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15. međunarodna naučna konferencija

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iNDiS

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iNDiS 2021

Departman za građevinarstvo i geodeziju, Fakulteta tehničkih nauka u Novom Sadu, organizuje petnaestu međunarodnu naučnu konferenciju „iNDiS 2021“. Ove godine, konferencija se održava na pedesetogodišnjicu osnivanja Departmana, što je čini posebno važnom.

Prvi skup održan 1976. godine bio je na temu „Industrijska izgradnja stanova“ zbog njene aktuelnosti u tom periodu. Kasnije su održavane konferencije sa nešto širom tematikom „Industrijalizacija građevinarstva“, da bi se ubrzo na skupu pojavili radovi iz svih oblasti graditeljstva, od urbanističkog planiranja i projektovanja objekata različitih namena, do održavanja i većih intervencija na izgrađenom graditeljskom fondu. To je uslovilo i proširivanje oblasti koje obuhvata ovaj skup na kome, pored građevinskih inženjera, učestvuju urbanisti, arhitekte, inženjeri drugih struka koji rade u graditeljstvu, sociolozi, ekonomisti i drugi.

Ova konferencija, kao i nekoliko prethodnih, obuhvata probleme planiranja, projektovanja, građenja i obnove graditeljstva, geodezije, upravljanja rizicima od katastrofalnih događaja i zaštite od požara, što je naišlo na adekvatan odziv istraživača i inženjera različitih profila iz naše zemlje i inostranstva.

Članovi međunarodnog naučnog komiteta aktivno su učestvovali u pripremi konferencije, i kao recenzenti i kao autori. Očekuje se da će prezentacije radova i diskusije na konferenciji omogućiti definisanje glavnih pravaca razvoja graditeljstva u skladu sa savremenim trendovima, budući da je promovisano mnoštvo ideja i rezultata eksperimentalnih i teorijskih istraživanja u oblastima graditeljstva i zaštite životne sredine.

Za ovu konferenciju, Zbornik radova sadrži radove na engleskom i srpskom jeziku, što omogućuje bolju i plodniju komunikaciju i razmenu iskustava sa kolegama iz inostranstva. Dodatno, od značaja je i mogućnost sklapanja novih i jačanja postojećih profesionalnih i kolegijalnih veza. Ove godine na konferenciji učestvuju autori iz 16 zemalja, a Zbornik sadrži 116 radova.

Urednici svim autorima radova upućuju iskrenu zahvalnost na trudu uloženom u pisanje radova i doprinosu ovom događaju.

Urednici

Department of Civil Engineering and Geodesy, Faculty of Technical Sciences in Novi Sad, organizes the 15th International Scientific Conference "iNDiS 2021". This year, the conference is being held on the fiftieth anniversary of the Department founding, which makes it especially important.

The first conference took place in 1976, with its main topic "Industrial construction of apartments" due to its actuality in that period. In the following years, conferences were held with a somewhat broader topic "Industrialization of Civil Engineering", and soon papers from all areas of construction appeared, from urban planning and design of structures of various purposes, to maintenance and major interventions on the built construction fund. This led to an expansion of the conference topics, where urban planners, architects, engineers from other fields working in construction, sociologists, economists and others are participating alongside civil engineers.

This conference, as well as several previous ones, covers the problems of planning, design, construction and building renewal, geodesy, disaster risk management and fire safety, which resulted in an adequate response of researchers and engineers of various profiles from our country and from abroad.

Members of the International Scientific Committee actively participated in the preparation of the conference, both as reviewers and authors. It is expected that the presentations of papers and discussions at the conference will help in defining the main directions of construction development, which will be in line with contemporary trends since many ideas and results of experimental and theoretical research in the fields of construction and environmental protection were promoted.

For this conference, the Proceedings contain papers written in English and Serbian, which enables better and more fruitful communication and exchange of experiences with colleagues from abroad. Additionally, it provides a great opportunity for making new and strengthening existing professional and collegial relationships. This year the authors from 16 countries participate in the conference, and the Proceedings contain 116 papers.

Urednici The editors are sincerely grateful to all the authors for the effort invested in writing papers and for the contribution to this event.

