IDENTIFICATION OF HOTSPOTS ROAD LOCATIONS OF TRAFFIC ACCIDENTS WITH PEDESTRIAN IN URBAN AREAS

SVETLANA BAČKALIĆ, BOŠKO MATOVIĆ, DRAGAN JOVANOVIĆ

FACULTY OF TECHNICAL SCIENCES, SERBIA
E-mail: basic@uns.ac.rs, boskom@uns.ac.rs, draganj@uns.ac.rs

Abstract:

Despite all efforts and activities of local communities the problem of road safety in urban areas is still a problem. Between all accidents particularly stand out those ones with pedestrian involvement.
Pedestrians are the most vulnerable road users and because of this it is necessary to take in consideration individual factors related to the occurrence of traffic accidents and the severity of their consequences in which they are involved. This is a very complex process due to the heterogeneity of the data.
The objective of this study is the following: (1) to explore interdependencies between the individual factors and to identify homogenous subsets within casualty's pedestrians applying typological analysis; (2) to identify traffic accidents density for each of the clusters and identification of hotspot locations with homogenous traffic accident characteristics.
This approach enables narrowing the field of measures application that is selected according to established clusters. It is important to get the appropriate allocation of resources for safety improvements and proper strategic decisions.
Key-words: Traffic accidents, pedestrian, hotspot locations, cluster analysis

Gelöscht: ¶

1. Introduction

In the worldwide, 50% out of the total number of the killed in traffic accident comprise vulnerable road users (pedestrians, cyclists and users of motorized two- and three-wheelers). Pedestrians being more at risk in low and middle income countries (WHO, 2013). In the structure of the killed, pedestrians were 26% out of the total number of the killed in the territory of the Republic of Serbia in 2009 (WHO, 2013). In the period from 2008 to 2011, approximately 40% of the killed and serious injured participants in the traffic were pedestrians. These figures indicate that it is necessary to identified priority action and take appropriate interventions as soon as possible.

Pedestrians are at greater risk of serious injury in road crashes because they do not have a protective shell, and they are moving at low speeds compared to other categories of participation. In this case there is a disproportion between involve risk into traffic and exposure to traffic risk. There are many factors which might influence the risk and/or severity of traffic accidents involving pedestrians, and which are in connection with pedestrians, drivers, road and road environment, traffic characteristics, and social and demographic attributes.

Traffic accidents which involve pedestrians most usually take place in urban areas with an increased pedestrians activity as well as volume of traffic. In U.S. during 2003, 75% out of the total number of killed pedestrians were occurred in urban areas (Zegeer et al., 1993). In researches which were conducted in Europe, there were similar trends that showed that the most fatal traffic accidents which involved pedestrians took place in urban areas (SafetyNet, 2009).

Data about traffic accidents are often heterogeneous, which can cause the relationship between certain attributes remain hidden (Depaire, 2008). Therefore, the researcher (Bedard et al., 2002, Zhang et al., 2000, Zajac and Ivan, 2003) often tends to reduce this heterogeneity by studying only some attributes. This approach has limitation because influence of some factors on traffic accidents is ignored. The primary objective of this paper is to apply typological analysis on a heterogeneous set of pedestrian casualties how to identify relationships between individual characteristics and after that create homogeneous subsets of pedestrians. This approach allows the selection of measures that can be directed towards to these subsets.

GIS is a technology for managing and processing location and related information (Longley et al., 2005). The GIS methods enable the efficient manipulation, analysis and visualization of spatial data. The secondary objective of this paper is to determine the density of traffic accidents for each cluster. This approach enables identification of hotspot locations with homogeneous traffic accidents characteristics. In this manner the decision makers can easily identify hotspot locations for specific pedestrian groups, and that is important for the appropriate allocation of resources for safety improvements.

