DOI: https://doi.org/10.14256/JCE.2705.2019

Građevinar 8/2020

Primljen / Received: 8.5.2019.
Ispravljen / Corrected: 18.1.2020.
Prihvaćen / Accepted: 22.4.2020.
Dostupno online / Available online: 10.9.2020.

The influence of the construction of raised pedestrian crossing on traffic conditions on urban segments

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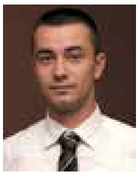

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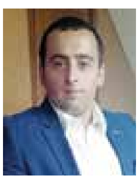

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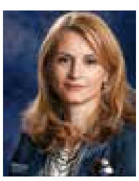

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Research paper

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The influence of the construction of raised pedestrian crossing on traffic conditions on urban segments

One of solutions that is often used in recent times in street networks is vertical shift in pavement level at mid-block pedestrian crossings. This measure is aimed at reducing vehicle speed and increasing the motorist yield rate. Research results about the influence of raised mid-block pedestrian crossings on pedestrian and driver behaviour are presented through analysis of traffic flow parameters. The research was conducted at a mid-block signalised pedestrian crossing prior to and after rehabilitation of that crossing.

Key words:

road rehabilitation, raised pedestrian crossing, speed tables, traffic flow speed

Prethodno priopćenje

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Utjecaj gradnje uzdignutih pješačkih prijelaza na uvjete prometovanja gradskim prometnicama

Jedno od rješenja koje se u novije vrijeme na cestovnim mrežama često primjenjuje jest uzdizanje kolnika na izdvojenim pješačkim prijelazima. Ovom se mjerom žele smanjiti prilazne brzine vozila te povećati stupanj propuštanja pješaka od strane vozača. U radu su prikazani rezultati istraživanja o tome kako uzdizanje kolnika na pješačkom prijelazu utječe na ponašanje pješaka i vozača analizirajući parametre prometnog toka. Istraživanje je provedeno na izdvojenom signaliziranom pješačkom prijelazu i to prije i nakon rekonstrukcije prijelaza.

Ključne riječi:

rekonstrukcija prometnice, uzdignuti pješački prijelaz, usporivači prometa, brzina prometnog toka

Vorherige Mitteilung

Nemanja Garunović, Vuk Bogdanović, Jelena Mitrović Simić, Goran Kalamanda, Biljana Ivanović

Einfluss des Baus erhöhter Fußgängerüberwege auf die Verkehrsbedingungen auf Stadtstraßen

Eine der Lösungen, die in jüngster Zeit häufig in Straßennetzen eingesetzt wird, ist das Anheben von Fahrbahnen an ausgewählten Fußgängerüberwegen. Zweck dieser Maßnahme ist es, die Annäherungsgeschwindigkeit von Fahrzeugen zu verringern und die Anzahl der Fußgänger zu erhöhen, die die Fahrer über die Straße gehen lassen. Die Arbeit präsentiert die Ergebnisse von Untersuchungen darüber, wie sich die Höhe der Fahrbahn an einem Fußgängerüberweg auf das Verhalten von Fußgängern und Fahrern auswirkt, indem die Parameter des Verkehrsflusses analysiert werden. Die Forschung wurde an einem ausgewählten beschilderten Fußgängerüberweg sowohl vor als auch nach der Rekonstruktion des Überwegs durchgeführt.

Schlüsselwörter:

Rekonstruktion des Verkehrswegs, erhöhter Fußgängerüberweg, Vorrichtungen zum Verlangsamen des Verkehrs, Verkehrsflussgeschwindigkeit

1. Introduction

Development of sustainable traffic system and mobility in cities unavoidably includes assessment of the pedestrian traffic quality over the entire street network. Basic pedestrian movement operations, such as road crossing, are highly affected by a large number of objective and subjective factors in the traffic system. For pedestrians, being the most vulnerable group of traffic participants, the most critical points in the street network are crosswalks, where pedestrian flows cross motor vehicle flows at the same level. At these points, it is necessary, on one hand, to provide for safe passage of pedestrians across the road and, on the other hand, an undisturbed motor vehicle traffic.

Depending on local conditions regulated by national or local authorities, various types of pedestrian crossings can be found in the street network, where priority of pedestrian traffic flows is defined in relation to motor vehicle traffic flows. However, due to objective factors, such as vehicle speed, road geometry, volume of pedestrian traffic flow, etc., there can be deviations from the rules defining behaviour of drivers and pedestrians. Various measures are taken in order to increase safety of pedestrians, or to provide them with the legally prescribed priority. Frequent measures of this type are structural interventions that imply making changes to geometric characteristics of the road. These measures are implemented in order to compel drivers to comply with the defined traffic regulation regime (e.g. speed limitations). One of these measures is a vertical shift of pavement at the place where pedestrian and vehicle traffic cross one another. In this case, instead of conventional crosswalk paint markings, the crosswalk is raised on a platform, with access ramps at a certain angle, and the whole setup functions as a traffic calming device, while also visually highlighting the place where pedestrians go across the road.

