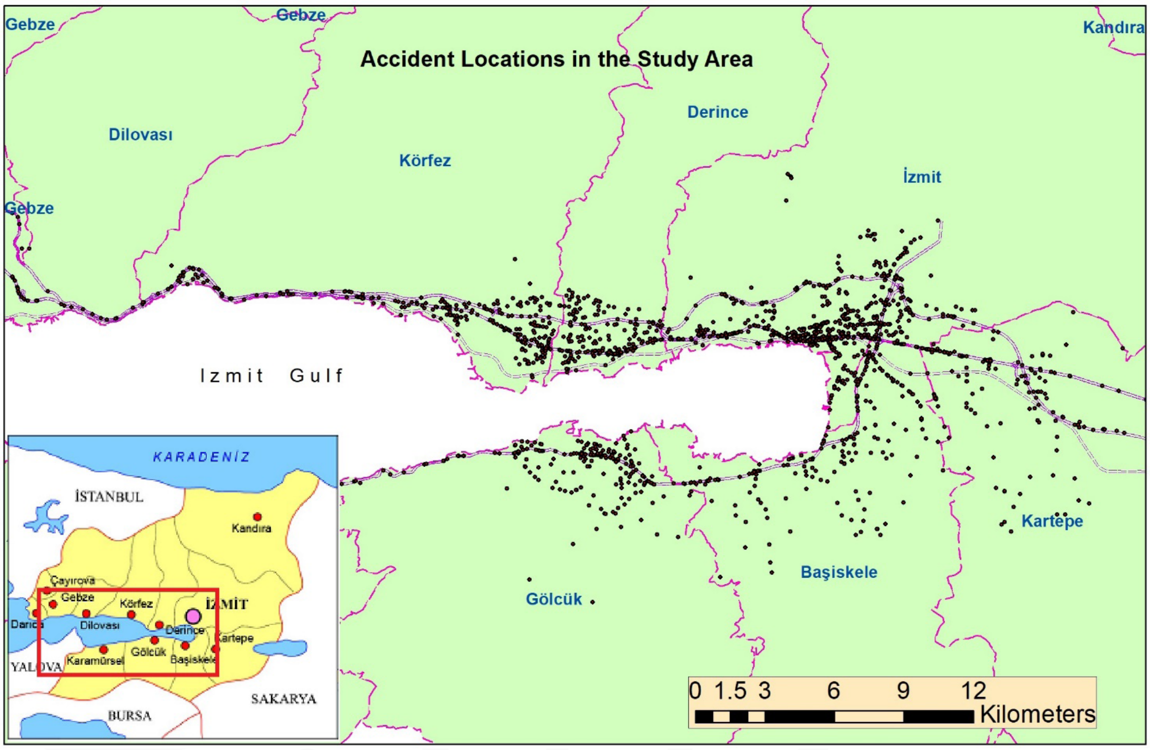

Figure 1. Study area, major highway and accident locations for the year of 2015.

1.1. Accident Density Pattern Analysis

Spatial analysis techniques have recently been used as an innovative approach to identify high risky areas (Flahaut et al., 2003; Xie and Yan, 2008; Malin et al., 2019; Anderson, 2009; Chung et al., 2009; Loo et al., 2011; Yu et al., 2014). In this approach hazardous road locations can be thought of as places where accidents are spatially concentrated. Accidents occurring in neighboring spatial units are assumed to be spatially dependent; and local risk factors constantly change between neighboring spatial units. Dangerous road segments are usually defined as a series of adjacent spatial units characterized by an index reflecting the spatial intensity of accidents. There are many geospatial analysis methods for determining accident-prone risk locations, among which the most widely used are the local spatial autocorrelation method and the density estimation method. By definition, with the spatial autocorrelation approach, each spatial unit is evaluated as the level of spatial dependence between accidents observed in neighboring spatial units. As noted in the related literature autocorrelation methods, such as Ripley's K-function, Getis's G-statistics and Moran's I, determine whether a given point distribution across the study area differs from a pre-defined random distribution (Boots and Getis, 1988; Ripley, 1981; Getis and Ord, 1992). One of the most widely used studies in the literature to detect traffic accident hot spots is the core density (KDE) estimation approach. Density estimation is a method used to estimate the density function from observed data. Considering spatial point data, it is similar to bivariate probability density estimation (Silverman, 1986; Bailey and Gatrell, 1995).