2. Metodology

2.1. Area of research and procedures for collection and data analysis

The area of the study is based on the pedestrian traffic accidents which took place in urban area of Novi Sad in the period from 2008 to 2011. Novi Sad is the second largest city in Serbia, as well as the administrative, economic, and cultural center of the Autonomous Province of Vojvodina. The traffic accidents data were obtained by the Ministry of Interior the Republic of Serbia. It was relational database about road traffic accidents, causalities and vehicles, and daily police reports which gives a detailed description of each event, i.e. traffic accidents. Within the relational database on traffic accidents description of locations of traffic accidents is based on three referential systems, such as kilometer for accidents that occurred in rural areas, street addresses for accidents that occurred in urban areas or the streets name which intersect or conjoin (in case of traffic accidents which took place at intersections or crossroads). This approach does not allow the precise identification of location for the purposes of a geocoding process. Because of this limitation the data have been supplemented based on the daily police reports which contain detailed descriptions of those events. Each of traffic accidents is studied in detail, after which is done manually geocoding of locations on digital maps within a GIS. On this way we supplemented a relational database which is managed by using software pack the Microsoft Access 2007. For the purpose of further analysis this database is exported to the SPSS 20.0 software package. The connection between the police and the GIS database is based on a primary key (ID). This approach enables the effective traffic safety analysis taking advantage of the various methodological approaches, i.e. various software solutions SPSS 20.0 and ArcGIS 10.1.

2.2. K-means cluster analysis

The first segment of the data analysis implies the application of K-means cluster analysis, i.e. arranging similar elements into groups, characterized by their maximum homogeneity within a clusters and the maximum heterogeneity between the clusters created.

K-mean cluster analysis has been applied for grouping pedestrian casualties on the basis of the key variables related to the person (gender and age, crossing the road or street with respect to the direction of travel of the vehicle), environment (whether the accident occurred at the intersection or not, at or away of a pedestrian crossing, the lighting conditions), time (time of day, working days/weekend, period of year) and the type of vehicle.

Although the hierarchical clustering method is advantageous in determining the number of clusters present in the data, it cannot produce the most optimal cluster solution pertaining to between-cluster heterogeneity. This is because the method is unable to separate clusters created at previous steps. It is therefore recommended to run a K-means cluster analysis after the number of clusters has been determined, using the centroids (i.e. the cluster centre means) generated from the hierarchical analysis as a starting point (Milligan and Sokol, 1980).

2.3. Creation of traffic accident density maps by the application of Kernel Density Estimation (KDE)

One of the main tasks for decision-makers is how to select certain the traffic safety measures for improving traffic safety. Geographic Information Systems (GIS) is a very important and comprehensive tool (computer software) that is able to deal with a huge database in an efficient manner. GIS is suitable for the data analysis and their visualization, enabling to find link between them and represent it on maps. Using GIS, the analysts can merge accident and highway data, geocode the accident data and locations, calculate frequency and rate of accidents, select a variable for stratification to calculate mean and standard deviation of accident rates (Liang et al., 2005). Using this system, the user can identify high risk accident locations, obtain the accident location's ranking, visualize the road accident and location information, input and retrieve the accident database, perform statistical analysis on the selected accident locations and so on within a short period of time (Erdogan et al., 2008)

Traffic accidents are events that can be represented by dots in space. It is very difficult to describe of traffic accidents, and the biggest problem is overlapping of the points representing the traffic accidents which happened at the same location. Therefore, in this paper it was applied Kernel Density Analysis to calculates traffic accident density in the certain area. On this way we solved problems of represent traffic accidents as dots on maps.

KDE is a non-parametric method that involves introducing a symmetrical surface over each point feature, assessing the distance from the point to a reference location based on a mathematical function, and subsequently, adding the value of all the surfaces for that reference location (Levine, 2004).

