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Research Article

Analysis of Children's Traffic Behaviour at Signalized Crosswalks as a Precondition for Safe Children Routes Design: A Case Study from Croatia

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Children pedestrians represent road users with some specifics because of which it is important to study and take into account their traffic behaviour when traffic infrastructure is designed. Design should ensure and enhance their traffic safety because for decades, traffic accidents have been among the first few causes of children and adolescent mortality. Pedestrian speed is one of the important inputs when pedestrian infrastructure, especially crosswalks, is designed. On corridors where children are expected on a daily basis as independent pedestrians, the infrastructure should be adjusted to their characteristics and needs. The results of a study conducted in two Croatian cities of a similar size but of different urban and traffic conditions are presented in this paper. This study aimed at establishing and analysing children's pedestrian speed while crossing the signalized crosswalk in the buffer area of elementary schools, mostly on primary roads in the school vicinity. Children aged 5–15 were observed, and accordingly V_{15}, V_{50}, and V_{85} speeds were established on the basis of altogether 600 measurements. Speed was established for children walking individually, in a group and supervised by adults, and of a different age, and based on their gender, the impact of infrastructural elements on their speed in traffic was also analysed. Significant differences were found between children's speed measured in similar conditions in analysed cities and between some of the analysed groups. This fact proves that when improving conditions for children's independent movement, it is important to consider their specifics in order to ensure safe design adjusted to children's needs and limitations. As design speed in this paper, 15 percentile speed (V15) is considered. Suggestions on how to establish children pedestrian speed for design of routes regularly used by school children are proposed as well as some inputs elicited from the study done in Croatia are presented.

1. Introduction

Traffic safety data show that for certain children age groups, traffic fatalities are among the first reasons for mortality, both globally and in the EU. It is also important to note that 30% of children who are killed in traffic are children pedestrians, and in the USA, children aged from 5 to 14 years are mostly killed at intersections [1]. Numerous researches and studies have been carried out to determine the reasons and the relevant impacts both on children's behaviour and on their fatality rates as pedestrians. Research carried out in different parts of the world show that children pedestrians are more often killed on corridors they regularly use–in residential neighbourhoods [2, 3], near schools or parks [4, 5]. The reason might be that traffic infrastructure is designed without taking into consideration their specific traffic behaviour among which when pedestrian crossings are considered, walking speed is an important issue.

Analysis of the available studies shows that the assumption of relevant walking speed values as well as the application of uniform walking speed standards for different conditions is not justified and that for the enhancement of traffic safety at children's school routes, the local analysis of children's behaviour parameters is important.

This paper presents the results of a study conducted in two Croatian cities on a sample of children aged from 5 to 15 years. The aim was to analyse and determine the movement speed of children at signalized pedestrian crosswalks in specific local conditions of two cities with a very similar number of inhabitants but, considering the spatial location, with very different population and urban density, Rijeka and Osijek. Previously conducted studies [6] show that the parameters of the microsimulation model describing the driver behaviour differ significantly for traffic models that are calibrated for the traffic conditions in Rijeka from the ones calibrated for Osijek. Drivers in Rijeka, on average, drive more temperamentally, have a shorter reaction time, and enter risky situations more often than what the average indicators show for drivers in Osijek. This is consistently confirmed by numerical traffic safety indicators; so, for 2019, in Rijeka we have 16 traffic accidents per 1000 inhabitants and 0.9 dead and seriously injured persons in traffic, while the same indicators for Osijek are 7 and 0.6, respectively [7].

As part of the analysis of the movement speed of children pedestrians in each of the cities, data were collected for a total sample of 300 crossings, which enabled a comparison of the results obtained with the same methodology. The speed was measured based on video recordings of children while crossing signalized pedestrian crosswalks.

The goal was to analyse the relevant movement speeds of children moving individually and in a group, the speed according to the age and gender of children, and whether the children were accompanied by an adult or walking independently. The previous studies have shown that there may be a significant difference between these groups.

The impact of certain infrastructural parameters on the children's movement speed—the length of pedestrian crosswalk and the duration of pedestrian green time was also analysed.

In all of the cases, the V_{15}, V_{50}, and V_{85} crossing speeds of children pedestrians are analysed and compared to mean crossing speeds.

This study represents the first systematic research of the speed of children pedestrians in Croatia in an effort to determine whether, despite some similar characteristics of cities and analysed children (population, school system, and traffic education of children), the differences that exist among these cities, conditioned by urban design and consequently the transport system, affect the children pedestrians' behaviour. The overall purpose of the study was to generate general recommendations, as well as the ones for Croatia for speeds that should be respected on the corridors where children are expected to move in the vicinity of schools. The results were compared to the relevant research conducted worldwide. Finally, the possible use of developed methodology is discussed.