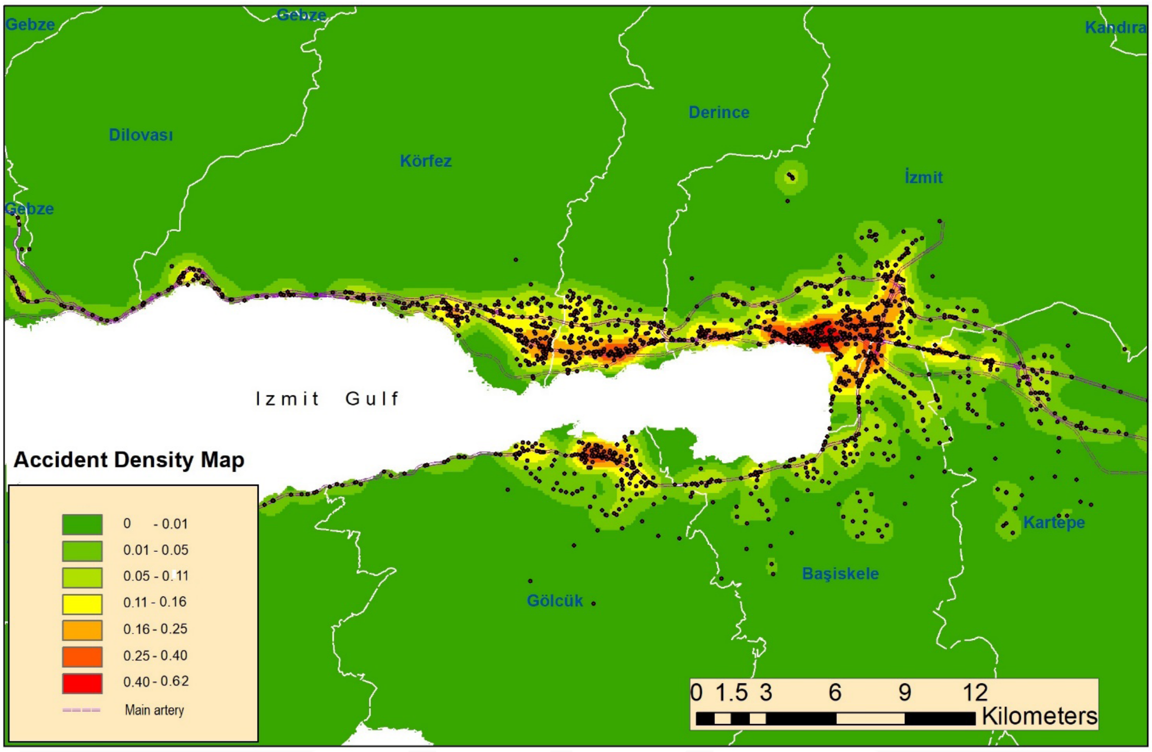

Figure 2. Simple density map for the accidents for the year 2015.

As mentioned earlier, there are two ways to measure density, the simple method and the kernel method. In the simple method, the entire field is divided into a predefined number of cells and a circular neighborhood is created around each cell to calculate individual cell density values. Radius of the bandwith directly influences the resulting density map. Figure 2 shows the result map of simple density map produced for the accidents occurred in 2015. Usually, kernel density methods calculate the density of dot features around each output raster cell by dividing the entire area into grid cells. The raster cells with high values are directly related to the accident concentration areas. Unlike the simple density method, the kernel method defines a circular neighborhood around each feature point (e.g. accident) instead of considering of a circular neighborhood around each cell and then applies a mathematical function.

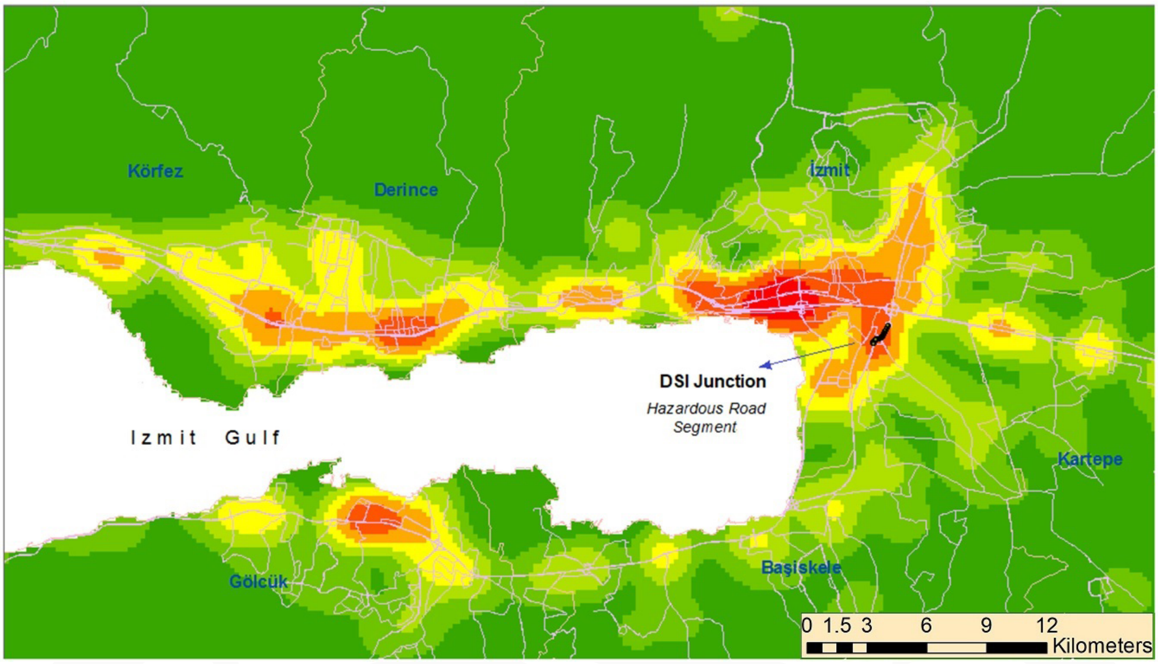

Figure 3. Kernel density map for the accidents for the year 2015 and hazardous road segment (DSI Junction) detected.

