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AN INTEGRATED METHOD OF IDENTIFYING AND RANKING DANGER SPOTS FOR PEDESTRIANS ON MICROLOCATION

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Abstract. In traffic safety, various methods, procedures and techniques are adapted for traffic safety needs. Diverse methods lead to a different degree of exactness, accuracy and precision. The selection of research methods depends primarily on the research objective. Research methods most frequently applied for traffic safety include a statistical method, experiment, observation, tests, a questionnaire and interview, a comparison and analogy, etc. Each method has its advantages and disadvantages; however, a well devised combination of several methods and the reliability of research results can be increased. The problem of danger for pedestrians, as vulnerable road users, is constantly expressed and present in all regions. Therefore, special attention should be paid to pedestrian safety. To determine danger spots for pedestrians, the analyses of traffic accidents are most frequently used, which is the so called reactive approach to traffic safety improvement. Apart from the reactive approach, for the purpose of preventing traffic accidents in the future, it is necessary to combine some of the methods that can proactively indicate potential danger spots for pedestrians. This paper shows the method of identifying and ranking danger spots for pedestrians on micro locations, which incorporates the analysis of traffic accidents, the examination of the subjective attitudes of participants in traffic and the use of a conflict technique. Along with the so called 'overlapping' danger spots detected in the analysis of traffic accidents, danger spots detected based on the analysis of the subjective attitudes of pedestrians and drivers and danger spots detected in the conflict technique, a map of the so called objective and subjective danger spots is obtained. By eliminating all such identified danger spots, black spots as well as potential traffic accidents are removed. The method presented in this paper can be a very useful tool for decision-makers, for improving pedestrian safety on a micro location and for allocating funds.

Keywords: research methods, pedestrians, danger spots, proactive approach, micro location.

1. Introduction

Data provided by the World Health Organization (WHO) show that more than 1.3 million people die and up to 50 million are injured in traffic accidents every year (Global Status Report… 2009). In the EU, there were about 34500 fatalities in 2009 (CARE: Community Road Accident Database 2010). Out of the total number of traffic fatalities registered in the EU, according to CARE, 21% are pedestrians more jeopardized in urban areas (36%) rather than in the rural ones (10%). Compared to the EU, pedestrians in Serbia are jeopardized more frequently as they make 29% considering the total number of fatalities in traffic accidents (Vujanić *et al.* 2009a). However, in Belgrade, the capital of Serbia, the situation regarding danger for pedestrians is significantly better, namely pedestrians make only 7.4% taking into account the number of fatalities in traffic accidents (Vujanić *et al.* 2009a).

Traffic accidents of a vehicle-pedestrian type are, as a rule, accidents with severe consequences, and thus it is necessary to pay special attention to pedestrians and pedestrian traffic when planning, designing and defining traffic regime. It is also necessary to establish a protection system that enables pedestrians to be safe in traffic. In order to define adequate protection measures directed towards safe participation of pedestrians in traffic, first, it is required to identify danger spots, namely the locations with increased danger for pedestrians in traffic. For this purpose, different methods such as the analysis of traffic accidents, a conflict technique, scientific observation, experiment, questionnaire, etc can be used. High quality identification of danger spots facilitates a precise definition of traffic safety problems and a definition of countermeasures.

Most studies that deal with researching and identifying locations with increased danger for pedestrians

are based on the analysis of statistical data on traffic accidents with pedestrians (Schneider *et al.* 2001, 2004; Ng *et al.* 2002; Karim 1992; Duncan *et al.* 2002; Austin *et al.* 1995; Butchart *et al.* 2000; Landis *et al.* 2001; Clifton *et al.* 2009). However, supposedly, it is significant to analyze the risk perception of participants in traffic. In order to determine the risk of occurring pedestrian accidents, Schneider *et al.* (2004) believes that by including locations with high risk perception in analysis could prevent from future accidents, by means of which the so called proactive approach of traffic safety improvement would be achieved, which is of special importance as accidents with pedestrians often have severe consequences.

One of the previous studies on the development of methods for forecasting traffic accidents and determining locations of increased danger in traffic identified a potential traffic accident as a 'conflict in traffic' (Perkins, Harris 1968). Afterwards, many researchers have developed their own conflict techniques pursuant to their circumstances and needs. Thus, Van der Horst and Hogema (1993) established the relation between time to conflict (TTC) and the weight of the conflict within their conflict technique. The basic idea of introducing and applying the conflict technique is the proactive approach to improving traffic safety for the purpose of preventing traffic accidents in the future. Thus, Gårder (1989), having in mind the advantages of the conflict technique, uses it among other techniques for determining the risk for pedestrians at intersections, while the attitudes of participants to traffic are obtained from interviews. Tiwari *et al.* (1998) also use the conflict technique for determining the interaction between motorized and non-motorized traffic.

Rosenbloom (2009) observed the behaviour of pedestrians when crossing pedestrian crossings with traffic lights. Having examined the crossing of 1392 pedestrians on pedestrian crossings with traffic lights, Rosenbloom (2009) found that over 40% of pedestrians crossed or finished crossing the pedestrian crossing when the red light was on. Bearing that in mind, he proposed to motivate pedestrians to respect light signals with media campaigns and by setting a traffic light cycle period. On the other hand, certain researches (Pulugurtha *et al.* 2007; Ng *et al.* 2002) also use modern technologies – Geographical Information Systems methodology – for determining locations of increased danger for pedestrians.