The research shown in this article was conducted in order to determine, in a concrete situation under real traffic flow, if and to what extent differences occur in qualitative traffic indicators after rehabilitation of the crosswalk. In the analysed case, the comparison of qualitative traffic flow indicators at the crosswalk in Dr Sime Miloševića Street in the campus of the University of Novi Sad was made before and after rehabilitation of the street network. Basic changes made at the stated location involve the change in crosswalk geometry, which was only defined with appropriate road marking before the rehabilitation, while the crossing assumed the form of a raised platform after the rehabilitation work.

The aim of the research conducted in the scope of this article is to show the effects the measures applied on this crosswalk had on both the traffic flow and behaviour of pedestrians and drivers at this crosswalk.

2. Previous research studies

Crossing of pedestrian and vehicle traffic flows at the same level (at-grade pedestrian crossing) is in most cases an inherited element of the street network and, also, to a great extent, unavoidable element when designing a new road system. Crosswalks are generally defined as specially marked surfaces designated for pedestrian circulation on the pavement, that is, across the road [1]. Depending on the needs resulting from the geometry of the crossing and pedestrian flow demand, three basic types of at-grade road crossings can be differentiated:

- Zones in which pedestrian and vehicle traffic cross, where crosswalk markings are not necessary;
- Zones in which pedestrian and vehicle traffic cross, where unsignalised crosswalk markings are necessary;
- Zones in which pedestrian and vehicle traffic cross, where traffic lights are necessary [2].

Unsignalised crosswalks are crossing points that are marked with legally defined road markings and appropriate traffic signs. Crosswalk marking can differ depending on standards and regulations applied in various countries. The most commonly used crosswalk marking patterns are shown in Figure 1.

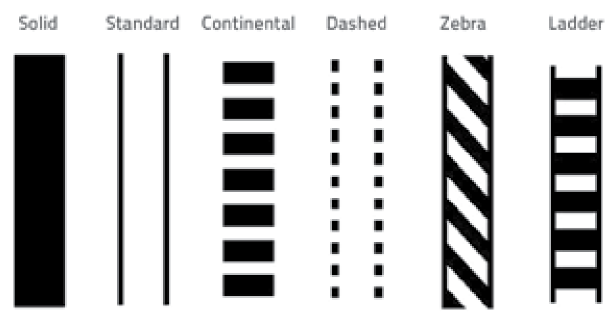

Figure 1. Common crosswalk markings [1]

When marking or constructing the crosswalk, it is very important to make it easily available to all users. This especially applies to special needs users, persons in wheelchairs, and mothers with pushchairs, because the barrier curb at the crosswalk edges represents an obstacle or makes the crossing more difficult. In order to overcome this problem, road crossing ramps are built at the end of the pavement and the beginning of the crosswalk. One of the ways of realizing road crossing ramps with minimal dimensions of its elements according to AASHTO (American Association of State Highway and Transportation Officials) is shown in Figure 2.

At crosswalks characterized by intensive passage of pedestrian flows across the pavement where, for some reason, the installation of traffic lights is not justified, a number of measures can be applied in order to reduce the risk of accidents. Considering the fact that pedestrians are a group of traffic participants who usually have the right of way in relation to motor traffic, reduction of the allowed speed of vehicles is nearly always applied as a safety measure in zones of intensive road crossing by pedestrians. If necessary, appropriate traffic calming devices are also installed. The main function of traffic calming devices (speed tables or speed bumps) is to warn drivers about the speed limit, or to physically prevent vehicles to drive at a speed that is higher than the allowed one on a particular road section or part of a street network.

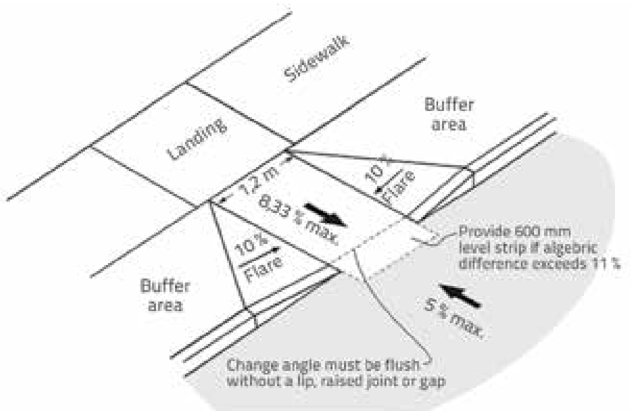

Figure 2. Example of road crossing ramp [3]

Traffic calming devices are basically classified into warning devices, which include optical and sound calming devices, and physical obstacles, which are built on the pavement and which physically disable vehicles movement at speeds higher than the defined ones, or make driving at higher speed less comfortable. Raised platforms, commonly applied at midblock crosswalks, are a special type of vertical traffic calming devices that cover a larger surface (Figure 3).

Figure 3. Midblock in the function of a sidewalk [5]

Basic characteristics of such platforms are their spread from one edge of the pavement to the other, and modularity, i.e. they can be constructed as modular - made of rubber or plastic materials, or permanent - made of asphalt mixtures, concrete, or prefabricated materials. An advantage of such platforms lies in an undisturbed movement of pedestrians and cyclists across the street, since the height of the platforms always matches that of the sidewalk (Figure 4) or cycling path.