Figure 3 shows the kernel density map produced for the accident records for the year of 2015. The kernel density estimation involves evaluating the distance defined for each point based on a mathematical function and then summing the values of all surfaces for that reference location. This procedure is recurred for consecutive points as in the following (Fotheringham et al., 2000).

$$f(x,y) = \frac{1}{nh^2}\sum_{i=1}^{n} K\left(\frac{d_i}{h}\right) \quad (1)$$

where f (x, y) indicates the density estimate at position (x, y); n is the number of observations, h is the bandwidth (i.e. kernel size), K is the kernel function, and di is the distance between the location (x, y) and the location of the i th observation (TRIP, 2009). As clearly be seen from the figures that traffic accidents are concentrated along the major highway in the city. The resulting surface is a combination of high density raster cells. In this surface, grid cells are distributed along the highway in the study area and most of the pixels are grouped together to show different sizes in high density hot spots (Silverman, 1986; Fotheringham et al., 2000). The choice of bandwidth will naturally have an impact on the outcome of the hotspots. For this study the bandwidth was determined as 500 m. Kernel density estimation came out as in fact a successful spatial clustering method.

One of the main concerns is with whether or not the traffic accidents tend to gather around some road sections in the region. Accident data can simply be considered as geospatial points. An accident cluster appears as spatial patterns with high intensity accidents in that area. Therefore, the geospatial clustering method can help identify heavy accident areas. As is widely known, spatial clustering is the process of grouping similar objects according to their spatial relationships (distance, contiguity, or relative density) in space (Han et al., 2001). One of our concern is with whether or not the traffic accidents tend to cluster. To answer this question, we used the Ripley K function, which defines the distribution patterns of points in space at different scales to examine the spatial structure of accidents at various spatial scales (Mountrakis and Gunson, 2009; Ripley, 1976). The K function enables a comparison of the expected density assuming complete spatial randomness with the expected number of points in a local neighborhood of the radius distance at any point in the data set. Here points close to the domain boundary need to be handled correctly to get an accurate estimate of the K function through the "edge smoothing" process (Okabe and Yamada, 2010). Numerous variations of Ripley's original K function have been proposed in the literature. Here, a common transformed version of the K-function, often referred to as L(d), is performed as

$$L(d) = \left(A\sum_{i=1}^{N}\sum_{j=1}^{N} k(i,j) / \pi N(N-1)\right)^{1/2} \tag{2}$$

where A is the whole study area, N is the number of points, d is the distance, and k(i,j) is the weight. The result of the function is shown in Figure 4. The red line shows the observed K-function, while the blue line indicates the expected K function obtained, provided the points are randomly distributed over the region according to the uniform distribution. When the observed K function is compared with the expected K function, it is revealed that traffic accidents tend to cluster in Kocaeli. The analysis of K function graph shows that there are regular clusters on 5000 meters for traffic incidents. It is also possible to estimate the average distance among clustering patterns for the accidents in the region.

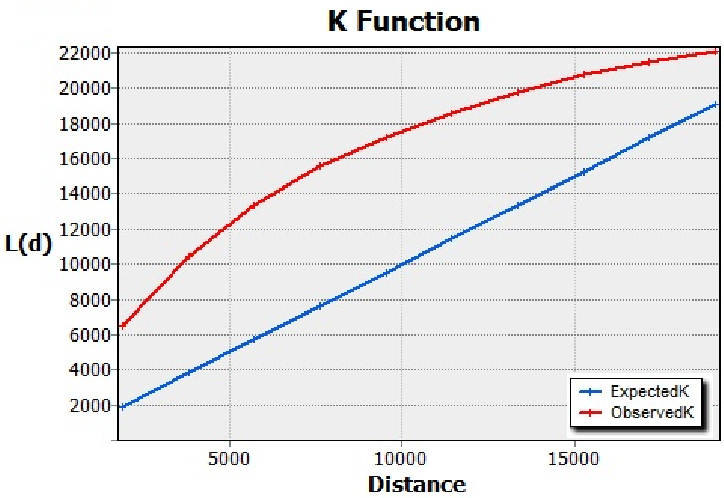

Figure 4. K- function calculated for the accidents (2015).

2. RESULTS AND DISCUSSIONS

This work gives an insight into the detection of the most accident prone road sections in the district using spatial density methods. Naturally if an area in the density map is plotted as high risk, it can be concluded that that area is more vulnerable to accidents. Then the road sections located in these risky areas are examined from the geometrical perspective since the accidents can be related to road infrastructure characteristics in the region. Some accident-prone road sections in Kocaeli province were specifically examined to determine the relationship between road accidents and the geometric and physical road infrastructure variables. If the accident-prone road sections which have "poor" road geometry are identified the severity of serious traffic crashes at hazardous locations could be diminished through road geometry improvements. This research revealed some potential accident-prone locations for the period of 2015 and a definite road section was identified and shown as a black line in Figure 3. In the study, this segment is examined from a geometric perspective to determine design parameters. In order to specify the most important parameters affecting road accidents, the road geometry of the section was measured on the road surface using GPS technique (Çepni and Arslan, 2017).

2.1. Critical Segment Observed: DSI Junction

The hazardous road section identified in the region is called "DSI Junction" and it is the road segment mentioned in the previous section.DSI junction is a junction on the E881 highway that overpasses from D130 highway. According to official records, the most mortal and injured accidents in Kocaeli City has been occurred at this road segment for many years (Figure 5). Accident records at the DSİ Junction region are denoted as yellow points in Figure 6. This section is 591 meters long. It is believed that poor horizontal road geometry tends to increase accidents in the district.