This paper presents the method of identifying and ranking danger spots for pedestrians on a micro location, bearing in mind that each of the abovementioned methods for determining locations of increased danger in traffic has advantages and disadvantages. The method presented in this paper implies a simultaneous use of analyzing a traffic accident, the analysis of participants' subjective attitudes to traffic and results of applying the conflict technique. A simultaneous combination of several methods makes possible to observe danger spots for pedestrians from different standpoints. A spatial analysis of traffic accidents allows determining objective danger spots for pedestrians, while the analysis of subjective attitudes of pedestrians and drivers and the application of the conflict technique facilitate determining subjectively and objectively potential danger spots for pedestrians. In that manner, a reactive and proactive approach to improving pedestrian traffic safety is integrated, namely, the elimination of danger spots and future danger spots for pedestrians is enabled.

The main objective of developing the method of identifying and ranking danger spots for pedestrians on a micro location was to integrate a reactive and proactive manner of improving pedestrian traffic safety. In that way, the process of a precise definition of danger spots, i.e. traffic safety problems is improved. The proposed method also has a practical value as it can be used by decision-makers who can more efficiently allocate funds for traffic safety improvement based on such integral analysis of danger spots.

2. The Method of Identifying and Ranking Danger Spots for Pedestrians

The method of identifying and ranking danger spots for pedestrians on a micro location consists of three steps (Vujanić *et al.* 2009b):

1. *Step one* – the analysis of traffic accidents involving pedestrians. By analyzing data on traffic accidents, the so called objective danger spots are obtained, namely the locations where traffic accidents involving pedestrians actually occur.
2. *Step two* – the application of a subjective conflict technique. By using the conflict technique, objectively potential danger spots, namely the locations with frequent conflicts in traffic between pedestrians and motorized traffic, which can result in traffic accidents, are obtained. Due to the complexity of applying the objective conflict technique, this paper uses the subjective conflict technique, however, without taking into consideration time to collision.
3. *Step three* – conducting a questionnaire or interview in order to determine subjective attitudes of participants to traffic regarding risk. The questionnaire gives subjective danger spots or locations where participants in traffic feel especially unsafe.

After determining danger spots in all three ways, 'overlapping' such determined danger spots is carried out and danger spots are reached where necessary to apply adequate countermeasures (Vujanić *et al.* 2009b) (Fig. 1).

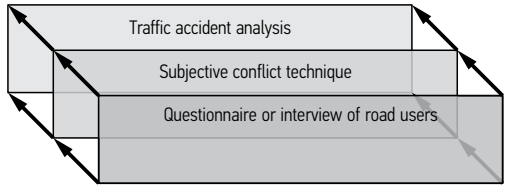

Fig. 1. 'Overlapping' danger spots (Vujanić *et al.* 2009b)

Vujanić *et al.* (2009b) states that the following cases are possible when overlapping danger spots:

- danger spots fully overlap;
- danger spots partially overlap;
- danger spots are completely different.

When eliminating danger spots, it is of extreme importance to apply adequate countermeasures on all locations, namely, on objective danger spots, objectively potential danger spots and subjective danger spots. In that manner, there is both reactive and proactive acting. Apart from objective risk, the subjective risk of danger in traffic is eliminated, and thus pedestrians get the feeling of safety and security, which is also the objective of traffic safety improvement.

Similarly to the above mentioned information, Schneider *et al.* (2004) carried out a statistical analysis of traffic accidents and examined subjective participants' attitudes to traffic regarding risks so that to identify the cases of full overlapping, partial overlapping and a complete divergence of objective and subjective risk highlighting it was necessary to eliminate all risks due to the fact that by removing objective risk danger spots were actually eliminated and by removing subjective risk future danger spots were taken out.

In the paper, the composite method, particularly the sum-of-the-ranks (SR) method, was used for verifying the results of ranking danger spots obtained by 'overlapping'. The principle of the sum-of-the-ranks method is the combination of the ranks of danger spots obtained from individual methods for ranking danger spots. Practically, each of the applied methods within the method for identifying and ranking danger spots for pedestrians (the analysis of traffic accidents, the application of the subjective conflict technique and research on the subjective attitudes of participants to traffic using a questionnaire) can detect and define danger spots according to a certain rank (R_i). Thus, by applying the composite method the outcome is a composite rank (CR) that is the overall rank of danger spots, which combines and incorporates ranks obtained in each individual method. An expression of calculating the composite rank is the following:

$$CR = \frac{R_1 + R_2 + R_3}{3}, \tag{1}$$

where: R_1 – the rank of danger spots determined based on the analysis of traffic accidents; R_2 – the rank of danger spots determined based on the subjective conflict technique; R_3 – the rank of danger spots determined based on questionnaire research on the subjective attitudes of pedestrians and drivers.

When calculating the composite rank, an adequate weight factor can be allocated to different analyses for determining the rank. The authors of this paper believe that in practical sense, the ranks defined in the above mentioned analyses do not bear the same significance and that it is necessary to allocate an adequate weight factor to each of the calculated ranks. For allocating weight factors in traffic safety, the following wide-known methods, including Data Envelopment Analysis (DEA), Analytical Hierarchical Process (AHP), Factor Analysis (FA), Budget Allocation (BA), Equal Weighting (EW) (Hermans *et al.* 2008; Cambon de Lavalette *et al.* 2009; Zavadskas *et al.* 2010; Tupėnaitė *et al.* 2010; Keršulienė *et al.* 2010; Yan *et al.* 2011; Keršulienė, Turskis 2011; Kaya, Kahraman 2011) are mostly used.