Mathematically, the Kernel Density Estimation is represented by the following equation (Shi, 2010, adjusted according to Silverman, 1986):

$$\hat{f}_{(x,y)} = \frac{1}{nh^2} \sum_{i=1}^{n} K\left(\frac{d_{i,(x,y)}}{h}\right) \tag{1}$$

where $\hat{f}_{(x,y)}$ estimated density value at location (x, y), n is the total number of event points considered (the total number of traffic accidents), *h* represents the window width, or the smoothing parameter or the kernel bandwidth, by some authors, $d_{i(x,y)}$ represents the distance between the event point *i* and the location *(x,y)*, whereas *K* is the density function (in most cases, *K* is a symmetric probability density function).

A result of this method is a raster map, where the intensity of traffic accidents is represented by continuous surfaces. In most case lighter shades represent locations with a lower traffic accident density, while darker shades represent locations characterized by the highest traffic accident density. Size of the appropriate density surface depends on the bandwidth, which depending on the circumstances and the subjective assessment of researchers. Greater bandwidth includes more accidents into consideration, which resulting in a smoother output raster (Figure 1). It is often necessary to try several variants and find out logical solution and after that select a adequate size of bandwidth. In this paper was applied a bandwidth of 250 m and cell size of 25 m. The kernel density estimation method divides the entire study area into predetermined number of cells. Rather than considering a circular neighborhood around each cell (the simple method), the kernel density estimation method draws a circular neighborhood around each feature point (the accident) and then a mathematical equation is applied that goes from 1 at the position of the feature point to 0 at the neighbourhood boundary (Figure 2) (Anderson, 2009).

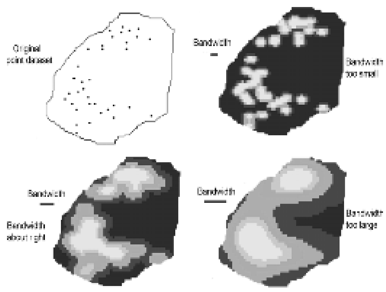

Figure. 1. Effect of bandwidth choice (Plug, 2011)

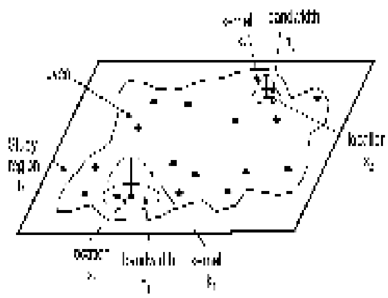

Figure. 2. The Principle of Kernel function (Erdogan, 2008)

3. Results

Table 1 represents results of the K-means cluster analysis. There were a total of 798 pedestrian casualties in the four-year period of this analysis, from 2008 to 2011. Due to the incomplete data for two cases the cluster analysis was conducted for the 796 pedestrian casualties. In the gender structure of the pedestrian casualties, male population represents 40,3% (n=321) of the pedestrians, whereas 59,7% (n=475) of the pedestrian casualties were female. The most frequent age group were pedestrians between 15 to 29 years (30,2%, n=240). The largest number of pedestrians became casualties outside intersections (59,3%, n=472), whereas almost the same number of pedestrians were injured at crosswalks (45,4%, n=361) and away from them (54,6%, n=435).

When the direction of walking of the pedestrians is considered, as opposed to the direction of travel of the vehicle, the majority of pedestrians became casualties when moving from the right to the left (42,6%, n=339). The pedestrians were most often injured in the conditions of a good daylight visibility (65,5%, n=521), but, taking into consideration a lower exposure, a significant percentage of pedestrian casualties at night conditions, when the road is not sufficiently lit, is also noticed (29,9%, n=238). In terms of week days, the working days are a specific period for accidents involving pedestrians (82,9%, n=660), and the part of the day between 12 P.M. and 5 P.M. as a characteristic period during a day (41,6%, n=331). There is equal distribution of pedestrian casualties by seasons. Pedestrians are most often come into contact with passenger cars (86,1%, n=685) and freight vehicles (6,4%, n=51). The total number of pedestrian casualties is evenly distributed into three specific clusters, based on the variables included into the analysis, which characterize each of these groups (Table 1).