Editors

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THE ANALISYS OF IMPACT OF THE SIDEWALK OBSTRUCTIONS ON PEDESTRIAN WALKING SPEED AND WALKING BEHAVIOR

Abstract: Walking is the most common form of transportation. The worldwide trend is to promote walking as a way toward the more sustainable urban environment. Besides many factors influencing sustainable development, the mobility issue is the very present topic. This paper considers pedestrian facility characteristics, of which the sidewalk width is the important parameter. The aim of this paper is to compare the pedestrian free flow walking speeds influenced by different sidewalk width caused by temporary or permanent obstructions. The research was carried out in the city of Novi Pazar, Serbia, by using the method of continuous video recording of the selected area. The data were extracted by graphical and video analysis software Kinovea v.0.8.15 .The processing of data was done by statistical software package IMB SPSS v25. The results showed that differences between the speeds of the pedestrians under the influence of different sidewalk characteristics does exists. The differences in speed are at very low level, however, the pedestrian behavior at the observed area due to the change in sidewalk width have significant differences. The results of this paper implies the necessity to improve the pedestrian facility level of quality by using the appropriate engineering measures.

Key words: Effective width, pedestrians, pedestrian behavior, sidewalk, walking speed

UTICAJ FIZIČKIH PREPREKA NA TROTOARU NA BRZINU KRETANJA I PONAŠANJE PEŠAKA

Rezime: Pešačenje je najčešći vid kretanja. Promocija kretanja i pešačenja kao vid održivog životnog okruženja je svetski trend. Pored mnogih faktora koji utiču na održivi razvoj, pitanje mobilnosti je veoma prisutna tema. Ovaj rad se odnosi na fizičke karakteristike prostora za pešake, od kojih je najznačajnija širina prostora za kretanje. Cilj ovog rada je upoređivanje brzine kretanja pešaka pod uticajem stalnih ili privremenih prepreka, kao i karakteristika ponašanja pešaka u slobodnom toku. Istraživanje je sprovedeno na teritoriji grada Novog Pazara, Srbija, koristeći metod kontinualnog video snimanja oglednog poligona. Podaci su prikupljeni putem video analize materijala, upotrebom Kinovea v.0.8.15. softvera. Obrada podataka je sprovedena upotrebom statističkog softvera IMB SPSS v25. Rezultati analize su pokazali razlike u brzini kretanja poešaka pod uticajem prisustva različitih vrsta prepreka. Razlike u brzinama kretanja pešaka su na malim ali statistički značajnim nivoima, međutim, ponašanje pešaka na posmatranom poligonu ima značajne razlike. Osnovni rezultat ovog rada ukazuje na potrebu da se konstantno unapređuje nivo kvaliteta prostora zapešake, primenom odgovarajućih inžinjerskih mera koje se odnose na posmatrane parametre.

Ključne reči: Širina trotoara, pešaci, ponašanje pešaka, trotoar, brzina kretanja

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1. INTRODUCTION

The sustainability of worldwide cities is a most common phrase in architects and urban planners science community. This paper is focused on the mobility issues in cities. The most common form of people's mobility is walking, because, after the any other mean of transport it is used as the basic way to satisfy their needs. Promoting walking as a main strategy for urban development is crucial for increasing quality of life in cities, if there are enough conditions to compete with other transportation choices [1]. In medium size cities, in the Republic of Serbia, walking is the most common form of transport (approximately 88%) [2]. According to the official [2] statistical indicators of the traffic safety, almost one quarter (24%) of casualties are the pedestrians, as a vulnerable group of traffic participants. It is necessary to improve the terms for pedestrians in urban areas by improving the parameters of facilities towards quality usage. Although it is a single parameter amongst many others, the sidewalk width is very important for the analysis. It belongs to the category of pedestrian convenience and the basic assumption is that it has an impact on the pedestrian behavior in the network, as it influences the pedestrian route choice and compliance with traffic rules.

The aim of this paper is to determine the level of service of the sidewalk facility, based on travel time and speed of pedestrians, under the heterogeneous traffic conditions and at specific geometrical characteristics of a sidewalk caused by temporary or permanent obstacles. Because of the oscillation of the pedestrian density and flow rate at the facility and different peak points over the day, the pedestrian behavior, travel time and speed at free flow may vary over time.

The vehicle lane facility concept is usually defined by the traffic demand, using the traffic flow theory parameters [3] but this concept should not be used for pedestrian lane facility analysis, because the pedestrians do not walk in organized lanes as vehicles [4]. However, the sidewalk width is usually defined by the possibility to permit the two pedestrians to pass each other conveniently. According to several recommendations, the sidewalk width is determined by pedestrian space requirements (body ellipse – 0.6 m^1 x 0.5 m^1; walking space requirements), and it should have at least 0.8 m^1 of width for each passing pedestrian [4], the minimum of 0.75 m^1 of width per pedestrian [3] or 1.0 m^1 of width for each walking pedestrian [5]. In reality, the sidewalk width differs from case to case, and its common form is following the urban morphology. Considering the sidewalk width from various aspects, there are several researches dealing with this parameter. Landis et al. [6] quantified the pedestrian perception of safety and comfort using sectional design of the sidewalk, and examined the influence of its width and lateral separation from traffic on users. Moura et al. [7] found that minimal sidewalk width (cut-off value = 1.2m^1) must be in correspondence with critical group needs (impaired mobility users, persons with children, parents with baby strollers, etc.) Regarding the process of estimation of pedestrian facilities quality, Mozer [8], Galin [9], Muraleetharan et al. [10] states that the width of a sidewalk is very important parameter, along with many others, whose value lies between 0.8 m^1 up to 4.5 m^1 and more.