The opinion of the authors of this paper is that budget allocation is the simplest method for allocating weight factors, which could allocate weight factors to each of the analyses for rank determination in a fast, efficient manner with high precision. Five professors in the field of traffic safety in Serbia were asked to allocate €10000 to the significance of developing methods and to the significance of the results obtained based on the analysis of traffic accidents, conflict techniques and data on the analysis of questionnaires among pedestrians and drivers. After data were obtained, the BA method and data normalization on a scale of 0 to 1 were carried out. The results of the BA method showed that traffic safety experts gave the highest importance to analyses on traffic accidents followed by conflict techniques, and finally, the results of the conducted questionnaire among pedestrians and drivers; namely, the BA method showed that danger spots determined based on the analysis of traffic accidents had a weight factor of 0.56 (w_1), danger spots determined based on the conflict technique had 0.26 (w_2) and danger spots determined based on the questionnaire among pedestrians and drivers had 0.18 (w_3).

Taking into consideration weight factors (w_i), the expression of calculating the composite rank is:

$$CR = \frac{R_1 \cdot w_1 + R_2 \cdot w_2 + R_3 \cdot w_3}{3}. \tag{2}$$

Considering all above mentioned information, Fig. 2 presents the algorithm of methods for detecting

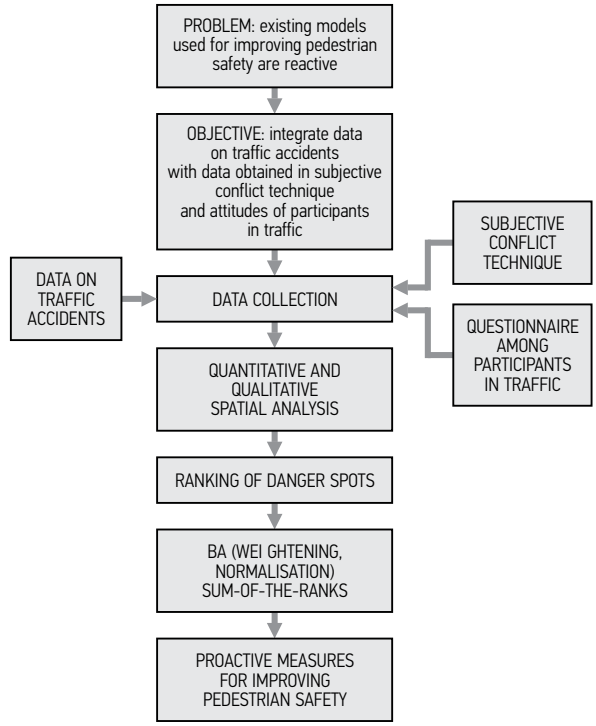

Fig. 2. The algorithm of methods for detecting and ranking danger spots for pedestrians

and ranking danger spots for pedestrians, which uses an integrated analysis of traffic accidents, a modified conflict technique and the analysis of subjective participants' attitudes to traffic.

3. Results of Applying Methods for Identifying and Ranking Danger Spots for Pedestrians: A Case Study

3.1. Study Background

A method for identifying and ranking danger spots for pedestrians was first applied in Serbia in 2009 in the study on improving pedestrian safety in Trg Nikole Pašića Square in Belgrade. Trg Nikole Pašića Square is situated near an untypical and irregular intersection with a very complex traffic regime. An additional problem is caused by the vicinity of the city centre that induces large flows of both motorized and non-motorized traffic.

According to official statistics provided by the Ministry of Interior of Serbia, 50 pedestrian traffic accidents occurred in the zone of Trg Nikole Pašića square in 2008. The analysis of the existing situation was done considering the task to observe the condition of signalization, street network, traffic regime, parking, public transportation, pedestrian flows, etc.

Data on special significance were obtained from counting pedestrian and motorized traffic in the peak hour from 15:00 to 16:00 as a strong interaction between pedestrian and motorized traffic was necessary. Visibility is the best at the day time; thus, high perception was ensured. Video recording was done in order to count pedestrian and motorized traffic. Counting showed that pedestrian flows and motorized flows were of high intensity (Fig. 3).

Such general analysis gave only a slight indication of the problems in safe traffic functioning in the research zone. Therefore, it was necessary to apply some of the methods for more precise detection of the problems considering pedestrian traffic safety.

3.2. Defining and Detecting Danger Spots

3.2.1. Definition and Analysis of the Problems Based on Data on Traffic Accidents

Among the most significant results of analyzing data on traffic accidents that involve pedestrians, the following points can be highlighted: 50 traffic accidents involving pedestrians occurred, Tuesday and Friday were the days of the highest danger, the most dangerous period during the day was from 11:00 to 13:00. Analyzing the locations of traffic accidents involving pedestrians, 68% of traffic accidents involving pedestrians occurred in front of number 10 in Trg Nikole Pašića Square and 41% of those were accidents resulting in severe injuries to pedestrians.

By positioning and grouping data on traffic accident locations on the map, the spatial distribution of traffic accidents was obtained. The rank of danger spots in the research zone and the results of these analyses are presented in Fig. 4.