2. Literary Review

The behaviour of children in traffic varies considerably from adults' behaviour and depends on their cognitive development. It is established that the ability of children to perceive the traffic dangers [1, 8, 9] as well as their reaction time and resistance to distracters increase with their age. A recently conducted laboratory survey in Croatia shows differences in the reaction time of children in traffic compared to the control group of adults as well as when compared to a group of different age categories of children (up to 11 years) [10]. When investigating the reaction time in the Czech Republic, it was determined that the reaction time varies significantly between children aged up to 15 years of age, but that there are no significant differences in reaction time between age categories 15–18 and the control group, 20–30 years [11].

Historical data show that the proportion of children who walk or cycle to school is decreasing; in the USA, in 1969, 48% of children walked to school compared to only 11% in 2009 [12]; in the UK, in 1975–76, 74% of children walked to school while it decreased to 49% in 2017 [13]. In the European Council for Traffic Safety report, Croatia is highlighted as one of the EU countries where children walk to school independently in a larger share than in the other EU countries [14].

Nikitas et al. [13] provide an exhaustive overview of the research related to reasons of decline in the share of children pedestrians and analysed parents' attitudes on active travel to school based on a survey carried out in the United Kingdom.

There are studies and numerous initiatives that promote walking to school, which in addition to an important element of education and preparation of children for independent movement in traffic, highlight as an important element the arranging of "safe routes" and the application of "child-friendly design" on corridors where regular movement of children pedestrians is expected. In its document, "Reducing Child Deaths on European Roads," the European Council for Traffic Safety [14] highlights that ensuring a safe environment around residential and school areas is an important measure for boosting road safety for children. The road environment must be designed in a manner that recognizes and takes into account the capabilities and limitations of children. The science-based methodologies directed toward analysis and improvement of the condition of home-to-school routes are also developed, i.e., to encourage the children to walk to school every day [15, 16].

In this paper, we analyse important elements for ensuring safe pedestrian routes to school for children aged from 5 to 15 years. Signalized pedestrian crosswalks are analysed in order to suggest their design in the function of children's traffic safety.

Walking in general, as a form of transport, is very difficult to describe with objective transport indicators because it is a very flexible way of movement affected by different parameters, which is very easily detected when comparing walking speeds of different categories of pedestrians in different walking circumstances [17–20].

The information on the speed of pedestrian movement is an essential element when planning and designing the transport infrastructure in order to ensure an adequate level of safety and traffic flow capacity. It is possible to analyse the mean walking speed as relevant for pedestrian movements, but in order to ensure the traffic safety at signalized pedestrian crosswalks, the moving speed of 15% of analysed population (V_{15} speed) of pedestrians should be taken as relevant when pedestrian green time is designed. Expected age groups of pedestrians and their needs should be also respected [21].

Pedestrian crosswalks are particularly sensitive places for pedestrians since there they come into direct conflict with vehicles and hence, they are subject of different studies. Numerous researches are related to defining the influential parameters related to pedestrian characteristics that affect their behaviour and speed on pedestrian crosswalks [6, 22]. In addition, previously publicized results of this study indicate the characteristics of children and their behaviour which affect the crossing speed of the signalized pedestrian crosswalks, which are age, gender, the manner of movement (on their own, accompanied, or in a group of peers), and the use of mobile devices or the existence of mobility difficulties [6, 23].

A study conducted in Nygami [24] showed that the length of the pedestrian crosswalk was compared to the other two included infrastructure parameters–the length of the green time and the width of the pedestrian island had the greatest impact on the crossing speed. A significant difference between the speed on the approach to a pedestrian crosswalk, while crossing the street, and while leaving the pedestrian crossing zone has been identified. In addition to the characteristics of pedestrians and the infrastructure, other environmental conditions have shown to have an impact on pedestrians crossing the street, like weather conditions (sunny, cloudy), air temperature, etc. [25].

In transport planning and design, when there are no locally defined recommendations, a speed of 1.2 m/s is often taken as the relevant speed at pedestrian crosswalks [26, 27] while the speed of 1.45 m/s is suggested as the free flow speed for the general population in the 2010 HCM methodology [27]. Recommendations on the relevant speed for the calculation of pedestrian green time in Germany and Japan suggest 1.5 m/s as the relevant speed, but it is almost a unique recommendation to apply 1.0 m/s as the relevant walking speed on crosswalks where people with disabilities and/or elderly people are expected [28].

Detailed analysis of existing research and recommendations for pedestrian speed on pedestrian crosswalks [25] showed that the actually determined mean walking speed (MWS) and V_{15} walking speed for older pedestrians varied from 0.97 m/s to 1.4 m/s, and from 0.67 m/s to 1.22 m/s, respectively. On the other hand, the MWS and V_{15} walking speed for the younger pedestrians varied from 1.35 m/s to 1.51 m/s and from 1.10 m/s to 1.28, m/s respectively. Conclusion of an extensive analysis of scientific papers and professional studies from 1967 to 2017 dealt with the crossing speed [29] and reveals that the sociodemographic factors (such as gender, age, group size), geometric characteristics (such as road width, road classification), and flow conditions are the significant factors influencing the crossing speed of pedestrians at signalized crosswalks. It is also interesting to note that the conclusion from the same study stated that over a period of time, the average pedestrian crossing speed has increased from 1.24 to 1.43 m/s. Although the study provides a comprehensive overview of pedestrian speed testing at pedestrian crosswalks, children pedestrians are not mentioned as a special category in any of the analysed studies.