Travel path for pedestrians is described as a length of a corridor and it is a constant value in any analysis of pedestrian network. However, the travel time is the parameter which varies according to network conditions. Travel time could be measured at any time, and we can use those values for extracting pedestrian walking speed for any observed segment of pedestrian network. The walking speed of the pedestrians is very important parameter for planning and for the design of traffic network conditions (signal timing, crossing time, etc.). In general, the available studies regarding pedestrian walking speed included experiments on macroscopic, microscopic or mesoscopic level. In controlled terms or field observations, those studies has found that the pedestrian speed depends on several factors. Gates [10] found that the pedestrian characteristics such as age, gender, group size and design of infrastructure influences the walking speed. Pinna [12], Trpković [13], and Webb [14] explored the difference between the gender groups and the age groups (independently) and found that there is a significant difference in walking speed between younger and older pedestrians, but slightly difference between male or female pedestrians in correspondence with the each age group.

Jiten [15], Chandra [16], Chattaraj [17], Onelcin [18], Marisamynathan [19] examined the pedestrian walking speed and general behavior influenced by facility geometry and design, and found that it has the impact on pedestrian walking speed and travel time. By reviewing the literature considering pedestrian speed in the network, there is an opinion [20] that the most superior tool for evaluating the level of service at this level (considering basic traffic flow parameter such is speed) is the TRB's Highway Capacity Manual, as it is the basis for many other tools developed over time. The scale for determining the level of service of pedestrian network considering pedestrian speed is very precise, and it could be used for determining the quality of observed network.

So far in the Republic of Serbia there are few [13,21,22] researches covering the pedestrian speed as an important parameter for traffic analysis and planning, considering the age impact, crossing type, facility characteristics, as well as pedestrian behavior at the site. Until now, this type of research which considered the sidewalk width and its influence on walking speed of a pedestrian has never been conducted in Serbia, so this paper represents an attempt to contribute to the exploring of this problem in local terms.

The main objective of this paper is to determine the actual impact of a sidewalk effective width on a pedestrian walking speed and to examine the pedestrian behavior in the network during the process of analysis. Also, the level of compliance to traffic rules in terms of the perceived safety will be considered.

2. MATHERIALS AND METHODS

Speaking of local terms, the polygon for this research was set to the city of Novi Pazar (43°08'12.01" N 20°30'43.99" E) because of its specific configuration of urban matrix. The specificity is reflected in the morphology of the terrain and the inherited urban pattern of urban development from the Otoman period. The general characteristic of cities in the mountainous regions of Serbia is the low spatial distribution and high population density. Most cities in southwestern Serbia are located in the valleys, with unregulated or modified urban matrix relative to the inherited condition. Such cities are the Novi Pazar, Užice, Sjenica, Ivanjica and several others. General spatial characteristics of those cities are narrow streets (mostly one-way), with very small percent of infrastructure for vulnerable groups of users.

Relying on the field observation, we have determined that the main street in the city of Novi Pazar have the best physical characteristics compared to other streets in the city. The street profile is consisted from two traffic lanes (two-way street), each $4.1m^1$ wide and sidewalks at the both side of the street, with variable width. The widest segment of the sidewalk is $8.3m^1$, while the narrowest segment is $1.05m^1$ wide. The street is 1.17km long. Due to the mixed-use character of the city center, this street represents the best route for daily needs of the citizens, regardless of type of transportation.

Data collection for this research was divided in two parts. The first part involved collecting general traffic data on this street, because, this urban artery is the most affected by traffic. For the first part, the data collection was carried out using the method of manual counting of traffic on: 11th of April 2016, 29th of January 2018 and 11th of September 2018. Data sorting showed that the highest peaks of traffic flow are in the period from 11 hours to 14 hours during the day, and from 20 hours to 22 hours in the evening. For the second part of this research we have decided to set the on-site experiment. The experiment was consisted from two phases. The first phase is the real time video recording for one full hour during the day. The main purpose of this recording was to observe variations in pedestrian speed due to the impact of sidewalk effective width in selected segment of the street without any interventions to the sidewalk. The recording was set to the period of time when at the sidewalk were an average number of pedestrians and vehicles, i.e. from 13:00 hours up to the 14:00 hours. This part of the experiment was done at 5th of April 2019, at the good weather day, without street greenery, with the average values of the traffic flow. All of the recordings were done by using the rented helicopter drone – model DJI Drone 4 RTK, 20.0Mpix. The selected sidewalk segment was captured with high definition camera with 1080p of resolution. The limitations of this camera caused the selection of one short segment of the main street.