From analysis it can be seen that gender structure of the pedestrian casualties is evenly distributed. Also within each cluster, the results are similar and do not great deviate from results of the overall gender structure. A more significant female casualty can be explained by the greater exposure of women in traffic as pedestrian. Other attributes to a greater or lesser extent, express certain characteristics in each category.

Category 1: Child and young pedestrians who were injured in accidents on working days, in the period 12 P.M. and 5 P.M., outside intersections, while crossing the roadway from the right to the left side, in the conditions of good daylight visibility.

In relation to the total number of pedestrians injured, this category comprises 36,7% (n=292) of the pedestrian casualties. This group is categorized by children under 14 (70,6%, n=84) and young pedestrian of 15 up to 29 (56,7%, n=136). Analysis within cluster shows that children represent smaller category (28,8%) comparing young pedestrian (46,6%). Temporal attribute of traffic accidents is viewed from three aspects: (1) season; (2) time during day and (3) week or working days. The spring (42,8%, n=80) and the summer (44,9%, n=75) are typical seasons for this cluster. They were most often injured in the period from 12 P.M. to 5 P.M. (54,4%, n=180). On workdays, 39,5% (n=261) of the pedestrians were injured, while in this category pedestrian who were most often injured on workdays is around 89,4% of the total population. The spatial distribution of traffic accidents shows that majority of the pedestrians were injured outside intersections (37,5%, n=177), with equal distribution at pedestrian crossings (39,1%, n=141) or outside (34,7%, n=151). When the movement of the pedestrians is considered, in relation to the direction of travel of the vehicle, within this category, 43,4% (n=147) of the pedestrians were injured while walking from the right to the left side. These pedestrians were usually in contact with the passenger car (88,7%, n=259) in the conditions of good daylight visibility (56,0%, n=292).

Table 1: Classification of the pedestrian casualties into homogeneous groups, in accordance with the specific attributes, Novi Sad, 2008 – 2011