Figure 4. Sidewalk connecting with the raised platform

The platforms ensure speed reduction, both for motor vehicles and motorcycles. According to the research conducted by the Institute of Transportation Engineers, the speed reductions for 12-foot humps is 12.2 km/h (7.6 mph), 12.4 km/h (7.7 mph) for 14-foot humps, 10.6 km/h (6.6 mph) for 22-foot speed tables, and 5.1 km/h (3.2 mph) for speed tables longer than 22 ft [4]. Functional evaluation of measures applied from the aspect of traffic is stated in qualitative indicators. Qualitative indicators of traffic conditions given in the analysis are: speed of individual vehicles measured immediately before the crosswalk, speed of pedestrians walking across the pavement, motorist yield rate, and delays in pedestrian flows. The examples given are described in the following section 2.1.

2.1. Pedestrian and vehicle traffic flow characteristics

Most characteristics of pedestrian flows are similar to those of vehicular traffic: free choice of movement speed and passing of another parked - moving participants in traffic. However, many characteristics are specific to pedestrian traffic flows only. Some of them are: movement in opposite direction in relation to the main pedestrian flow, pedestrian circulation without conflicts or changes in walking speed, and pedestrian delays at signalised and unsignalised intersections.

Rules for basic parameters of pedestrian flow (flow, speed, density) are the same as those applied for vehicles. Thus, pedestrian flow is the result of the speed and density of pedestrian movement. With an increase in speed of pedestrian flow, there is also an increase in distance among pedestrians, which leads to decrease in density. The density decreases with an increase in speed because of the distance the pedestrians have to have when they move, and also because they need a greater physical space due to longer strides at higher speeds.

Although an increase in distance among pedestrians is affected by speed, the influence of human psyche, i.e. experience of private space of each individual, is also significant. This experience of private space around oneself is particularly important in situations when pedestrian flows are stopped or significantly decelerated (speed around zero). In such cases, the density of pedestrian flow is relatively high as it is of great significance to know the flow parameters when analysing massive happenings and events involving presence of a large number of people.

Pedestrian circulation speed is greatly dependent on characteristics of pedestrian population. Namely, the percentage of older pedestrians (aged 65 and more) and children, as well as the purpose of travel, are only some of the factors that affect the speed of movement. There are several other factors that can affect reduction of the average movement speed, such as slope bigger than 5 %, which should definitely be considered when doing calculations. Also, it has been determined during research that the speed of pedestrians crossing the road is higher for the pedestrians who individually cross the road compared to for those who cross it in a group [6-9].

The procedure for calculating the level of service (LOS) for pedestrians at signalised and unsignalised intersections is presented in the Highway Capacity Manual (HCM) issued in 2000 [10]. The LOS for the crosswalks at unsignalised intersections is based on average pedestrian delays, which refers to the time spent waiting to cross the road. LOS is marked by classes, from "A" to "F", where "A" is the best, and "F" the worst. The LOS belonging to class "F" occurs in situations when there is no convenient interval for pedestrians to safely cross the road. Such situations are characterized by a very long waiting time, when delays exceed the limit of 45s. This methodology is based on fixed time intervals. The LOS calculation method for pedestrians includes a series of steps, which demand input data relating to the intensity of traffic and pedestrian flows, as well as to geometric conditions. Based on results obtained in the scope of research studies conducted in the meantime, it was established that the LOS of pedestrian flow is greatly influenced by vehicles which stop and decelerate in order to give the right of way to pedestrians wishing to cross the road. Consequently, a new parameter, known as the motorist yield rate (labelled My in calculations) was introduced, and the existing methods, which ended with the calculation of average delays, and which were used for LOS determination, were extended by one step in which average delays are obtained through assessment of the reduction of waiting time due to motorist yield to pedestrians.

Motorist yield to pedestrians is one of primary measures of efficiency at unsignalised crosswalks. The motorist yield rate is calculated as the ratio of the number of vehicles that have stopped or decelerated before the crosswalk to the total number of vehicles that could have stopped or decelerated in order to let pedestrians walk across the road [11]. This parameter is usually expressed in values ranging from 0 to 1 but, in literature, especially in the territory of the USA, this parameter is given as a percentage ranging from 1 to 100 %. Based on technical research studies, HCM 2010 provides motorist yield rate recommendations, so that the value of 0 should be given for unmarked crosswalks, while it should be 0.5 for clearly marked crosswalks. However, the experience with the recommended values of other traffic flow parameters in procedures used for LOS determination have shown that local measurements can have a significant influence on their values and that it is necessary to use, whenever possible, motorist yield rate information precisely determined at the location under study. In cases when the motorist yield rate can not be measured, it can be calculated through mathematical modelling, taking into account characteristics of the location and vehicular and pedestrian flow data. The influences and specificities of local environment and traffic flow characteristics can thus be evaluated, which had not been done before, and which contributes to a more precise LOS determination at crosswalks [12].