After several test recordings, the altitude for the drone was set to 105m^1 from the ground, with the cone angle of 110°. By using those settings the camera was able to record the total length of the selected street segment of 310m^1. Because of the variations in sidewalk width, the analyzed area was divided to three sub-segments (Fig. 1), each 2.65m^1 wide (seg. A), 2.05m^1 wide (seg. B) and 3.15m^1 wide (seg. C), respectively, in order to compare collected data according to the given width. General characteristics of the observed segment are: irregular curb-parking along the corridor (which is narrowing the effective sidewalk width), presence of obstacles, high pedestrian flow rate, bi-directional uninterrupted flow of the sidewalk.

The second phase of the experiment refers to the recordings of the selected segment of the street, but this time with an intervention to the sidewalk. The intervention relates to the setting of the traffic cones along the entire recorded sidewalk in order to prevent the irregular curb-parking. The purpose of this action was the observation of variations in pedestrian speed due to the impact of sidewalk effective width relieved form the presence of obstacles which could be removed. The recording was set to the same period of time next day, i.e. 13:00 – 14:00 at the 6th of April 2019.

In each part of the experiment, in order to validate the participant results, it was necessary for the pedestrian to enter the recorded segment at the beginning by stepping on the curb and to step off the curb at the end of it. If there were violators, i.e. pedestrians who stepped off the course (did not complete the designated route), they were noted, but excluded from the analysis. There were no instructions for the pedestrians who were at the segment at each stage of the experiment, in order not to influence their behavior. The participant groups were consisted from randomly distributed pedestrians.

The data processing after recording of the experimental area was done by using the freeware software Kinovea v.0.8.15 which allows the pedestrian marking (tagging by recognizing selected pixel group). This procedure results with written trajectory of the marked body, along with its speed of movement and total traveled time. The procedure for processing the data was repeated multiple times in order to gather enough valid data. Complete database was formed by using Microsoft Office Excel v.2007 program. Each trajectory of analyzed pedestrian was overlapped over the existing true scale map of the analyzed segment.

The basic methodology of this research is statistical analysis and comparative analysis of graphical display of pedestrian trajectories.

2.1. Statistical analysis

Since the involvement of the multiple factors influencing pedestrian speed brings to a very complex calculation model [12] which is very difficult to interpret, we decided to exclude factors such as age classes, gender, tiredness, walking abilities and physical characteristics of a pedestrian. It this sense, the statistical analysis was conducted over the large random sample of pedestrians, in order to determine the influence of the effective sidewalk width on overall population walking speed.

All the data were processed in the statistical software IBM SPSS v 25. The sample distribution normality was tested by analyzing the histogram, and the Kolmogorov-Smirnov test. The test showed that observed continual variables did not statistically significantly deviates from the normal distribution, so we used the parametric test. For the analysis of significance of difference between the groups, the one-way factor ANOVA was used. The confidence level was set up to 95%, meaning the statistical significance is at 5%. The null hypothesis is rejected if $p \geq 0.05$ and Ha is accepted. If $p \leq 0.05$, Ho is accepted.

3. RESULTS OF THE RESEARCH

The general statistics of the observed population is given in the Table 1.

Table 1 – Observed population sample characteristics

Observed segments	General statistics				Route direction		NCDC*		K-S**
	n	Violators	∑n	Observations	A-B	B-A	Skewness	Kurtosis	p. value
Seg. A Untreated	713	12	694	1388	212	482	-0.023	-0.346	.152
Seg. B Untreated	711	5					0.057	-0.116	.076
Seg. C Untreated	706	2					-0.031	0.016	.200
Seg. A Treated	694	2	694		384	310	-0.022	0.005	.200
Seg. B Treated	694	0					0.179	-0.133	.091
Seg. C Treated	694	0					-0.165	0.120	.191

**Normality Curve Distribution Characteristics; **Kolmogorov-Smirnov test*

The analysis of the results showed that variety in walking speed amongst heterogeneous population does exist. The results are shown in Table 2.