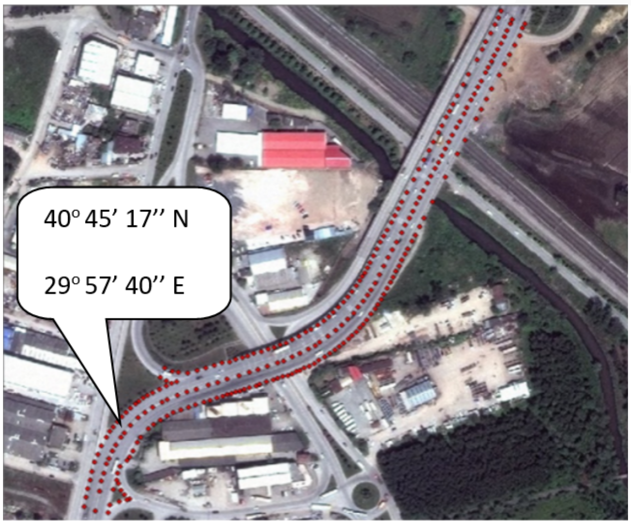

Figure 5. Road section in DSİ Junction.

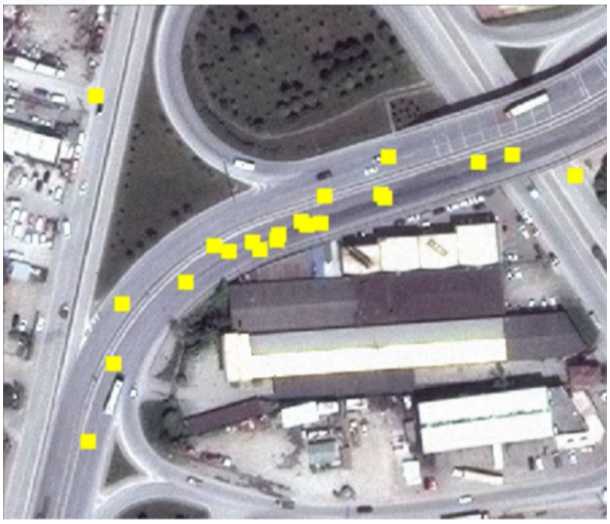

Figure 6. Accidents at the road section in DSİ Junction.

DSİ Junction is a reverse curb located at the crossover of north-south main artery and east-west D-100 highway artery and it also comprise of the intersections as trefoil junction (Figure 5). In order to analyze the frequent accidents on the region, GPS-RTK technique (with an accuracy of ± 4 cm) positioning surveys were conducted along the road alignment and curbs (Figure 7a). A total of 265 ground points were measured on the road surface. It was aimed to study both horizontal and vertical geometry of the region in the case study. Thus, horizontal plan, profile and cross-sections of the road section were also drawn by a CAD software.

Due to the fact that the junction is a reverse curb, horizontal curb geometry and cross slope (i.e. superelevation) have to be examined for the analysis of the road geometry. A moderate vertical slope along the crossover section of the junction is observed and first horizontal curb is combined with a vertical curb. Hence the curb has become more critical for the road geometry. The radius of curb has been estimated by the arc length and deflection angle of the curve as in the following equation.

$$R = \frac{d}{\Delta_{radian}} \tag{3}$$

where d is the arc of length that has been measured from survey points (Figure 7a). Δ is called as deflection angle and it represents the angle between two lines connected by the curb. Deflection angle is calculated from the measured line segments. From examining on the road plan with the aid of surveys, radii of reverse curbs were estimated as between 100 and 150 meters (Eq.3) respectively (Figure 7b). However, the speed limit on the E881 highway is 110 km/h and the design radius regarding to the speed should not to be less than 350-400 meters (Eq.4). The operating speed in the alignment just before the junction is at the limit values, so it is clear that the radius of the curbs is quite low considering the type of the road and these radius values are not appropriate for such a main artery. Although the curb radius is determined according to the design speed, in cases where the radius does not support the speed limit, the local speed at the curb is determined with respect to the current radius. Therefore, the operating speed must be reduced dramatically before the curb by slowing the traffic flow in the field.

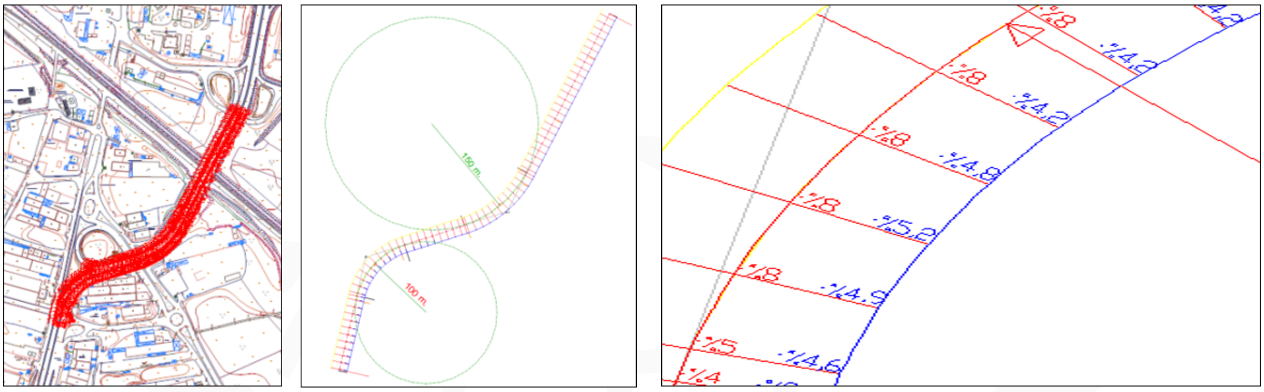

Figure 7. Road section in DSI Junction. (a) Surveying points. (b) Curb radius estimation. (c) Examination of superelevation on the road.