The rank of danger spots (R_1) is defined based on the number of consequences of traffic accidents by applying the expression of calculating the so called weighted number of traffic accidents (RR) (Vujanić, Dragač 2002):

$$RR = N_{pdo} \cdot p_{pdo} + N_{li} \cdot p_{li} + N_{si} \cdot p_{si} + N_f \cdot p_f, \quad (3)$$

where: N_{pdo} – the number of traffic accidents resulting in property damage only; N_{li} – the number of traffic accidents resulting in slight injuries; N_{si} – the number of traffic accidents resulting in severe injuries; N_f – the number of traffic accidents resulting in fatalities; p_{pdo} – a weight factor for accidents resulting in property damage only; p_{li} – a weight factor of accidents resulting in slight injuries; p_{si} – a weight factor of accidents resulting in severe injuries; p_f – a weight factor of accidents resulting in fatalities.

For determining the weight factors of traffic accidents having certain consequences, the costs of one accident having such consequences were used. Bearing in mind the costs of traffic accidents having certain con-

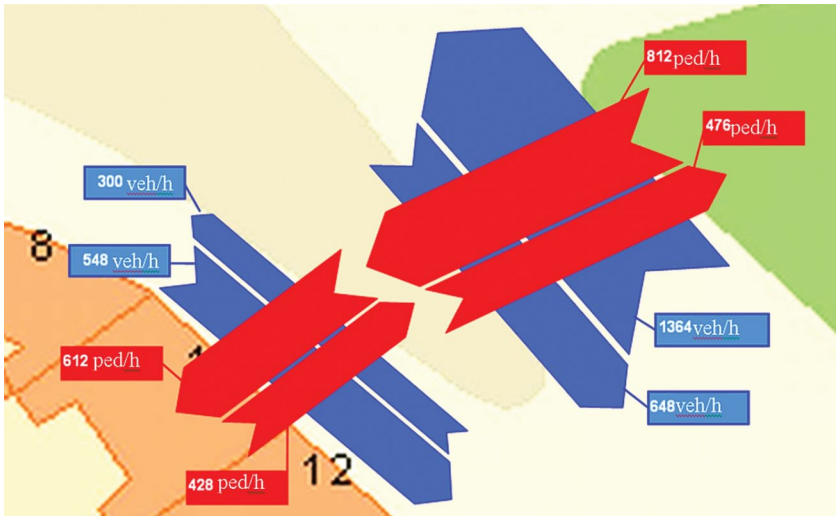

Fig. 3. The intensity of pedestrian and motorized traffic (Vujanić *et al.* 2009b)

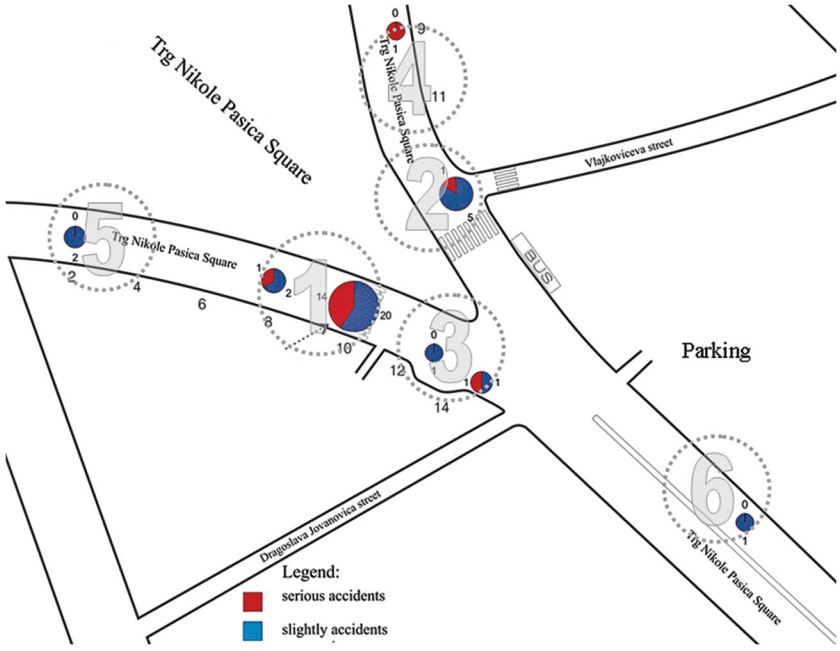

Fig. 4. The spatial distribution of traffic accidents (Vujanić *et al.* 2009b)

sequences, and according to The World Road Association – PIARC (Road Safety Manual 2004) for city streets, the weight factors of traffic accidents having certain consequences would be 0.1 for accidents resulting in property damage only, 1 for accidents resulting in slight injuries, 10 for accidents resulting in severe injuries and 85.1 for accidents resulting in fatalities (Lipovac *et al.* 2010).

In the research zone, all accidents that involved pedestrians were resulting in slight and severe injuries. Considering the above discussed findings, Table 1 presents the results of identifying and ranking danger spots based on the analysis of traffic accidents.

3.2.2. Definition and Analysis of Problems Applying the Subjective Conflict Technique

The subjective conflict technique implies the method of traffic safety analysis and is based on detecting and assessing the risk of accident occurrence – a conflict with an expert observer.