Table 2 – Statistical analysis of the results of compared mean speeds of the pedestrians

Multiple comparisons Dependant variable: Pedestrian speed Tukey – Post-hoc test						
(I) Groups	(J) Groups	Mean difference (I-J)	Std. error	Significance	95% confidence Lower bound	95% confidence Upper bound
Segment A untreated	Segment B untreated	.04833*	.01132	.000	.0161	.0806
	Segment C untreated	-.01078	.01132	.933	-.0431	.0215
	Segment A treated	-.05829*	.01132	.000	-.0906	-.0260
	Segment B treated	.02195	.01132	.379	-.0103	.0542
	Segment C treated	-.00870	.01132	.973	-.0410	.0236
Segment B untreated	Segment A untreated	-.04833*	.01132	.000	-.0806	-.0161
	Segment C untreated	-.05911*	.01132	.000	-.0914	-.0268
	Segment A treated	-.10661*	.01132	.000	-.1389	-.0743
	Segment B treated	-.02638	.01132	.182	-.0587	.0059
	Segment C treated	-.05703*	.01132	.000	-.0893	-.0248
Segment C untreated	Segment A untreated	.01078	.01132	.933	-.0215	.0431
	Segment B untreated	.05911*	.01132	.000	.0268	.0914
	Segment A treated	-.04751*	.01132	.000	-.0798	-.0152
	Segment B treated	.03272*	.01132	.045	.0004	.0650
	Segment C treated	.00207	.01132	1.000	-.0302	.0343
Segment A treated	Segment A untreated	.05829*	.01132	.000	.0260	.0906
	Segment B untreated	.10661*	.01132	.000	.0743	.1389
	Segment C Untreated	.04751*	.01132	.000	.0152	.0798
	Segment B treated	.08023*	.01132	.000	.0480	.1125
	Segment C treated	.04958*	.01132	.000	.0173	.0819
Segment B treated	Segment A untreated	-.02195	.01132	.379	-.0542	.0103
	Segment B untreated	.02638	.01132	.182	-.0059	.0587
	Segment C Untreated	-.03272*	.01132	.045	-.0650	-.0004
	Segment A treated	-.08023*	.01132	.000	-.1125	-.0480
	Segment C treated	-.03065	.01132	.074	-.0629	.0016
Segment C treated	Segment A untreated	.00870	.01132	.973	-.0236	.0410
	Segment B untreated	.05703*	.01132	.000	.0248	.0893
	Segment C Untreated	-.00207	.01132	1.000	-.0343	.0302
	Segment A treated	-.04958*	.01132	.000	-.0819	-.0173
	Segment B treated	.03065	.01132	.074	-.0016	.0629

Since there are evidences [12,13] that gender and age as a factor does influence the walking speed with minor fluctuations, we can disregard their influence and integrate them into the total balance of velocities of movement of the entire observed population. Table 1 shows the general statistics of the observed population. Taking into account the specificities of the observed segments, in this paper we have considered the speeds of pedestrian movement on the sidewalk, depending on its effective width. By using the one – factor analysis of variances (ANOVA) test we determined that there was statistically significant differences ($F(4.439) = 19.967$; $p < 0.0001$) between pedestrian walking speed as the continuous variable, according to the observed sidewalk width as the categorical variable. Based on the mean values of the pedestrian speed, the Levene's test of homogeneity of variances showed that the assumption of equal variances was not violated (Levene Statistic-1.594; $p>0.05$ (0.158)). The Post-hoc Tukey test was used for determining the differences in mean speeds between each of the observed segment.