In addition to the considerably smaller radius curb, it is realized that superelevation on the curb was designed incorrectly in the construction stage. By surveying of the cross-section points on the road segment, horizontal slopes were calculated throughout the curbs. Highway curves are often super elevated to cope with some part of the centrifugal force acting on a vehicle. According to national standards, superelevation of the curb is calculated as;

$$e = \frac{V^2}{127\,R} - f \tag{4}$$

where V is project speed; R is radius of the curb and f is coefficient of friction that ranged from 0.12-0.16 according to speed. For instance, if the projected speed on the road is 80 km/h, superelevations to be implemented to curbs will be more than 20 percent for 100 m and 150 m radii (when f=0.14 for V=80 km/h). As it is known in order to sustain route persistence and driver expectancy on open highways, proper superelevation for a curve should be selected, i.e. 8% superelevation rate may be preferred for highways in urban design areas. This means that the maximum cross slope allowed by highway national standards is 8-10 percent according to the national standard (Republic of Turkey, General Directorate of Highways, KGM). On the other hand, according to the field measurements made on the road surface, the full superelevation on the road was obtained only around 4-5 percent value (Figure 7c). In Figure 7c the numbers shown in red on the sections on the left show the values where the superelevation should be (Eq.4), while the blue ones on the right show the current values measured. It means that the safety speed on the curve is less than 40 km/h (from the Eq.4).As a result of insufficient acceleration, centrifugal force will affect the vehicles on the curb more negatively and as a result, the risk of slippage will increase. The slippage threshold, given by the following mathematical equation.

$$V_{slip} = 11.3\sqrt{\frac{R(e+f)}{1-e\,f}} \tag{5}$$

Considering the Eq.5, the slippage speed value in DSI Junction is around 50 km / h. However, the DSI Junction is a part of the intercity traffic and the average speed on the road is remarkably higher than the safety speed that should be on reverse curbs.

Another parameter to be considered in terms of geometric design is the tangential runout length (Lr). This distance means minimum length superelevation runoff (Figure 8a). These lengths are needed to accomplish change cross slope between zero and full value. As DSI Junction is a reverse curb superelevation transitions becomes more important to apply a suitable cross slope on both curves.

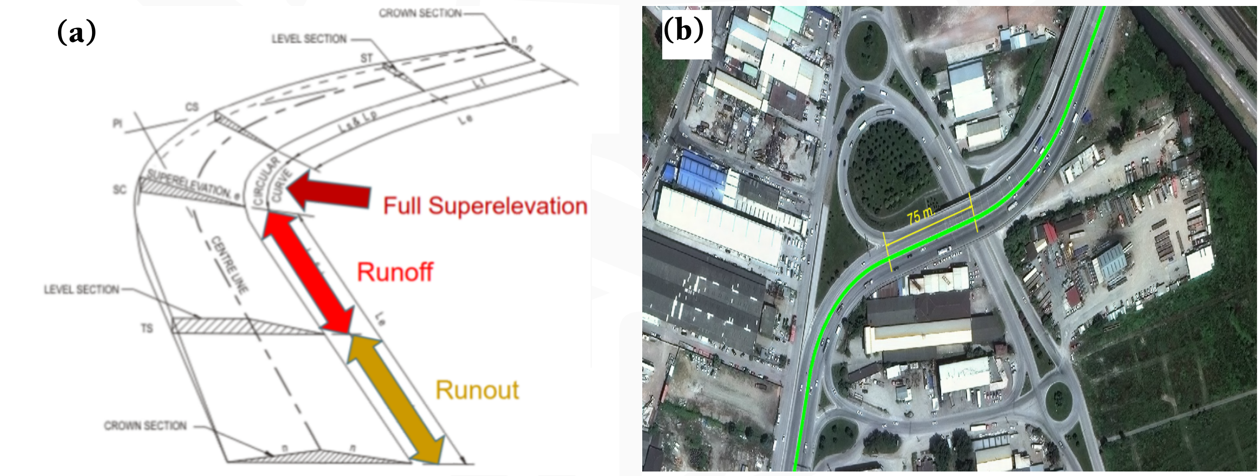

Figure 8. (a) Superelevation Transitions (URL-1). (b) Transitions at DSI Junction.

This distance is calculated from the equation below,

$$L_r = 0.0354\frac{V^3}{R} \quad (6)$$

and minimum distance of transition is given 45 m by national standards (KGM). If the operating speed is chosen more than 70 km/h the distance needed will be more than 120 meters whereas measurements show us that Lr distance is not provided even for lower speeds at the DSI Junction (Figure 8b).

It's plausible to say that the inadequacy of superelevation and its transition, notably very small curve radii make this section of the highway uncomfortable and unsafe. Vehicles that cannot not reduce their speed adequately owing to the poor design of the curb have seriously been faced the threat of not being able to take a sharp bend. It should also be noted that this section does not include shoulder lanes. In the view of the surveys and the analysis above, it has been revealed that the deficiencies of the geometric design caused to high risk and accidents at the DSI Junction.