Studies focusing on vehicle traffic flow characteristics were first made in the 1940s, but it is only after the year of 1950 that the scientific discipline dealing with these issues witnessed significant development. Since then, various research studies have been conducted within the area of traffic flow theory, inter alia the research related to relevant indicators on traffic flow and its characteristics. The basic traffic flow element is the vehicle. Starting from the fact that vehicle movement in the

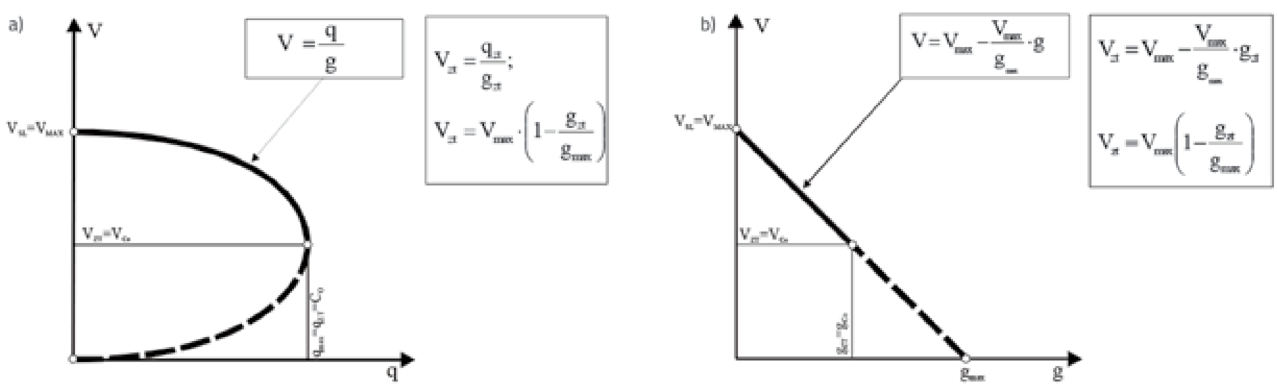

Figure 5. Diagrams showing correlation of traffic flow parameters in theoretically ideal conditions: a) speed-volume; b) speed-density [13]

conditions of free traffic flow can significantly be identified with the conditions for the movement of an individual vehicle in the flow, it represents a starting point in the description of general conditions of driving traffic flow characteristics [13]. The way of vehicle movement on the road mostly depends on road characteristics, characteristics of the "driver-vehicle" system, and general environmental characteristics. Basic parameters have been defined for describing traffic flow characteristics and rules of vehicle movement within it.

In the traffic flow theory, these parameters are defined as volume (q), flow density (g) and flow speed (v). The fundamental relationship between these three parameters of traffic flow (flow-speed-density relationship) was established by Bruce Greenshields in the 1940s [14], where the flow volume is equal to the product of density and traffic flow speed. In this research, the main emphasis is placed on the traffic flow speed as the qualitative indicator of traffic flow conditions in urban streets [15]. Functional interdependence between velocity, flow, and density of vehicles in abstractly imagined theoretically ideal conditions is shown in Figure 5.

3. Methodology and research location

Various methods and technologies can be used, which depends on the needs for determining certain traffic flow parameters. They range from simple ones that are applied for collecting data about a single relevant parameter of an individual participant over a certain time period, to system devices that are used for collecting a large number of traffic flow parameters throughout a year. The technology of video detection in combination with software packages for digital picture processing has proved to be a very reliable way for vehicle or pedestrian detection in traffic flows [13]. The method of processing video recordings for the collection of traffic flow data was first applied during the 1930s and, with the development of technology, it is nowadays possible to determine necessary parameters with high precision and accuracy [16-18]. In the scope of data collection, it is first of all necessary to define a fixed position of the video recording camera so that the recording properly covers the area significant for the research. Apart from this, the camera has to be set in a way that it is not noticeable to traffic participants so that their usual behaviour is not influenced [16]. Furthermore, using the Kinovea software package tools, referential points situated at a known distance are added on the display of the video recording, and then referential lines are drawn from these points. Kinovea software has the frame-step video processing option, and video recording can be slowed down and stopped with the tolerance of 0.04 seconds, which provides for a high level of accuracy. In the following step, video recording is reviewed and time of passage of each vehicle or pedestrian over individual referential lines is noted, as well as their direction of movement, and in that way an appropriate database is formed, with the description of the events relevant for the predefined type of analysis.

Figure 6. Referential lines at crosswalk positioned using the Kinovea software

Figure 7. Referential lines in a traffic lane positioned using the Kinovea software

Parameters such as velocity of an individual vehicle or pedestrian, time a pedestrian needs to walk across the crosswalk, time distributions of flow, and other necessary data, are determined based on data sets formed by mathematical - statistical analysis. The research was conducted by recording traffic conditions on two occasions:

- Before rehabilitation of the crosswalk, in February 2015
- After rehabilitation of the crosswalk, in October 2017.

During traffic flow recording before and after rehabilitation, weather conditions were approximately the same, without precipitation, and with temperature ranging from 15 °C to 20 °C, which is favourable for pedestrian and motor traffic. Video recordings used for the analysis were made using the digital camera Nikon Coolpix L320 (16.1 MP). The recordings were processed by means of the Kinovea software package. The mathematical-statistical processing was carried out using two software packages: MS Excel and Minitab.