		Clusters											
		1			2			3			Total		
		n	R%	C%	n	R%	C%	n	R%	C%	N	R%	C%
Gender	Male	123	38,3	42,1	104	32,4	38,7	94	29,3	40,0	321	100,0	40,3
	Female	169	35,6	57,9	165	34,7	61,3	141	29,7	60,0	475	100,0	59,7
	Total	292	36,7	100,0	269	33,8	100,0	235	29,5	100,0	796	100,0	100,0
Age	0-14	84	70,6	28,8	35	29,4	13,0	0	0,0	0,0	119	100,0	14,9
	15-29	136	56,7	46,6	104	43,3	38,7	0	0,0	0,0	240	100,0	30,2
	30-44	72	61,0	24,7	42	35,6	15,6	4	3,4	1,7	118	100,0	14,8
	45-64	0	0,0	0,0	63	37,5	23,4	105	62,5	44,7	168	100,0	21,1
	65>	0	0,0	0,0	25	16,6	9,3	126	83,4	53,6	151	100,0	19,0
	Total	292	36,7	100,0	269	33,8	100,0	235	29,5	100,0	796	100,0	100,0
Period of year	Spring	80	42,8	27,4	44	23,5	16,4	63	33,7	26,8	187	100,0	23,5
	Summer	75	44,9	25,7	35	21,0	13,0	57	34,1	24,3	167	100,0	21,0
	Autumn	72	31,0	24,7	96	41,4	35,7	64	27,6	27,2	232	100,0	29,1
	Winter	65	31,0	22,3	94	44,8	34,9	51	24,3	21,7	210	100,0	26,4
	Total	292	36,7	100,0	269	33,8	100,0	235	29,5	100,0	796	100,0	100,0
Time of day	0-5	0	0,0	0,0	21	100,0	7,8	0	0,0	0,0	21	100,0	2,6
	6-11	87	39,4	29,8	9	4,1	3,3	125	56,6	53,2	221	100,0	27,8
	12-17	180	54,4	61,6	54	16,3	20,1	97	29,3	41,3	331	100,0	41,6
	18-23	25	11,2	8,6	185	83,0	68,8	13	5,8	5,5	223	100,0	28,0
	Total	292	36,7	100,0	269	33,8	100,0	235	29,5	100,0	796	100,0	100,0
Workdays/Weekend	Workdays	261	39,5	89,4	210	31,8	78,1	189	28,6	80,4	660	100,0	82,9
	Weekend	31	22,8	10,6	59	43,4	21,9	46	33,8	19,6	136	100,0	17,1
	Total	292	36,7	100,0	269	33,8	100,0	235	29,5	100,0	796	100,0	100,0
Intersection/ Non-intersection	Intersection	115	35,5	39,4	131	40,4	48,7	78	24,1	33,2	324	100,0	40,7
	Non-intersection	177	37,5	60,6	138	29,2	51,3	157	33,3	66,8	472	100,0	59,3
	Total	292	36,7	100,0	269	33,8	100,0	235	29,5	100,0	796	100,0	100,0
Crosswalk/Section	Crosswalk	141	39,1	48,3	139	38,5	51,7	81	22,4	34,5	361	100,0	45,4
	Section	151	34,7	51,7	130	29,9	48,3	154	35,4	65,5	435	100,0	54,6
	Total	292	36,7	100,0	269	33,8	100,0	235	29,5	100,0	796	100,0	100,0
Direction of pedestrian movement in relation to the direction of the vehicle	From left to right	82	30,7	28,1	115	43,1	42,8	70	26,2	29,8	267	100,0	33,5
	From right to left	147	43,4	50,3	99	29,2	36,8	93	27,4	39,6	339	100,0	42,6
	Parallel	63	33,2	21,6	55	28,9	20,4	72	37,9	30,6	190	100,0	23,9
	Total	292	36,7	100,0	269	33,8	100,0	235	29,5	100,0	796	100,0	100,0
Vehicle type	Passenger car	259	37,8	88,7	247	36,1	91,8	179	26,1	76,2	685	100,0	86,1
	Truck	12	23,5	4,1	8	15,7	3,0	31	60,8	13,2	51	100,0	6,4

	BUS	5	25,0	1,7	7	35,0	2,6	8	40,0	3,4	20	100,0	2,5
	Motocycle	6	33,3	2,1	4	22,2	1,5	8	44,4	3,4	18	100,0	2,3
	Other	10	45,5	3,4	3	13,6	1,1	9	40,9	3,8	22	100,0	2,8
	Total	292	36,7	100,0	269	33,8	100,0	235	29,5	100,0	796	100,0	100,0
Light conditions	Good, daytime	292	56,0	100,0	0	0,0	0,0	229	44,0	97,4	521	100,0	65,5
	Low,daytime	0	0,0	0,0	22	78,6	8,2	6	21,4	2,6	28	100,0	3,5
	Low, night	0	0,0	0,0	238	100,0	88,5	0	0,0	0,0	238	100,0	29,9
	Dark	0	0,0	0,0	9	100,0	3,3	0	0,0	0,0	9	100,0	1,1
	Total	292	36,7	100,0	269	33,8	100,0	235	29,5	100,0	796	100,0	100,0

Category 2: Young pedestrians involved in accidents on weekends, in the period of 6 P.M and 5 A.M. while they were crossing the roadway from the left to the right side, during the nighttime, at an insufficiently lit road.