Regarding the above mentioned data, detected conflicts in the observed zone are classified in the following three categories (Vujanić *et al.* 2009b):

- ***An extremely dangerous situation*** is an event in which an accident would occur if a driver did not brake intensively or if there were no sudden

Table 1. Ranking danger spots based on the analysis of traffic accidents (Vujanić *et al.* 2009b)

Danger spot ID	Danger spot location (address)	Number of traffic accidents resulting in slight injuries N_{li} [accidents]	Weight factor of accidents resulting in slight injuries p_{li}	Number of traffic accidents resulting in severe injuries N_{si} [accidents]	Weight factor of accidents resulting in severe injuries p_{si}	Weighted number of traffic accidents RR	Rank of danger spots R_1
A	Numbers 2 to 6 on Trg Nikole Pašića	2	1	0	10	2	5
B	Numbers 8 to 12 on Trg Nikole Pašića	22		15		172	1
C	Zone No. 14 on Trg Nikole Pašića	2		1		12	3
D	The parking lot on Trg Nikole Pašića	1		0		1	6
E	'Parking lot'	0		0		0	7
F	Numbers 9 to 11 on Trg Nikole Pašića	0		1		10	4
G	The intersection zone on Trg Nikole Pašića and Vlajkovićeva streets	5		1		15	2
H	Pedestrian crossing in Vlajkovićeva street	0		0		0	7
I	'Point' of the intersection	0		0		0	7

changes in the movement pattern (sudden change in the movement direction of drivers and/or pedestrians, sudden change in vehicle and/or pedestrian speed etc.). These include:
- ◦ crossing pedestrians on a pedestrian crossing when the red light is on;
- ◦ passing vehicles when the red light is on at a pedestrian crossing;
- ◦ crossing pedestrians away from a pedestrian crossing;
- ◦ crossing pedestrians away from a pedestrian crossing along other routes.

- ***A dangerous situation*** is an event in which the unsafe behaviour of participants in traffic is detected. Taking into account such spatial and time interval where a possibility of avoiding an accident without applying intensive manoeuvres occurs, only the manoeuvres of less intensity or those common in traffic (mild changes in the direction and speed of drivers and/or pedestrians) are considered. These include:
  - ◦ crossing pedestrians on a pedestrian crossing in a side street when the red light is on;
  - ◦ high vehicle speeds.
- ***A less dangerous situation*** is an event in which the unsafe behaviour of participants in traffic is detected, but in which an accident would occur if another participant appeared on the route of the participant who was observed to behave unsafely. These include:
  - ◦ unsafely parked vehicles;
  - ◦ u-turning of a vehicle on forbidden places (observed from the aspect of pedestrians).

Detected dangerous situations are positioned on the map. Spatial distribution was obtained. The rank of danger spots according to the modified conflict technique and the results of these analyses are presented in Fig. 5.

The rank of danger spots (R_2) is defined based on the composite number and the severity of dangerous (conflict) situations (RC) by applying the following expression (Vujanić *et al.* 2009b):

$$RC = N_{vd} \cdot p_{vd} + N_d \cdot p_d + N_{ld} \cdot p_{ld}, \quad (4)$$

where: N_{vd} – the number of extremely dangerous situations; N_d – the number of dangerous situations; N_{ld} – the number of less dangerous situations; p_{vd} – a weight factor of an extremely dangerous situation (10); p_d – a weight factor of a dangerous situation (5); p_{ld} – a weight factor of a less dangerous situation (1).

Weight factors (p_{vd}, p_d and p_{ld}) are determined by applying the expert method where three trained experts involved in conducting the subjective conflict technique were questioned how many times an extremely dangerous situation was more dangerous than a less dangerous situation. Thus, the values of weight factors were determined to the amounts of 10, 5 and 1, for p_{vd}, p_d and p_{ld} respectively.

The results of applying the composite number and the severity of dangerous situations (conflicts) are presented in Table 2.

3.2.3. Definition and Analysis of Problems Based on the Questionnaire among Participants in Traffic

After the subjective conflict technique was carried out, the determination of subjective danger spots in the research area was initiated. The used method was a questionnaire that involved 150 drivers and 150 pedestrians. The most important conclusions of the analysis of the subjective attitudes of pedestrians and drivers were as follows:

- According to pedestrians, the geometry of the intersection is such that to allow drivers to achieve high speeds. Therefore, the drivers come across significant pedestrian flows on pedestrian cross-