3.1. Characteristics of analysed location

The analysed crosswalk is situated at Dr. Sime Miloševića Street in the campus of the University of Novi Sad. This road section has a local distributor function in the urban area. There were no significant changes in traffic demand along this street between 2015 and 2017. The traffic volume at peak hour ranges from 250 to 300 veh/h, and the AADT amounts to approximately 3000 vehicles/day. The crosswalk is so positioned that it represents a major connection between two parts of the campus (dormitories on the one side, and faculty buildings on the other side), and is hence characterized by intensive pedestrian flows. On the other hand, this crosswalk is on the main roadway leading to the campus, where the traffic is mainly composed of passenger cars and public transport vehicles. Before the rehabilitation, this roadway consisted of two traffic lanes each 3.0 m in width, designated for two-way traffic, and the crosswalk width was 3.0 m. The crosswalk markings were in the "zebra" form with 0.5 m full and empty raster fields, and with appropriate informative traffic signs. On both sides of the pavement there used to be access ramps for the disabled, as well as an adequate space for pedestrians waiting to cross the road (Figure 8).

Figure 8. Crosswalk before rehabilitation

Figure 9. Crosswalk after rehabilitation

After the rehabilitation, the pavement width remained the same, and the crosswalk was raised to form a trapezium shaped platform the surface of which was paved with concrete paving-stone elements (behaton), 5.3 m in total width, where the useful raised surface is 2.9 m and the width of transition slopes on both sides is 1.2 m. The raised pedestrian crossing is 7,0 cm in height. Informative traffic signs for the crosswalk were kept on both sides of the pavement. The access to the crosswalk, as well as the waiting space, was adapted to the new appearance of the crossing (Figure 9).

4. Research results and discussion

Statistical analysis of vehicle velocity in the zone of the analysed crosswalk was conducted based on the data obtained in the scope of this research, before and after the rehabilitation. The aim of the analysis was to show if there is a difference in vehicle velocity and, if so, what is the extent of this difference. In order to eliminate the influence of pedestrians on the velocity of vehicles, only vehicle velocities near the crosswalk were considered in the situation when the crosswalk was not used by pedestrians, that is, when no pedestrians were waiting to cross the road. The observed samples have the following characteristics:

Table 1. Vehicle velocity measurement results

Variable	N	Mean	SEMean	StDev	Var	Min	Q1	Median	Q3	Max
Vv_no ped (BR)	72	8.20	0.31	2.71	7.34	2.52	6.34	7.97	9.84	17.80
Vv_no ped (AR)	83	4.57	0.25	2.35	5.53	1.16	2.93	3.83	5.49	14.00

Variable abbreviations:
Vv_no ped (BR) – vehicle speed before rehabilitation without pedestrian influence (m/s);
Vv_no ped (AR) – vehicle speed after rehabilitation without pedestrian influence (m/s)
Description of abbreviations used for statistic parameters:
N – Total number of observations; **Mean** – Sum of all the observations divided by the number of observations (arithmetic average); **SEMean** – Standard error of the mean; **StDev** - Standard deviation of data; **Var** – Variance, a measure of data dispersion; **Min** – Lowest value in the observed data set; **Q1** - First quartile of the observed data set, 25% of the data are lower than or equal to this value; Median - Middle of the data range, 50% of the data are lower than or equal to this value; **Q2** - Third quartile of the observed data set, 75% of the data are lower than or equal to this value; **Max** – Highest value in the observed data set.

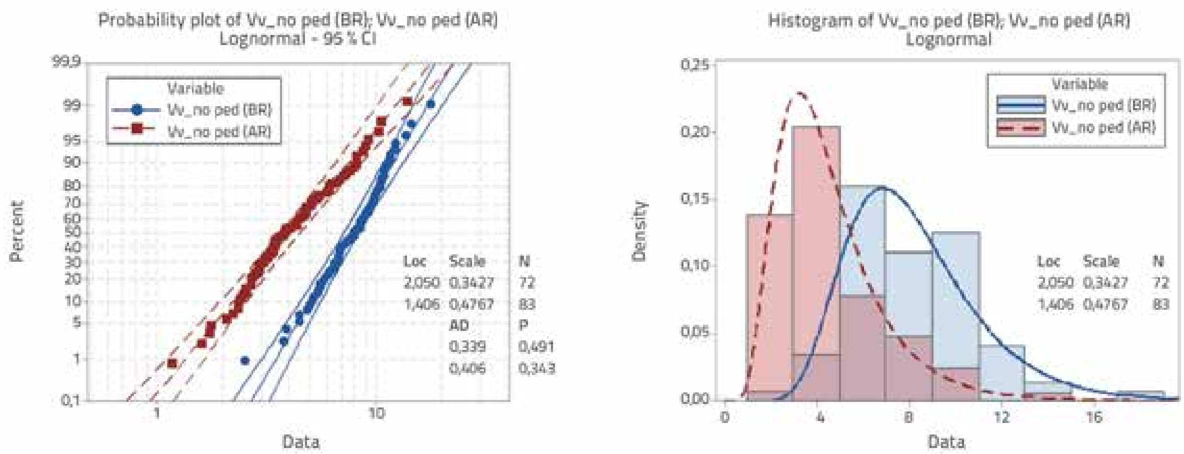

Figure 10. Probability plot and histogram of Vv_no ped (BR) vs. Vv_no ped (AR)

It was determined through analysis of measured vehicle velocities that the velocity samples collected before and after the crosswalk rehabilitation mostly exhibit characteristics of lognormal distribution, i.e. P-value for Vv_no ped (BR) is 0.491, and P-value for Vv_no ped (AR) is 0.343. The correspondence of data with a particular distribution was analysed according to the Anderson-Darling statistics with the significance level of α = 0.05. The hypotheses for the Anderson-Darling test are: H_0: the data follow a specified distribution, and H_1: the data do not follow a specified distribution. If the p-value is lower than the chosen significance level α, it can be concluded that the null hypothesis (H_0) can be rejected and that the data do not follow the specified distribution [19]. The following figure shows characteristic diagrams that describe the sample of vehicle velocities before and after rehabilitation of the crosswalk. Considering the fact that the observed samples behave according to the patterns of lognormal distribution, non-parametric tests have been applied for the needs of the analysis.