In relation to the total number of pedestrians injured, this category comprises 33,8% (n=269) of the pedestrian casualties. The age group which suffered most casualties included pedestrians aged 15 up to 29 (43,3%, n=104). Autumn (41,4%, n=96) and winter (44,8%, n=94) months are typical for this group. They were most often injured in the evenings, between 6 P.M. and 11 P.M. (83,0%, n=185), or during nighttime, between 12 A.M and 5 A.M. (100,0%, n=21), which is characteristic of young people and related for their lifestyle. Although in this cluster pedestrians were most often injured on working days 78,1% (n=210), it is important to emphasized that if we observed the total number of casualties during the weekend, this cluster comprises 43,4%. At intersections were injured 40,4% of pedestrians (n=131), while 38,5% (n=139) of pedestrians were injured at crosswalks, and away from them 29,9% (n=130). In this cluster 43,1% (n=115) of pedestrians were injured while they were crossing the roadway from the left to the right side, during the nighttime, at an insufficiently lit road. These pedestrians were usually in contact with the passenger car (36,1%, n=247).

Category 3: Elderly pedestrians, who were injured in accidents in the morning hours between 6 A.M. and 11 A.M., away from crosswalks, outside intersections, in the conditions of good daylight visibility.

This category is the smallest and comprises 29,5 % (n=235) injured a pedestrian. Elderly pedestrians over the age of 65 comprise 83,4 % (n=126) in this cluster. The majority of pedestrians (56,6%, n=125) became casualties in the morning, from 6 A.M. to 11 A.M., which is related to lifestyle and purpose of travel. In this cluster the majority of the pedestrians were injured during workdays (28,6%, n=189), outside intersections (33,3%, n=157), were walking away from crosswalks (35,4%, n=154), uniformly in relation to the direction of travel of the vehicle. Beside the number of pedestrians who were usually in contact with the passenger car (26,1%, n=179), significant proportion of pedestrians were in contact with truck (60,8%, n=31). The majority of the pedestrians were injured in the conditions of good daylight visibility (44,0%, n=229).

The GIS is suitable for the spatial analysis of traffic accidents. From one side it is very useful for visualization and for another it give opportunity of application certain statistic methods. By further application of the KDE method to the total number of accidents (n=764), it is easily to find out that locations with the high pedestrian and vehicle flow also high-density accident locations (Figure 3-a).

If we analyze the traffic accidents that belong to each cluster it is possible to identify a particular hotspot locations that are defined by characteristics of each cluster (Fig. 3b-d).

In the paper twelve hotspot locations have been identified for pedestrian casualties by clusters. At some locations (1, 2, 5, and 6) there are overlapping zone with high density of traffic accidents by more clusters and to them it is necessary to direct the joint action. Other locations (3, 4, 7, 8, 9, 10, 11 and 12) are defined by the individual characteristics of the cluster.