Besides geometric deficiencies, the DSI Junction has also an access point (Figure 9). Many of studies showed that access point have an impact on crash rates (Mouskos et al., 1999; Papayannoulis et al., 1999). Reference studies have pointed out that accident rates have a linear increases with the access point density. Hence, access point has an extra risk for the junction.

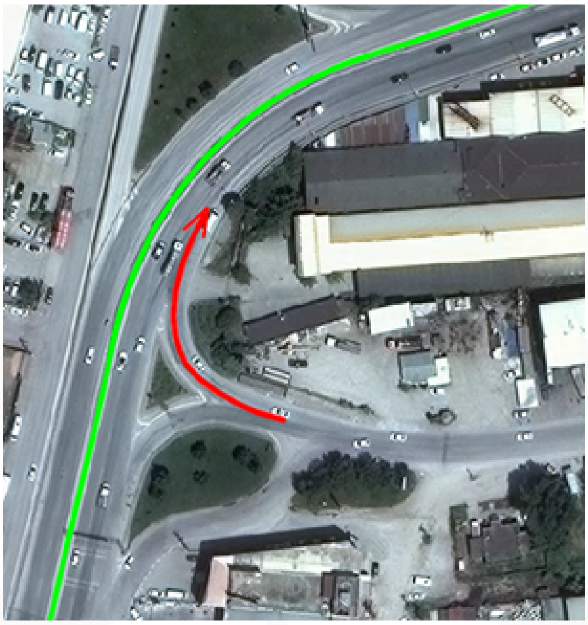

Figure 9. Access point at DSI Junction (red line).

The existing geometric features of the road section measured were compared with national highway standards (i.e. KGM) and results are presented in Table 2 below.

Table 2. Comparison of roadway elements with the national safety standards of Turkey (KGM).

Roadway Element	KGM Standards	Currently observed values
Design Speed	110 km/h depends on intracity speed limits	Operating
Radius of Curve	300 m. - 350 m. with respect to average speed on highway	100 m. and 150 m. reverse curves
Superelevation	%8 full superelevation	≈ %5
Superelevation Transitions Runoff + Runout	150 m. - 450 m. with respect to 70km/h - 110 km/h	≈ 60 m.
Number of Lanes	2+2 dual carriageway	2+2
Shoulder Width	2,00 m – 2,50 m.	none
Access Point	none	exist

Table 3 shows the safety audit checklist with entirely the field observations recorded during the site survey of the asphalt surface from the road section as previously mentioned.

Table 3. Examination of design flaws.

Problems	Comments
Unexpected and emergent hairpin curve	Driver's adaptation problem
Too small radius	Caused to loss of driving control and slippage
Inadequate cross slope (superelevation)	Slippage and overturn risk
Short transition distance	Incoherent superelevation on reverse curves
Lack of shoulder	Driving discomfort
Existing of access point on the curve	Increase crash risk

To sum up then it is clear that the current road plan has serious deficiency in terms of driving safety because of the sharp reverse curb. It is clear that in terms of roadway design elements DSİJunction is found to be a high risk point of the hazardous road section at Kocaeli city. An investigation was made to clarify the causes of the poor geometry of this road segment and it is apparent that the curbs were not designed to obtain optimal route geometry. Since the artery has a long alignment and a dense traffic flow, such a small radius curb has an adverse effect on the traffic safety by shortening crossing distances and reducing vehicle turning speed. This geometric weakness can be considered as the main cause of the accidents in the road segment. It has been speculated that at the stage of the road construction the curbs were planned so as to preserve the position of some current buildings or parcels upon the owner requisition in the environment. Figure 10 clarifies this inappropriate and undesirable selection of route location for the road section. In this figure standard (i.e. geometrically correct) curb required for the region is denoted as blue colored line while orange line indicates to the present route. The radius of standard curb was estimated as 250 meters in length in the region comparatively higher than the existing curbs radii (i.e. 100, 150 meters). To solve the geometrical problem of the road section some suggestions could be made to reduce the accidents. The main recommendation could be the replacement of the current route despite the high cost. The accidents leading to serious damages and loss of lives will happen again unless such a radical solution is found. Secondary suggestions might be based on the restoration of geometric features of the road segment (superelevation etc.) depending on the findings from the study. Other suggestions might be the limitation of the speed via strong cautionary.

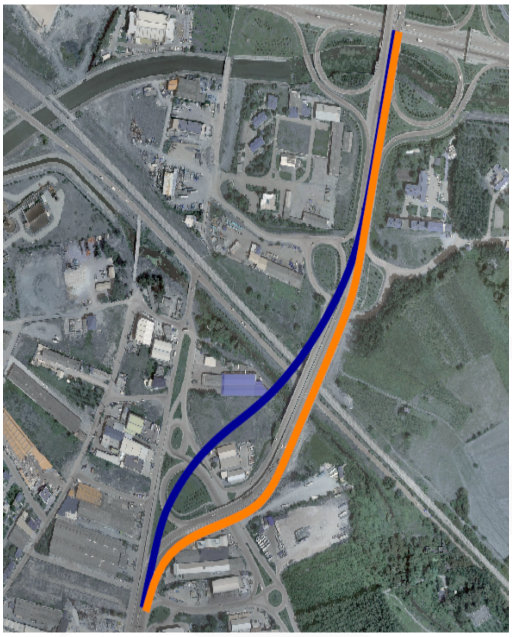

Figure 10. Current road plan (orange) and proposed new route (blue).