The comparison of vehicle speed before and after the rehabilitation was done by the Mann-Whitney non-parametric hypothesis test, which determines whether two populations have the same population median, and the importance threshold of α = 0.05 was defined in this analysis [19]. The null hypothesis of this test is that in this case there have not been any changes in vehicle velocity before and after the rehabilitation. As an alternative hypothesis, it was determined that vehicle velocity before the crosswalk rehabilitation is higher compared to the vehicle movement speed after the rehabilitation.

On the basis of the test results, the null hypothesis that there is no difference in velocities, that is, that the velocity median value before the rehabilitation and the velocity mean value after the rehabilitation of the observed crosswalk are equal, can be rejected. The determined difference between the velocity medians in two observed cases is 13.2 km/h (3.679 m/s) with the 95 % confidence interval ranging between 10.4 km/h (2,926 m/s) and 15.8 km/h (4.425 m/s).

For the purposes of additional analysis, the collected data were processed by means of the non-parametric Kruskal-Wallis test, which is a nonparametric alternative to the one-way analysis of variance [19]. In the case of this test, the null hypothesis is the statement that the changed crosswalk (Factor 2) does not affect the change in vehicle velocity. The z-value for Vv_no ped (AR) is -7.71 and it indicates that the mean rank for this parameter is lower than the mean rank for all observations. The mean rank for Vv_no ped (BR) is higher than the mean rank for all observations, as the z-value is positive (z = 7.71). On the basis of the obtained p-value, which is equal to zero or is negligibly small, the null hypothesis can be rejected.

Table 2. Results of Mann-Whitney test

Mann-Whitney Test i CI: Vv_no ped (BR); Vv_no ped (AR)			
Variable	**N**	**Median (η)**	**Point estimate za η1 - η2**
Vv_no ped (AR)	83	η1 = 3.836	3.679
Vv_no ped (BR)	72	η2 = 7.975	**95 % CI for η1 - η2**
Overall	155		(2.926;4.425)
Test of η1 = η2 vs η1 < η2 is significant at 0.0000			

Variable abbreviations:
Vv_no ped (BR) – vehicle speed before rehabilitation without pedestrian influence (m/s);
Vv_no ped (AR) – vehicle speed after rehabilitation without pedestrian influence (m/s)
Statistic parameters abbreviations:
N – Total number of observations;
Median (η) - The middle of the range of data, 50 % of the data are lower than or equal to this value; 95 % CI – 95 % confidence interval

Table 3. Results of Kruskal-Wallis test

Kruskal-Wallis Test na Vv_no ped (AR) vs. Vv_no ped (BR)				
Faktor_2	**N**	**Median**	**Ave Rank**	**Z**
Vv_no ped (AR)	83	3.836	52.1	-7.71
Vv_no ped (BR)	72	7.975	107.9	7.71
Ukupno	155		78.0	
H = 59.50	DF = 1	P = 0.000	(adjusted for ties)	
H = 59.50	DF = 1	P = 0.000		

Variable abbreviations:
Vv_no ped (BR) – vehicle speed before rehabilitation without pedestrian influence (m/s);
Vv_no ped (AR) – vehicle speed after rehabilitation without pedestrian influence (m/s)
Statistic parameters abbreviations:
N – Total number of observations; **Median** - The middle of the range of data, 50 % of the data are lower than or equal to this value; **Ave Rank** – Mean rank for observations; **Z** – Measure of the difference between an observed statistic and its hypothesized population parameter in units of its standard error; **H** - Test statistic; **DF** – Degrees of freedom; **P** – value, probability of obtaining a test statistic

The median of vehicle velocities obtained on pedestrian crossing after rehabilitation (raised pedestrian crossing) is 13.8 km/h (3.836 m/s). The following figure shows median speed on the raised pedestrian crossing obtained in this research as compared to research results obtained during some international studies [20, 21]. On the basis of the available references, it can be said that the speed obtained at the analysed pedestrian crossing is more than 50 % lower than the speed measured in other cities. Generally, a difference in speed can occur as a result of geometric design of a raised pedestrian crossing (e.g. height of speed table – h), but it can also be due to many other factors (e.g. pedestrian volume).