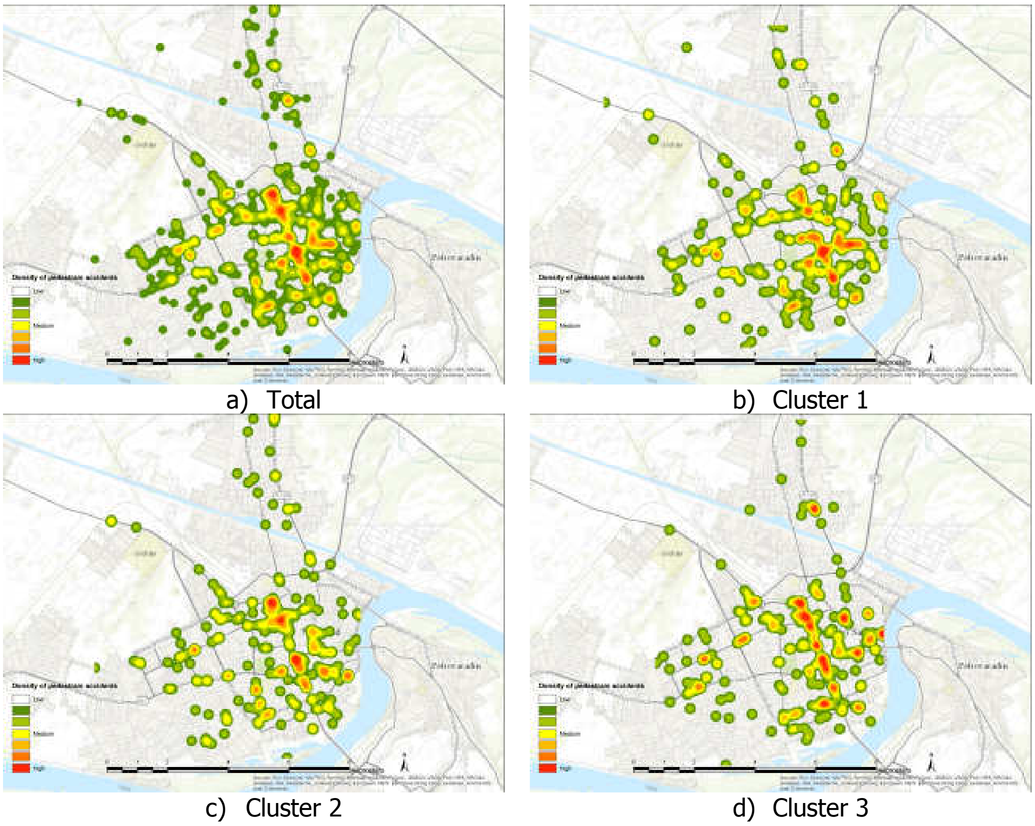

Figure 3. Spatial distribution of traffic accidents involving pedestrian casualties, by clusters and in total, Novi Sad, 2008 – 2011

Figure 4: The high-density accident locations by clusters, Novi Sad, 2008 – 2011

4. Discussion and Conclusions

In paper it was presented a combined approach of two methodological frameworks for solving problem of casualty pedestrians in the urban area of Novi Sad. The first approach is application of typological analysis for identification of homogeneous groups, which are extracted from heterogeneous data set. By K-mean cluster analysis it was identified three categories of pedestrian casualties that have particular attribute: 1) Child and young pedestrians who were injured in accidents on working days, in the period 12 P.M. and 5 P.M., outside intersections, while crossing the roadway from the right to the left side, in the conditions of good daylight visibility; 2) Young pedestrians involved in accidents on weekends, in the period of 6 P.M and 5 A.M. while they were crossing the roadway from the left to the right side, during the nighttime, at an insufficiently lit road; 3) Elderly pedestrians, who were injured in accidents in the morning hours between 6 A.M. and 11 A.M., away from crosswalks, outside intersections, in the conditions of good daylight visibility.

Typology of traffic accidents in which pedestrians were killed or injured in the largely is consistent with many researches from this area of traffic safety. Research conducted by Mabunda and others (2008) point out that children and adolescents become casualties most often between 12 PM to 17.P.M. Young pedestrians are most likely to be a casualties of traffic accidents during the weekend in night conditions (Mabunda et al., 2008, Prato, et al., 2010). Also, other research shows that old pedestrian is often injured in the morning for 6 AM to 11 A.M (Mabunda et al. 2008, Fontaine, 1997). The results show equal distribution of traffic accidents by season (Mabunda et al., 2008).

Spatial distribution of pedestrian casualties per cluster shows that children were injured in accidents which took place outside the intersection, which is similar to other studies (Prato et al., 2010). Looking at the old pedestrians who are often injured outside the pedestrian crossing, it is evident inconsistency with other studies (Fontaine, 1997; Mabunda et al., 2008, Prato, et al., 2012). In the second phase of the research by further application of the KDE method within the Geographic Information System for each cluster were obtained maps of density of traffic accidents. In the paper twelve hotspot locations have been identified for pedestrian casualties by clusters.

Hotspot locations are mostly distributed along the boulevard (Bulevar Oslobodjenja), and this boulevard has high pedestrian and vehicle flow. Also, there is the wider dispersion of the locations which belong to cluster 3. These locations are usually close to markets and stores that old people usually visit.