Under the heterogeneous traffic conditions, the width of a sidewalk is narrowed, mostly due to the irregular parking on the sidewalk over time. The observation period covered the illegal parking sequences. During the analysis, those parked vehicles were recognized as a fixed obstacles. Only those vehicles which left at the observed segment for the full hour of recording were considered as an obstacle. Along the corridor, we measured the width from parked car to side obstacle on 24 sub-sections on a segment A, 5 sub-sections on a segment B, and 23 sub-sections on a segment C. The average values of the measures thus taken were $0.95m^1$, $0.85m^1$ and $1.05\ m^1$ respectively. According to those values, the results of Tukey Post-hoc test showed that some mean speeds of pedestrians are different at statistically significant level. The untreated segment A (A(u)) mean speed was statistically significantly different ($p<0.001$) from the untreated segment B (B(u)), meaning that pedestrians walked slightly faster on A(u), than at B(u). There was no statistically significant difference ($p>0.05$) between A(u) and the C(u). The untreated case of B(u) was also significantly different from A(u) and C(u) (untreated segment C). By reviewing the mean speed values, we can see that pedestrians at the A(u) and C(u) walked faster than those on B(u). Considering the second case of the experiment settings, i.e. the conditions of the sidewalk treated with measures of disabling irregular parking, we can see that sidewalk width was restored to optimal conditions. After the intervention, the effective sidewalk width of segments was $1.85\ m^1$ (A), $0.85\ m^1$ (B) and $1.50\ m^1$ (C). The mean speed of pedestrians who walked under those conditions was at statistically significantly different level. The mean speed of pedestrians at the treated segment A (A(t)) was statistically different from speed at treated segment B (B(t)) and treated segment C (C(t)), also from A(u), B(u) and C(u). With the increase of the sidewalk width, there is noticeable a difference in speed means. Pedestrians at the A(t) were able to choose higher speed for walking than at previous state of A(u). Pedestrians at B(t) left at the approximate same level of walking ability as those at B(u). The Tukey test showed that there was no statistically significant difference ($p>0.05$) between C(t) and B(t), although there was a significant difference in change of a sidewalk width. However the difference was evident between C(t) and A(t), meaning that pedestrians at A(t) were able to walk faster than those at C(t). Walking speed of the pedestrians at the C(t) is the same as the speed at C(u) ($p>0.05$ – ($p=1.000$)). The most used form of speed analysis in all pedestrian studies is the 15th percentile walking speed [23], because a large number of pedestrians are walking at this breaking point of speed distribution curve. It is analogous to the 85th percentile speed which is used in motor traffic engineering and street design [13,23]. Table 3 shows the general pedestrian traffic flow descriptive statistics of the experiment, considering 15th percentile speed of pedestrians, flow rate of pedestrians as well as spatial characteristics of analyzed segments such as pedestrian space and density. The flow rate was defined by counting the number of pedestrians per minute for a given sidewalk width on the middle of the each segment for the both phases of the experiment. The average values are shown in the Table 3. As previously stated, the most practical tool for evaluating the sidewalk quality in the street network, is the HCM2010's calculation method [4] for the pedestrian walking speed. The last column in the Table 3 shows the grade of the observed segments in accordance with given mean values of the pedestrian walking speed. The score shows that after the intervention, observed sidewalk segments offers a better level of service for pedestrians.

Table 3 – Statistical analysis of the results of compared mean speeds of the pedestrians

Observed segments	**Speed characteristics**			**Width We (m^1)**	**Traffic flow values - average**			**HCM**
	Mean (m^1/s)	**SD**	**15th percentile**		**f ($p/min/m^1$)**	**M (m^2/p)**	**D (p/m^2)**	**LOS**
Seg. A Untreated	1.1834	0.20	0.964	0.95	26	2.85	0.35	D
Seg. B Untreated	1.1351	0.21	0.900	0.85	29	2.38	0.42	E
Seg. C Untreated	1.1942	0.22	0.970	1.05	22	3.22	0.31	D
Seg. A Treated	1.2417	0.20	1.034	1.85	13	5.55	0.18	C
Seg. B Treated	1.1615	0.20	0.940	0.85	31	2.22	0.45	D
Seg. C Treated	1.1921	0.21	0.979	1.50	12	5.88	0.17	D

*We - Effective width of a sidewalk; p – pedestrians; f – pedestrian flow rate; M-pedestrian space; D- pedestrian density; * Highway capacity manual 2010's scale of Level of service for sidewalks according to the speed of pedestrians*

As the width of a sidewalk increases, the possibility for pedestrians to walk faster along the corridor is increasing as well. Furthermore, this can be explained by observing the pedestrian walking routes we were able to capture and to overlap over the real-scale map of the observed segment. According to the analysis of the behavior of pedestrians in the case of the experiment without any intervention, the 23 participants (3.3%) completed the designated route, but they have made the decision to step off the sidewalk to the vehicle lane surface due to the lack of space to pass through. This type of behavior appeared in places where there was not enough width for unimpeded passage, especially on segment A and C. At those segments, the percent of the parked vehicles and the upstream flow was high. This caused the decision to bypass the obstacles and continue moving across the roadway surface, exposing them to the risk of traffic accident. At the segment B there were no obstacles in the form of parked vehicles, so the pedestrians chose to complete their route without stepping off the sidewalk in terms of decreasing their zone of personal comfort. This kind of behavior at each of observed segments could be explained by the relation of the speed and density, which indicates that with increasing the density at the segment caused by narrowing the sidewalk width, the walking speed of the pedestrian decreases due to the lack of space for manoeuvring. In comparison to this case, the result of the observed segment with an intervention shows that the pedestrians rather choose to stay on the sidewalk and to decrease personal zone of comfort than to evade the congested section of a route.