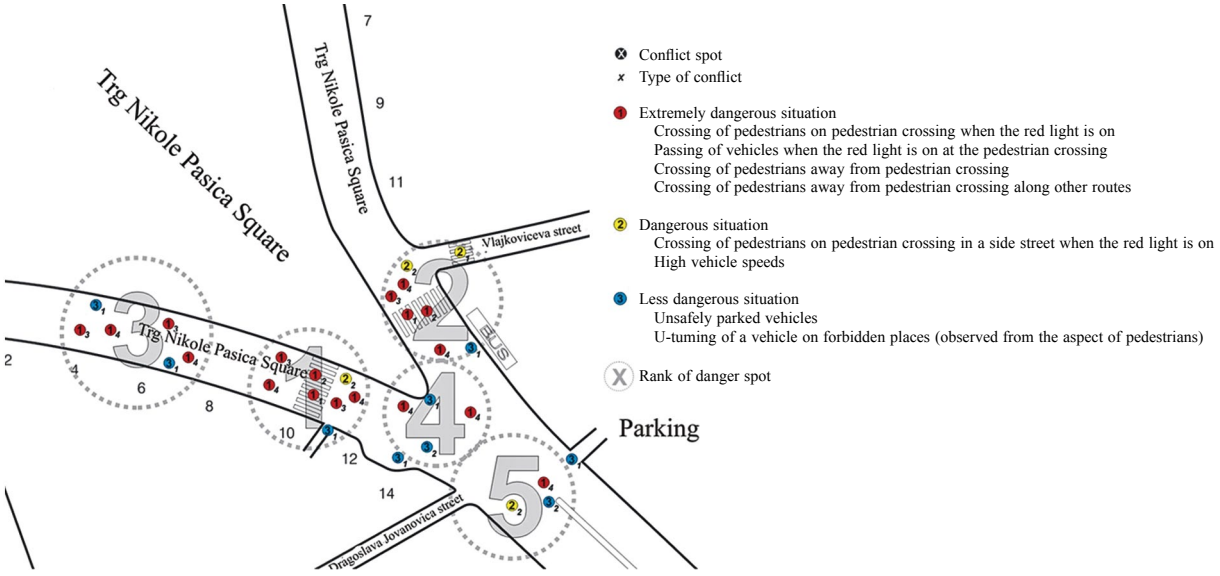

Fig. 5. The spatial distribution of conflicts (Vujanić *et al.* 2009b)

Table 2. Ranking danger spots based on the modified conflict technique (Vujanić *et al.* 2009b)

Danger spot ID	Danger spot location (address)	Number of extremely dangerous situations N_{vd} [situations]	Weight factor of an extremely dangerous situation p_{vd}	Number of dangerous situations N_d [situations]	Weight factor of a dangerous situation p_d	Number of less dangerous situations N_{ld} [situations]	Weight factor of a less dangerous situation p_{ld}	Composite number and severity of dangerous (conflict) situations RC	Rank of danger spots R_2
A	Numbers 2 to 6 on Trg Nikole Pašića	14	10	0	5	2	1	142	3
B	Numbers 8 to 12 on Trg Nikole Pašića	17		2		1		181	1
C	Zone No. 14 on Trg Nikole Pašića	8		0		4		84	4
D	The parking lot on Trg Nikole Pašića	4		2		3		53	5
E	'Parking lot'	0		0		0		0	6
F	Numbers 9 to 11 on Trg Nikole Pašića	0		0		0		0	6
G	The intersection zone on Trg Nikole Pašića and Vlajkovićeva streets	14		3		1		156	2
H	Pedestrian crossing in Vlajkovićeva street	0		0		0		0	6
I	'Point' of the intersection	0		0		0		0	6

ings in Trg Nikole Pašića Square. A number of pedestrians use two pedestrian crossings to cross the street. Traffic lights on pedestrian crossings are not harmonized, and therefore the flows of pedestrians who start at the green light on one pedestrian crossing are stopped with the red light on the other. Because of the big cycle and short time of the green light for pedestrians on both pedestrian crossings, pedestrians admit that very often they opt for crossing the other pedestrian crossing when the red light for pedestrians is on.

- Drivers, on the other hand, also state that the geometry of the intersection and the street before the intersection allows achieving high speeds. In most cases, they 'step on the gas' in order to make up for the lost time because they were waiting long on the previous intersection, and thus get in conflict with pedestrians who were crossing the street away from the pedestrian crossing, very often in long routes.

The questionnaire had a sketch of the research zone on the back and the questioned persons ranked the locations they thought as extremely dangerous, dangerous and less dangerous. This way, 7 danger spots were defined (Fig. 6).

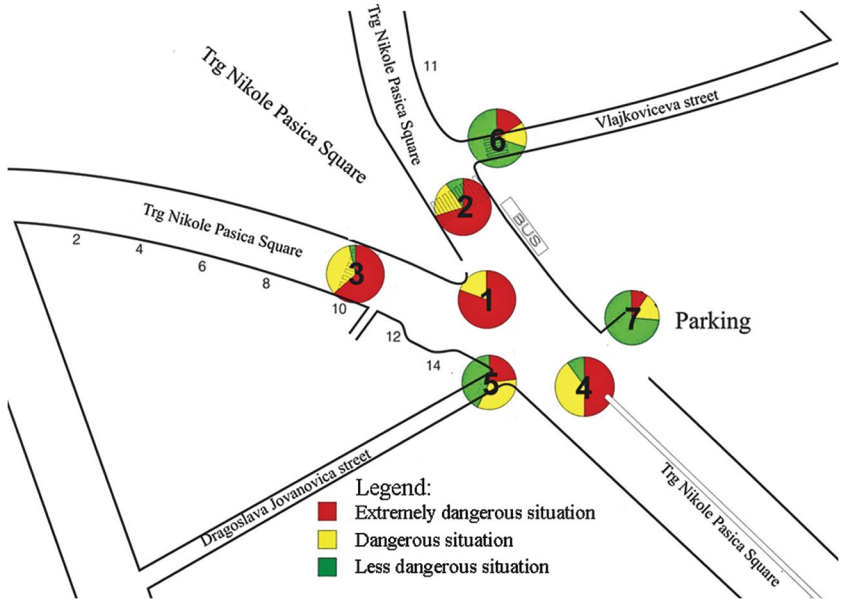

Fig. 6. Danger spots from the aspect of subjective assessments of participants in traffic (Vujanić *et al.* 2009b)