In the future it is necessary to provide a comprehensive database that will provide quality input for different methodological approaches. This will allow a comprehensive understanding of the impact of certain factors on occurrence of traffic accidents which involve pedestrians, as well as the severity of their consequences. It is necessary to promote certain activities related to pedestrian safety (especially for children and the elderly, as the most risky group). Also, application of certain measures that include education, engineering, enforcement, will probably improve the pedestrians safety.

5. Literature

Anderson, T. K., 2009. Kernel density estimation and K-means clustering to profile road accident hotspots. Accident Analysis and Prevention, 41(3), 359-364.

Bedard, M., Guyatt, G.H., Stones, M.J., Hirdes, J.P., 2002. The independent contribution of driver, crash, and vehicle characteristics to driver fatalities. Accident Analysis and Prevention, 34 (6), 717–727.

Depaire, B., Wets, G., & Vanhoof, K. (2008). Traffic accident segmentation by means of latent class clustering. Accident Analysis & Prevention, 40(4), 1257-1266.

Erdogan, S., Yilmaz, I., Baybura, T., & Gullu, M. (2008). Geographical information systems aided traffic accident analysis system case study: city of Afyonkarahisar. Accident Analysis and Prevention, 40(1), 174-181.

Fontaine, H., Gourlet, Y., 1997. Fatal pedestrian accidents in France: a typological analysis. Accident Analysis and Prevention 29, 303–312.

Levine, N., 2004. CrimeStat III: A Spatial Statistics Program for the Analysis of Crime Incident Locations. Chapter 8: Kernel Density Interpolation. Ned Levine & Associates/The Nationa lInstitute of Justice, Houston, TX/Washington, DC.

Liang, L.Y., Mo'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.

Longley, P. (Ed.). (2005). *Geographic information systems and science*. John Wiley & Sons.

Mabunda, M. M., Swart, L. A., Seedat, M., 2008. Magnitude and categories of pedestrian fatalities in South Africa. Accident Analysis and Prevention, 40(2), 586-593.

Milligan, G. W., & Sokol, L. M. (1980). A two-stage clustering algorithm with robust recovery characteristics. Educational and Psychological Measurement, 40, 755-759.

Plug, C., Xia, J. C., Caulfield, C., 2011. Spatial and temporal visualisation techniques for crash analysis. Accident Analysis and Prevention, 43(6), 1937-1946.

Prato, C. G., Gitelman, V., Bekhor, S., 2012. Mapping patterns of pedestrian fatal accidents in Israel. Accident Analysis and Prevention, 44(1), 56-62.

SafetyNet, (2009). Retrieved from:
http://ec.europa.eu/transport/roadsafety/specialist/knowledge/pedestrians/index.htm

Shi, X., 2010. Selection of bandwidth type and adjustment side in kernel density estimation over inhomogeneous backgrounds. International Journal of Geographical Information Science, 24(5), 643-660.

Silverman, B. W., 1986. Density estimation for statistics and data analysis. Published in Monographs on Statistics and Applied Probability, London: Chapman and Hall.

World Health Organization, 2013. WHO Global Status Report on Road Safety 2013: Supporting a Decade of Action. World Health Organization.

Zajac, S., Ivan, J., 2003. Factors influencing injury severity of motor vehiclecrossing pedestrian crashes in rural Connecticut. Accident Analysis and Prevention 35 (3), 369–379.

Zegeer, C.V., Stutts, J.C., Huang, H., Zhou, M., Rodgman, E., 1993. Analysis of elderly pedestrian accidents and recommended countermeasures. Transport Research Record 1405, 56–63.

Zhang, J., Lindsay, J., Clarke, K., Robbins, G., Mao, Y., 2000. Factors affecting the severity of motor vehicle traffic crashes involving elderly drivers in Ontario. Accident Analysis and Prevention, 32 (1), 117 125.

Milligan, G. W., & Sokol, L. M. (1980). A two-stage clustering algorithm with robust recovery characteristics. Educational and Psychological Measurement, 40, 755-759.