As stated in the previous sections, the study revealed evidently that the geometric design of the road segment called DSI Junction is quite poor. In fact, deficiencies in the geometry of this segment are clearly felt by the drivers while using the road in this segment, and the high rate of accidents that occur proves this problem. Moreover people crossing this segment on the daily traffic route still continue to witness accidents simultaneously. Accidents are frequent on this road section and there are some serious concerns that similar accidents may continue to occur in the future. It does not seem possible that these prominent design deficiencies will not be noticed during the construction and realization phase of the project. The main problem here is why road construction was completed in this way despite design flaws that can easily be noticeable in the road segment. It should be viewed as an ethical responsibility of engineers not to harm the public interest when creating such a project. Professional engineers naturally are bounded with ethical rules that govern their professions. These ethical rules include issues of both professional competence and morality and usually are included in regulatory codes adopted by the related state agency. Violations of these ethical codes have serious professional and criminal consequences as well. The current poor road geometry is believed to be a result of land use policies, not as a result of project design decisions or road implementation processes carried out by engineers. In order to protect the financial interests of the owners of some private buildings and parcels close to the specified road segment, it is considered that inappropriate and unethical decisions are taken by local authorities during the project implementation phase. Thus, the road plan has become restricted with inappropriate geometry. The main purpose of engineering planning is to realize scientific principles for the purpose of creating public interest. This study has proved that if engineering facts and scientific norms are replaced by relationships based on personal benefits or political expectations, the result will clearly be disappointing for the community.

CONCLUSIONS

A GIS-based approach has been used to solve traffic safety problems on urban roads from a geometric perspective in Kocaeli. The study intended highlighting the influential geometrical factors to accident occurrence at hazardous locations of local urban roads in the region. This study aimed to explore risky road segments related to urban road accidents using GIS analysis and make field surveys on these areas to define their possibly poor geometric design parameters. The study revealed some possible accident prone locations using spatial density maps for the period of 2015 in Kocaeli city.

Some spatial tools have been proposed and applied to detect road accident intensity and possible hotspots, from a geospatial perspective, typically including spatial autocorrelation methods and kernel density methods. We applied the K-function method to these assigned points in the region. When the road sections (or spot locations) containing the studied hazardous locations are determined, these areas are investigated from the perspective of geometrical design standards. To this end GPS measurements were made on the road surface of the accident-prone areas to reveal the road geometry. It was found that the risky road segment (i.e. DSİ Junction) has serious deficiency in terms of driving safety because of the sharp reverse curb. Thus, this junction area is found to be a high risk point of the hazardous road section at Kocaeli city. A field investigation was made to clarify the characteristics of the poor geometry of this road segment and it is apparent that the curbs were not designed to obtain optimal route geometry.

It is worth mentioning here that further improvements for geometric design of the detected road sections can reduce fatal accident rates in the region. It has been clearly demonstrated in the study that the determination of problematic locations in terms of traffic safety with GIS and the geometric features of these places by field surveys on the ground will help to reduce the traffic accidents in the relevant region.

REFERENCES

Anderson, T. K. (2009, May). Kernel density estimation and K-means clustering to profile road accident hotspots. Accident Analysis & Prevention, 41(3), 359–364. https://doi.org/10.1016/j.aap.2008.12.014

Bailey, T.C., & Gatrell, A.C. (1995). Interactive Spatial Data Analysis. John Wiley and Sons, New York, NY.

Bener, A. (2005, March). The neglected epidemic: Road traffic accidents in a developing country, State of Qatar. International Journal of Injury Control and Safety Promotion, 12(1), 45–47. https://doi.org/10.1080/17457300512331342225

Boots, B. N., & Getis, A. (1988). Point Pattern Analysis. SAGE Publications, Newbury Park, CA.

Cantillo, V., Garcés, P., & Márquez, L. (2016, February). Factors influencing the occurrence of traffic accidents in urban roads: A combined GIS-Empirical Bayesian approach. DYNA, 83(195), 21–28. https://doi.org/10.15446/dyna.v83n195.47229

Chung, K., Ragland, D.R., Madanat, S., & Oh, S. (2009). The Continuous Risk Profile Approach for the Identification of High Collision Concentration Locations on Congested Highways, Proceeding of 19th ISTTT, pp 463-480.

Çepni, M. S., & Arslan, O. (2017, March). A GIS Approach to Evaluate Infrastructure Variables Influencing the Occurrence of Traffic Accidents in Urban Roads. International Journal of Environment and Geoinformatics, 4(1), 17–24. https://doi.org/10.30897/ijegeo.306488

Elvik, R. (2007, January). Operational Criteria of Causality for Observational Road Safety Evaluation Studies. Transportation Research Record: Journal of the Transportation Research Board, 2019(1), 74–81. https://doi.org/10.3141/2019-10

Erdogan, S., Yilmaz, I., Baybura, T., & Gullu, M. (2008, January). Geographical information systems aided traffic accident analysis system case study: city of Afyonkarahisar. Accident Analysis & Prevention, 40(1), 174–181. https://doi.org/10.1016/j.aap.2007.05.004

Flahaut, B. (2004, November). Impact of infrastructure and local environment on road unsafety. Accident Analysis & Prevention, 36(6), 1055–1066. https://doi.org/10.1016/j.aap.2003.12.003

Flahaut, B., Mouchart, M., Martin, E. S., & Thomas, I. (2003, November). The local spatial autocorrelation and the kernel method for identifying black zones. Accident Analysis & Prevention, 35(6), 991–1004. https://doi.org/10.1016/s0001-4575(02)00107-0

Fotheringham, A. S., Brunsdon, C., & Charlton, M. (2000, January). Quantitative Geography. SAGE, Thousand Oaks, CA.