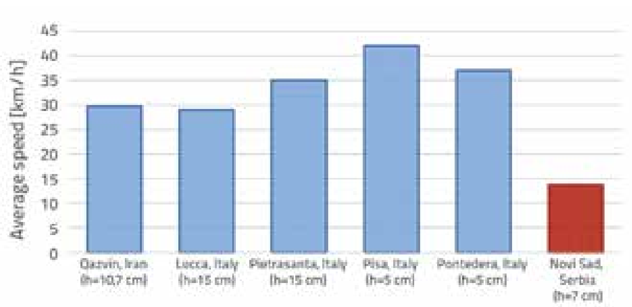

Figure 11. Comparative view of vehicle speed on raised pedestrian crossings

The importance of this construction measure can not be adequately described by taking into account speed reduction based on absolute value only. Velocity values analysed from the aspect of the length of stopping sight distance enable a clearer description of the importance of speed reduction achieved by this rehabilitation. Characteristic vehicle-velocity values are presented in the following graph in relation to the length of stopping sight distance during normal braking (assumed deceleration = 2.0 m/s²) and forced braking (assumed deceleration = 5.0 m/s²). Based on the median values, it was determined that with forced braking the length of the stopping sight distance is reduced by 9.3 m, that is by 16.4 m with normal braking, which represents a significant difference, when considered from the aspect of safe vehicle stopping in conflict situations.

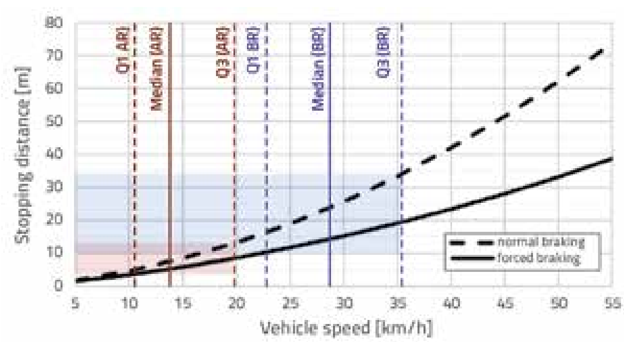

Figure 12. Typical vehicle-velocity values as related to stopping sight distance

In order to determine the influence of raised crosswalk construction on pedestrian traffic conditions, speed of movement

Table 4. Pedestrian speed measurement results

Variable	N	Mean	SEMean	StDev	Var	Min	Q1	Median	Q3	Max
Vp (BR)	247	1.233	0.013	0.217	0.047	0.58	1.09	1.22	1.36	1.88
Vp (AR)	182	1.244	0.017	0.236	0.056	0.80	1.08	1.24	1.41	2.02

Variable abbreviations:
Vp(BR) – pedestrian speed before rehabilitation (m/s); **Vp(AR)** – pedestrian speed after rehabilitation (m/s)
Descriptive statistic parameters abbreviations:
N – Total number of observations; **Mean** – Sum of all observations divided by the number of observations (arithmetic average); **SEMean** – Standard error of the mean; **StDev** - Standard deviation of data; **Var** – Variance, a measure of data dispersion; **Min** – Lowest value in the observed data set; **Q1** - First quartile of the observed data set, 25 % of the data are lower than or equal to this value; **Median** - Middle of the range of data, 50 % of the data are lower than or equal to this value; **Q2** - Third quartile of the observed data set, 75 % of the data are lower than or equal to this value; **Max** – Highest value in the observed data set

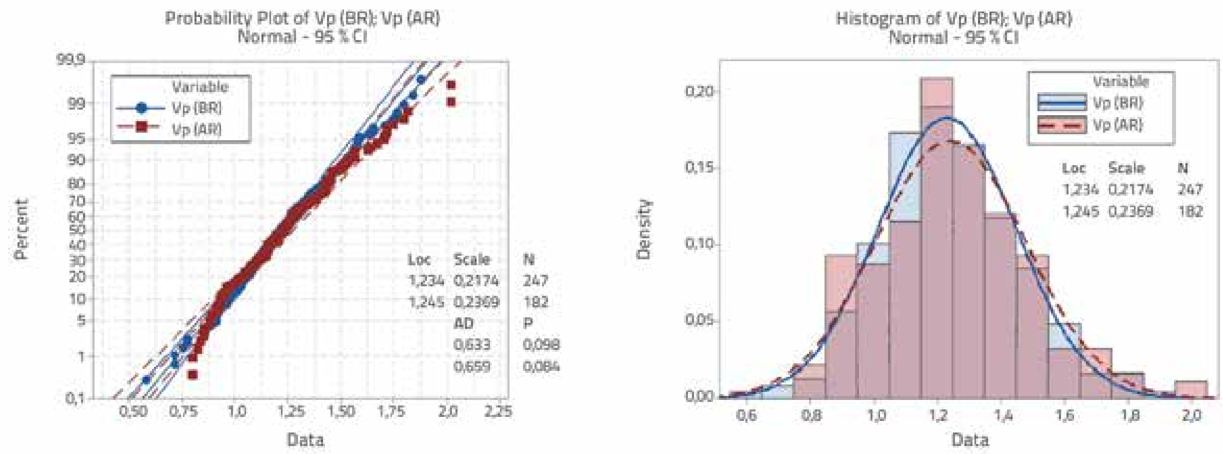

Figure 13. Probability Plot and Histogram of Vp (BR) vs. Vp (AR)

of pedestrians when crossing the road was measured, and the motorist yield rate was calculated. The samples of velocities of pedestrians crossing the road, collected before and after the rehabilitation, have the following characteristics:

According to statistical analysis (Anderson-Darling test with the significance level of α = 0.05), the assumption that pedestrian velocities have the characteristics of normal distribution (P-value for Vp(BR) is 0.098, and P-value for Vp(AR) is 0.084) cannot be rejected, which is clearly noticeable in the following graphs which describe characteristics of pedestrian velocity at the observed crosswalk before and after rehabilitation. Based on the graph shown in Figure 13, it can be assumed that there are no significant differences in pedestrian velocities before and after rehabilitation. In order to confirm this assumption, the ANOVA test was used with null hypothesis that there were no changes in pedestrian speed before and after rehabilitation.