4. DISCUSSION

The results of this research indicates that 15th percentile speed of observed population is between 0.90 m/s – 1.03 m/s, with mean value of 0.965m/s. According to the relevant literature, Chandra et al. [16] pointed out that 15th percentile speed of pedestrians vary from 0.96 m/s - 1.11m/s based on gender factor, as well as the type of the facility. Trpković et al. [13] found that 15th percentile speed of older population range from 0.77 m/s -1.05m/s based on the age factor. Pinna et al. [12] determined the 15th percentile speed from 0.89 to 1.03m/s, relating to the age and gender factors, also the facility type. The commonly used value of the walking speed for the design of the pedestrian facility is 1.2m/s according to HCM [4]. More evidences from the studies on this topic states that US walking speed is at the range from 1.07m/s -1.2 m/s based on the 15th percentile speed [24]. Several studies conducted in India states that walking speed based on the 15th percentile is varying between 0.89 m/s – 1.05m/s [19], based on the type of travel 1.00 m/s – 1.18 m/s [25] and the speed of 1.3m/s in unobstructed corridors [17]. For the other regions, Tanaboriboon and Guyano [26] compared the mean speed among countries, and found that Asian pedestrians have different walking speeds which range from 1.08m/s – 1.31m/s, English pedestrians approximately 1.31m/s and Canadian pedestrians walks at speed of 1.33m/s. The common value for the design and planning the pedestrian infrastructure in Serbia is 1.2m/s [5] which is no different from the velocities analyzed previously. The results of this paper are in accordance with results from previous studies. As we can see, the mean values of the measured speed are in accordance with theoretical and previously researched values. The speed at A(u) (1.18m/s / 0.96m/s) is statistically significantly different ($p<0.05$, .000) from the A(t) (1.24m/s / 1.03m/s). The segment A(u) effective width was 0.95m in comparison to restored width of segment after the intervention A(t) of 1.85m. The increase in the width was almost double, however, the speed increased for 0.06m/s, which is not proportional to the increase in width of a sidewalk. However, as the space available for the walking increased (2.85m²/p to 5.55m²/p), the pedestrian could choose to walk faster, instead, the pedestrians have walked slightly faster than at previous conditions. An increase in available space, led to the pedestrian dissipation and consequently to a possibility for evasive or invasive measures during the trip. This was confirmed by reviewing and comparing the recorded trajectories (Fig. 2) of pedestrians at both case of the experiment. At the case of A(u) the pedestrians walked slower than at the A(t) but with a significant difference in usage of sidewalk space. The 18 pedestrians (2.6%) which were completed the segment A course have failed to comply with regulations to stay at sidewalk during the walk. By comparing the situation with the second case of the experiment (Fig. 3), it is evident that increased space enabled the evasive and also invasive manoeuvre in overcoming the designated course.