Ranking danger spots (R_3) is defined based on the composite number and the severity of danger spots according to the subjective attitude of drivers and pedestrians (*RS*) (Vujanić *et al.* 2009b):

$$RS = N_{vd} \cdot p_{vd} + N_d \cdot p_d + N_{ld} \cdot p_{ld}, \quad (5)$$

where: N_{vd} – the number of extremely dangerous situations according to the opinion of pedestrians and drivers; N_d – the number of dangerous situations according to the opinion of pedestrians and drivers; N_{ld} – the number of less dangerous situations according to the opinion of pedestrians and drivers; p_{vd} – a weight factor for extremely dangerous situations (10); p_d – a weight factor for dangerous situations (5); p_{ld} – a weight factor for less dangerous situations (1).

Weight factors (p_{vd}, p_d and p_{ld}) are determined by applying the expert method in the case where three trained experts conducted the questionnaire and assessed how many times a dangerous situation mentioned and described by pedestrians and drivers in the questionnaire was more dangerous than a less dangerous situation. That way, similarly to the conflict technique, the values of weight factors are determined to be 10, 5 and 1 for p_{vd}, p_d and p_{ld} respectively.

Ranking danger spots based on the subjective attitudes of pedestrians and drivers is given in Table 3.

3.2.4. Definition of the Composite Rank of Danger Spots

The conducted analysis revealed that conflicts, subjective and objective danger spots were 'overlapped' and the final map was reached, which defines danger spots and gives the rank of the micro locations of increased danger for pedestrians on the basis of an overall analysis of traffic accidents, conflicts and subjective attitudes of the road user (Fig. 7).

Fig. 7 presents top five danger spots according to the rank of danger defined based on the composite and sum-of-the-ranks methods. This method practically calculates the composite rank of danger spots, taking into consideration weight factors for each rank; thus, subjective and objective risks and danger spots are incorporated. In other words, reactive and proactive approaches to improving pedestrian safety are incorporated. The re-

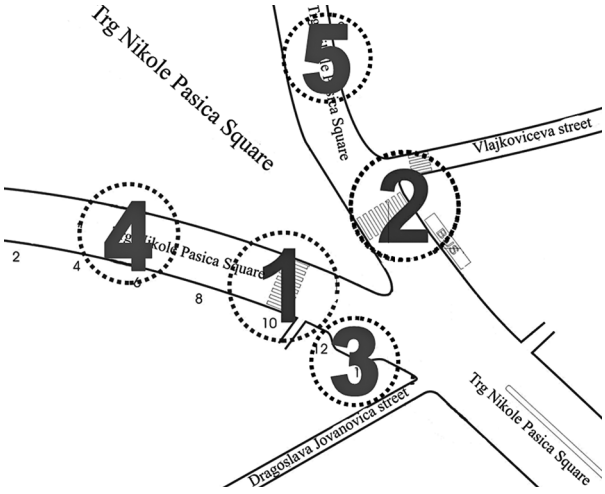

Fig. 7. The final rank of danger spots for pedestrians (Vujanić *et al.* 2009b)

Table 3. Ranking danger spots based on the subjective attitude of drivers and pedestrians (Vujanić *et al.* 2009b)

Danger spot ID	Danger spot location (address)	Number of extremely dangerous situations according to the opinion of pedestrians and drivers N_{vd} [situations]	Weight factor for extremely dangerous situations p_{vd}	Number of dangerous situations according to the opinion of pedestrians and drivers N_d [situations]	Weight factor of dangerous situations p_d	Number of less dangerous situations according to the opinion of pedestrians and drivers N_{ld} [situations]	Weight factor of less dangerous situations p_{ld}	Composite number and the severity of danger spots according to the subjective attitude of drivers and pedestrians *RS*	Rank of danger spots R_3
A	Numbers 2 to 6 on Trg Nikole Pašića	0	10	0	5	0	1	0	8
B	Numbers 8 to 12 on Trg Nikole Pašića	189		101		10		2405	3
C	Zone No. 14 on Trg Nikole Pašića	72		102		126		1356	5
D	The parking lot on Trg Nikole Pašića	149		122		29		2129	4
E	'Parking lot'	30		49		221		766	7
F	Numbers 9 to 11 on Trg Nikole Pašića	0		0		0		0	8
G	The intersection zone on Trg Nikole Pašića and Vlajkovićeva streets	212		58		30		2440	2
H	Pedestrian crossing in Vlajkovićeva street	49		39		212		897	6
I	'Point' of the intersection	240		60		0		2700	1

Table 4. Composite ranking of danger spots (Vujanić *et al.* 2009b)

Danger spot ID	Danger spot location (address)	Rank of danger spots based on traffic accidents R_1	Rank of danger spots based on a conflict technique R_2	Rank of danger spots based on questionnaire R_3	Composite rank CR	Sum-of-the-ranks SR
A	Numbers 2 to 6 on Trg Nikole Pašića	5	3	8	1.67	4
B	Numbers 8 to 12 on Trg Nikole Pašića	1	1	3	0.45	1
C	Zone No. 14 on Trg Nikole Pašića	3	4	5	1.21	3
D	The parking lot on Trg Nikole Pašića	6	5	4	1.79	6
E	'Parking lot'	7	6	7	2.25	9
F	Numbers 9 to 11 on Trg Nikole Pašića	4	6	8	1.75	5
G	The intersection zone on Trg Nikole Pašića and Vlajkovićeva streets	2	2	2	0.67	2
H	Pedestrian crossing in Vlajkovićeva street	7	6	6	2.19	8
I	'Point' of the intersection	7	6	1	1.89	7

sults of applying the sum-of-the-ranks method pursuant to expression (2) are presented in Table 4, and the top five locations according to the rank of danger are displayed in Fig. 7.