Getis, A., & Ord, J. K. (1992, July). The Analysis of Spatial Association by Use of Distance Statistics. Geographical Analysis, 24(3), 189–206. https://doi.org/10.1111/j.1538-4632.1992.tb00261.x

Han, J., Kamber, M., & Tung, A.K.H. (2001). Spatial clustering methods in data mining: A survey. Geographic Data Mining and Knowledge Discovery, Miller H. and Han J. (eds), Taylor and Francis.

Hong, S. J., & Oguchi, T. (2005). Evaluation of highway geometric design and analysis of actual operating speed. Journal of the Eastern Asia Society for Transportation Studies, 6, 1048-1061.

Jima, D., & Sipos, T. (2022, July). The Impact of Road Geometric Formation on Traffic Crash and Its Severity Level. Sustainability, 14(14), 8475. https://doi.org/10.3390/su14148475

Le, K. G., Liu, P., & Lin, L. T. (2019, December). Determining the road traffic accident hotspots using GIS-based temporal-spatial statistical analytic techniques in Hanoi, Vietnam. Geo-Spatial Information Science, 23(2), 153–164. https://doi.org/10.1080/10095020.2019.1683437

Liang, L. Y., Ma'soem, D. M., & Hua, L. T. (2005). Traffic accident application using geographic information system. Journal of the Eastern Asia Society for Transportation Studies, 6, 3574-3589.

Loo, B. P., Yao, S., & Wu, J. (2011, June). Spatial point analysis of road crashes in Shanghai: A GIS-based network kernel density method. In 2011 19th international conference on geoinformatics (pp. 1-6). IEEE.

Ma, Q., Huang, G., & Tang, X. (2021, September). GIS-based analysis of spatial–temporal correlations of urban traffic accidents. European Transport Research Review, 13(1).

Malin, F., Norros, I., & Innamaa, S. (2019, January). Accident risk of road and weather conditions on different road types. Accident Analysis & Prevention, 122, 181–188. https://doi.org/10.1016/j.aap.2018.10.014

Mohammed, S., Alkhereibi, A. H., Abulibdeh, A., Jawarneh, R. N., & Balakrishnan, P. (2023, July). GIS-based spatiotemporal analysis for road traffic crashes; in support of sustainable transportation Planning. Transportation Research Interdisciplinary Perspectives, 20, 100836. https://doi.org/10.1016/j.trip.2023.100836

Mountrakis, G., & Gunson, K. (2009, November). Multi-scale spatiotemporal analyses of moose–vehicle collisions: a case study in northern Vermont. International Journal of Geographical Information Science, 23(11), 1389–1412. https://doi.org/10.1080/13658810802406132

Mouskos, K. C., Sun, W., Chien, S. I., Eisdorfer, A., & Qu, T. (1999, January). Effect of Midblock Access Points on Traffic Accidents on State Highways in New Jersey. Transportation Research Record: Journal of the Transportation Research Board, 1665(1), 75–83. https://doi.org/10.3141/1665-11

Mungnimit, S. (2001). Road Traffic Accident Losses. Transport and Communications Policy and Planning Bureau, Ministry of Transport and Communications, Thailand.

Obaidat, M. T., & Ramadan, T. M. (2012). Traffic accidents at hazardous locations of urban roads. Jordan Journal of Civil Engineering, 6(4), 436-447.

Okabe, A., & Yamada, I. (2010, September). The K-Function Method on a Network and Its Computational Implementation. Geographical Analysis, 33(3), 271–290.

Papayannoulis, V., Gluck, J.S., & Feeney, K. (1999, June). Access spacing and traffic safety. Transportation Research Circular E-C019: Urban Street Symposium. Transportation Research Board, Washington D.C. [Original source: https://studycrumb.com/alphabetizer]

Ripley, B. D. (1976, June). The second-order analysis of stationary point processes. Journal of Applied Probability, 13(02), 255–266. https://doi.org/10.1017/s0021900200094328

Ripley, B. D. (1981). Spatial Statistics. John Wiley & Sons, New York, 252. https://doi.org/10.1002/0471725218

Silverman, B. (1986). Density Estimation for Statistics and Data Analysis. 1st ed. Chapman and Hall, London.

TRIP. (2009). Future Mobility in West Virginia: Meeting the State's Need for Safe and Efficient Mobility, U.S. Department of Transportation, Washington, D.C.

Xie, Z., & Yan, J. (2008, September). Kernel Density Estimation of traffic accidents in a network space. Computers, Environment and Urban Systems, 32(5), 396–406. https://doi.org/10.1016/j.compenvurbsys.2008.05.001

Yu, H., Liu, P., Chen, J., & Wang, H. (2014, May). Comparative analysis of the spatial analysis methods for hotspot identification. Accident Analysis & Prevention, 66, 80–88. https://doi.org/10.1016/j.aap.2014.01.017

URL-1 http://techalive.mtu.edu/modules/module0003/Superelevation.htm