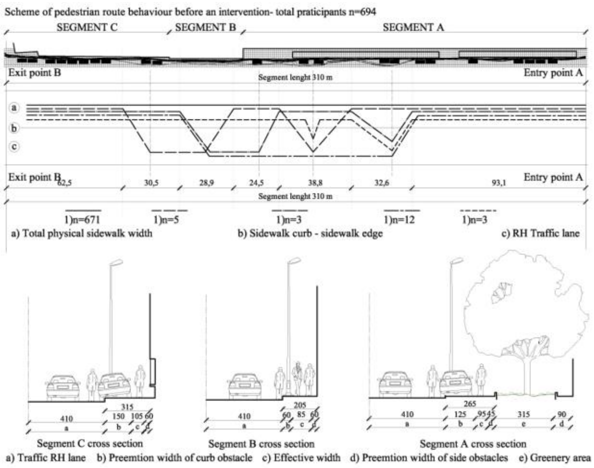

Figure 1 – Untreated settings of the experiment

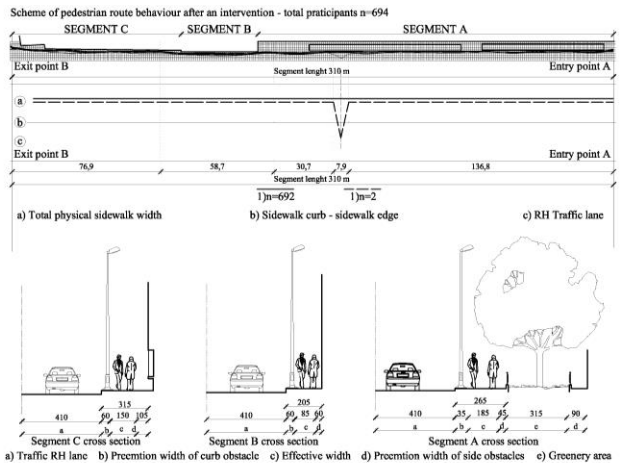

Figure 2 – Treated settings of the experiment

The speed at B(u) (1.13m/s / 0.90m/s) was not found to be statistically significantly different ($p>0.05$, .182) from the B(t) (1.16m/s / 0.94m/s). The difference in speed was 0.03m/s, which is practically negligible. However, based on the pedestrian behavior, the two cases of experiment differ from each other. The segment B did not have the case of parked vehicles, but due to the unchanged width of the sidewalk (0.85m), the pedestrian movement speed left approximately the same at the both cases. The difference between those two cases is in the non-compliance with the traffic rules of using the sidewalk for walking instead of the roadway surface. The 6 persons (0.86%) stepped off the sidewalk because of the lack of walking space and thus exposed themselves to a risk of accident. Based on the possibility to manoeuvre over the pedestrian space, the both cases of the experiment didn't provided enough space for avoiding other passers-by or for taking the initiative in the walking. Under those circumstances, in this segment for both cases the pedestrians walked slower in line following their predecessor, when the density was at the level of minor conflicts. The density for this observed segment was 0.42p/m² - 0.45p/m², which refers to the Level of service "C" according to HCM [4]. For the last observed segment, the walking speeds at C(u) (1.19m/s / 0.97m/s) and the speed at the C(t) (1.19m/s / 0.98m/s) are the same at great statistical significance level ($p>0.05$, 1.000). The available pedestrian space increased significantly (3.22m²/p to 5.88m²/p), however, the pedestrians did not showed any need for faster walking. Because of the dissipation of the pedestrians along this corridor, due to the increased available pedestrian space, the flow rate significantly decreased per width unit (22p/min/m to 12p/min/m, also the density (from 0.31p/m² to 0.17p/m²). This means that pedestrians at this observed segment for the case of increased sidewalk width (1.50m) were able to perform evasive and invasive manoeuvre, in comparison to first case of sidewalk width (1.05m). Considering the trajectories of pedestrian at this segment, for the first case of experiment, the 5 persons (0.72%)

violated the traffic rule and used the roadway surface for avoidance of obstacles during the walk. After the intervention to the segment, with restored width of 1.50m, there were no violators from the entire observed population. The previous analysis implies that the width of the sidewalk affects the walking speed on a low level but on a much higher level on pedestrians' behavior. In this regard, it is necessary to consider the width of the sidewalks to meet the basic needs of pedestrians in terms of personal space for comfortable movement and space for manoeuvring while walking. The minimum width of the sidewalks must be sufficient to allow passing in both directions and thus provide the necessary space. The recommendations for sidewalk width refer to the single pedestrian space needed for passing through. Federal highway administration (FHWA) proposing the minimal width for a sidewalk of 1.52 m[1] in order to meet the requirements for people with disabilities. The recommendations [2] for sidewalk facilities in Serbia states that minimal width is 1.0m per each passing pedestrian for two-way sidewalks. For the observed segment A, the analyzed width is in accordance with these recommendations. The width of the observed segments B and C is not sufficient to meet the pedestrian flow needs.

5. CONCLUSION

This paper considered the dependence of the free flow walking speed according to the sidewalk width under the heterogeneous traffic conditions. The basic hypothesis of this work was that pedestrians are waking at different speeds relative to the width of the sidewalk. Based on the overall analysis, we can conclude that pedestrians move at different speeds depending on the width of the sidewalk, but the differences in speeds are negligible. The results obtained in this paper do not deviate from the usual velocities compared to previous studies. In fact, those results are smaller than values of speed in other studies. A possible reason for this phenomenon is the integration of the influence of age factor on the walking speed into the overall population study analyzed in this paper. The essential difference between the widths of the sidewalks lies in the pedestrian behavior on the facility. If we consider the routes and the path of pedestrians, we can see that due to the lack of space for maneuvering, they choose the worst case, which is the use of a roadway for avoidance of the obstacles through the facility, thereby risking traffic accidents. The overall analysis showed that sufficient sidewalk width must meet requirements for the unimpeded passage for at least two walking pedestrians, which for our local terms is minimum 2.0m. The practical application of the findings from this research can be the basis for the development of strategies for the cities that have traffic infrastructure which is not sufficiently developed, in order to meet the needs of all users.

The shortcomings of this research are the lack of more developed model for analysis, or the extension of the experiment. It is necessary to develop a model with linear growth of interval of the pedestrian sidewalk width in order to define a more precise scale for evaluating the level of service based on the effective width of a sidewalk. This could be achieved by various simulations at macro level or by repeating the real time experiment with multiple measurements. In general, this paper implies the need to improve the level of pedestrian safety on the sidewalk facilities and to provide more comfortable public spaces, with the aim of moving the cities in the Republic of Serbia upwards on the scale of urban sustainability.

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