3.3. Proposed Measures for Improving Traffic Safety of Pedestrians on the Research Location

After detecting locations of increased danger for pedestrians in the zone of Trg Nikole Pašića Square, adequate proactive measures for improving pedestrian safety were defined (Vujanić *et al.* 2009b):

1. On pedestrian crossing situated on Number 10, Trg Nikole Pašića Square, a platform should be placed. The surface of the platform should be adequate for surfaces designed for pedestrian movement (sidewalk), which would clearly indicate that this surface is primarily for pedestrians.
2. Green light for pedestrians should be extended (at the moment, it makes only 16 s and cycle reduction is 110 s). Besides the above pedestrian lanterns, a LCD display should be placed which would indicate the remaining time in seconds until the green light for pedestrians is on; above the display, a sign should be placed bearing the following message: 'Better lose a moment in life than life in a moment – wait for the green light!'. For disabled persons, a vibrating device should be installed (apart from the sound signal).
3. The disposition of jardinières (street furniture) should be organized so as to disable pedestrians to pass between them, which would at the same time disable pedestrians to cross away from pedestrian crossings. In other words, pedestrian flows are to be channelized to pedestrian crossings.

The proposed measures were implemented at the beginning of January 2009.

3.4. Effects of Applying the Method of Identifying and Ranking Danger Spots for Pedestrians and Proposed Measures

For measuring the effects of applying adequate measures, assessment 'before and after' was applied, namely, a comparison of absolute indicators regarding the number of traffic accidents in total and according to consequences. Data on traffic accidents that occurred in 2009 were compared with that collected in 2008. Taking into consideration that the applied measures were implemented at the beginning of January 2009, the comparison was considered to be valid. The results showed a significant drop in the number and consequences of traffic accidents. Table 5 presents data on the number and consequences of traffic accidents for the period 2008–2009.

Having in mind the number of traffic accidents for the period 2008–2009, it can be concluded that the application of the method for detecting and ranking danger spots, presented in this paper, along with the proposal and implementation of adequate measures, has contributed to a reduction in the number of traffic accidents involving pedestrians by almost one-third where the number of accidents having severe consequences

Table 5. The number and consequences of traffic accidents for the period 2008–2009 *(http://www.mup.rs* – Ministry of Interior of the Republic of Serbia)

Year	Total number of accidents that involved pedestrians	Fatality accidents	Serious accidents	Slight accidents
2008	50	0	17	33
2009	34	0	10	24
Δ [%]	–32.0	0	–41.2	–27.3

decreased by 41% and the number of accidents having slight consequences decreased by 27%. Practically, it is obvious that there are significant positive effects on pedestrian safety.

4. Discussion and Conclusions

1. This paper presents a new integrated method of identifying and ranking danger spots for pedestrians. The method uses a simultaneous analysis of pedestrian danger in traffic considering three aspects: objective risk (based on the analysis of traffic accidents), potentially objective risk (based on the subjective conflict technique) and subjective risk (based on the analysis of participants' attitudes to traffic).
2. Besides the identification of danger spots, the application of the presented method enables ranking identified danger spots, which can be an input for priority in the elimination of identified danger spots. Pulugurtha *et al.* (2007) came to a similar conclusion in their research on identifying and ranking locations with high danger for pedestrians and highlighted it was an important step in allocating and directing resources for improving traffic safety of pedestrians.
3. Practically, the basic ideas of defining an integrated method for identifying and ranking danger spots for pedestrians are the following: the identification of danger spots for pedestrians having in mind different aspects of observing the problem of danger for pedestrians, ranking danger spots for pedestrians, a more precise definition of the problem, the creation of a proactive approach to improving pedestrian safety and the creation of a useful tool for decision-makers, which, apart from the identification of danger spots, can also be used for a more efficient allocation of resources for pedestrian safety improvement.
4. In conclusion, it can be stated that the integrated method of identifying and ranking danger spots for pedestrians enables the identification of danger spots for pedestrians based on different standpoints.
5. The integrated method enables to eliminate the identified black spots based on the analysis of traffic accidents, which eliminates the existing danger spots for pedestrians.
6. By applying the subjective conflict technique, the method can also improve pedestrian traffic safety by eliminating potential danger spots for pedestrians.
7. The method also enables the elimination of subjective risks in traffic and is based on the analysis of participants' attitudes to traffic, which is of extreme importance because one of the main objectives of traffic safety management is to create the feeling of safety and security among participants in traffic.
8. The method identifies and ranks 9 danger spots for pedestrians. A composite rank of danger spots varied from 0.45 (the most dangerous spot) to 2.25 (the least dangerous spot).
9. After implementing the method and countermeasures, the total numbers of accidents that involved pedestrians decreased by 32% where the number of accidents having severe consequences decreased by 41%, and the number of accidents having slight consequences decreased by 27%.

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