The ANOVA (analysis of variance) test can be used to determine whether the mean values of two or more groups differ. This

Table 5. Results of ANOVA test for measured pedestrian velocities

Null hypothesis			All means are equal		
Alternative hypothesis			At least one mean is different		
Significance level			α = 0.05		
Equal variances were assumed for the analysis.					
Factor Information					
Factor	**Levels**	**Values**			
Factor	2	Vp (BR); Vp (AR)			
Analysis of variance					
Izvor	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Factor	1	0.0128	0.01278	0.25	0.617
Greška	427	21.7842	0.05102		
Ukupno	428	21.7970			
Means					
Factors	**N**	**Mean**	**StDev**	**95 % CI**	
Vp (BR)	247	1.2338	0.2174	(1.2056; 1.2621)	
Vp (AR)	182	1.2449	0.2369	(1.2120; 1.2778)	
Pooled StDev = 0.22586					

Factor abbreviations:
Vp(BR) – pedestrian speed before rehabilitation (m/s); **Vp(AR)** – pedestrian speed after rehabilitation (m/s)
Anova parameters abbreviations:
DF - degrees of freedom from each source DF=n-1; **Adj SS** – adjusted sum of squares between groups (factor) and the sum of squares within groups (error); **Adj MS** – adjusted sum of squares between groups (factor) and the sum of squares within groups (error); **F-value** – statistic parameter of F-distribution, calculated by dividing the factor Adj MS by the error Adj MS; **P-Value** – probability of obtaining a test statistic; **N** – total number of observations; **Mean** – sum of all observations divided by the number of observations (arithmetic average); **StDev** - standard deviation of data; 95 % CI – 95 % confidence interval.

Table 6. Values of motorist yield rate and pedestrian delays before and after rehabilitation

	Before rehabilitation	After rehabilitation
Motorist yield rate	0.66	0.82
Pedestrian delays (s)	7	5
Pedestrian LOS	**B**	**A**

test can be performed on data which follow normal distribution. One way of using ANOVA is to compare two means from two independent (unrelated) groups using the F-distribution. The null hypothesis for the test is that the two means are equal, and this hypothesis can be rejected if p-value of test is lower than the defined significant level α [19]. On the basis of the determined p-value = 0.617 which is bigger than the defined importance threshold α = 0.05, the null hypothesis that there is no speed difference cannot be rejected. On the basis of this test, it can be said that, from the aspect of pedestrian movement velocity, the conditions remained unchanged.

The quality of pedestrian traffic is primarily defined on the basis of pedestrian delays when waiting to cross the pavement. Average pedestrian delays, and the motorist yield rates, were determined in this research for the situation before and after the rehabilitation. The values of the achieved delay were determined by calculation, based on the known methodology [10], while the value of the motorist yield rate was obtained by measuring concrete samples. The values of these two parameters in the situation before and after the crosswalk rehabilitation are shown in the following table.

As can be seen in Table 7, the motorist yield rate has slightly improved, and after the rehabilitation it is 0.82, which means that almost 82 % of drivers decelerate or stop their vehicle in order to give right of way to pedestrians when crossing the road. As to reduced pedestrian delays, they were described before the rehabilitation by the level of service B while, after the rehabilitation, this parameter was described by the highest level of service A.

5. Conclusion

Although the pedestrian flow priority in relation to vehicular flows has been defined through general traffic rules, it is often necessary to conduct various structural interventions in order to make everyone obey the defined movement regime. One of these interventions at the point where pedestrian and vehicular flows intersect is the vertical shift of pavement aimed at bringing the crosswalk onto the platform, which functions as a traffic calming device and highlights more clearly the place where road is crossed by pedestrians. The effects of structural measures were determined by analysing traffic conditions and behaviour of pedestrians and drivers at a unsignalised mid-block crosswalk in the campus of the University of Novi Sad, and the extent of difference in qualitative traffic indicators was determined.

Comparison of qualitative traffic-flow indicators at the crosswalk before and after its rehabilitation has revealed that the mean value of vehicle velocity was reduced by approximately 50 % after the rehabilitation. From the traffic safety aspect, this reduction within the range of the observed velocities, is equivalent to the reduction of stopping sight distance by 16.4 m at normal braking, i.e. 9.3 m at forced braking. As far as the average pedestrian speed is concerned, the analysis has shown that this parameter has remained unchanged. Following analysis of parameters which reflect pedestrian traffic, it was concluded that construction of a raised pedestrian crosswalk at this spot had a positive effect on the pedestrian traffic conditions. This improvement is reflected in the reduction of pedestrian delays, and in an increase in the level of service offered to pedestrians.

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