Existing research on children's speed at crosswalks include those on signalized and unsignalised crosswalks and tend to establish the influence that gender, age, and manner of movement (walking individually or in the group) have on children's walking speed. Field measurement done in China on a sample of adults, adult-child pairs, and child alone established that children walking alone walk faster than the other two groups. Adults were moving on most of the crosswalks at a speed of around 1.20 m/s while the speed of children walking alone was 1.35 m/s. In this case, only the mean speed was considered [30].

In a study conducted in Canada [31] in the vicinity of a primary school, the walking speed of unaware young pedestrians crossing the marked crosswalk was measured. The results showed that speed increased with age and decreased when children were walking in pairs or in a group. Also, measured data showed that children walked faster on the way to school in the morning than when they were going home, the difference amounted to 8%. Walking speeds V_{15}, V_{50}, and V_{85} of young pedestrians were measured in this study, and V_{15} measured for individual males and females was, respectively, 1.20 m/s and 1.25 m/s. Depending on the age, the V_{15} speed for males differed from 1.11 m/s (age 5–6 years and 13–14 years) up to 1.33 m/s (age 7–8 years) and for females 1.22 (age 11–12 years) up to 1.34 (age 9–10 years). The increase in speed was not related with the increase of children's age.

Another study done in Sydney, Australia [32], tended to establish the correlation between pedestrian speed of children aged 5–17 years and their age, height, and weight. Also, V_{15}, V_{50}, and V_{85} speeds were established for boys and girls for walking, jogging, and running speeds. The V_{15} walking speed of girls in this study varied from 1.33 m/s (age 5 years) up to 1.70 m/s (age 9 years), average V_{15} speed of all female age groups is 1.56 m/s. The same speed (V_{15}) for male age groups varied from 1.45 (age 17 years) to 1.73 m/s (age 8 years) with a mean of 1.57 m/s. Interesting is the fact that walking speed used for determining the pedestrian walking time and pedestrian's clearance time is usually 1.2 m/s, and for areas with slower pedestrians (e.g., elderly), 1.0 m/s can also be used [33].

In the field study conducted in Idaho, USA, in the buffer area of 7 elementary schools, walking speeds at marked crosswalks were collected and analysed [34]. The analyses included calculation and comparison of V_{15}, V_{50}, and V_{85} speeds for individuals and groups, and the average speed of all of them exceeded 1.22 m/s (or 4.0 feet/s). In this study, there was no uniquely determined relation between individual and group speed and there were significant differences between V_{15} established at different locations, from 1 m/s up to 1.45 m/s.

Analysis of the existing studies [31] shows that when determining the speed of movement of younger traffic participants, tests are conducted more frequently with the participants who know that they are being monitored and are less frequently with those who provide a more objective perception of movement–with participants (in this case children pedestrians) recorded without being aware of it. Comparing the determined movement speed of children who did not know that they were recorded with the results of studies in which the children were aware that they are a part of an experiment showed that children were crossing the street slower when they were unaware of the observer [31].

3. Methodology

3.1. Implementation of Field Measurements. In this study, methodology was based on data gathered from the video recordings of children when crossing signalized pedestrian crosswalks. The recordings were carried out in such a manner that children were unaware of the cameraman, and this is why it may be considered that their moving speeds were objectively determined. Based on the videos, the children's crossing time was determined, and the speed was calculated according to the duration of the journey on the measured path length (in this case, the length of the pedestrian crosswalk). Multiple image reviews also defined other parameters that were determined to affect children's movement speed: individual movement, group movement, or companion of an adult, and the children's age and gender were estimated. The children's age was estimated based on their appearance as well as based on certain characteristics typical for a certain age and appearance of school children (clothing, type of school bag, etc.). In each of the cities included in the study, over 300 data— children's crossings were collected, from which for the analysis in this paper, we selected those transitions that could be processed by visual inspection.

The research was conducted within the bi-lateral Croatian–Slovenian project, "Development of prediction model of pedestrian children behaviour in the urban transport network" and a positive opinion was given on the research plan by the Ethical commission for Research of the University of Rijeka, Faculty of Civil Engineering and Ethical commission for research of the Josip Juraj Strossmayer University of Osijek, Faculty of Civil Engineering and Architecture Osijek.

The locations where the measurements took place were chosen in such a manner that the conditions in which the children were crossing the road were as similar as possible. The pedestrian crosswalks were selected in the buffer area of a primary school, on the nearest primary street. All the intersections at which the children were recorded were equipped with a standard traffic light device, and the pedestrian crosswalks were marked with horizontal signalization.

A total of 14 pedestrian crosswalks were analysed: 6 pedestrian crosswalks at 3 intersections in Rijeka and 8 pedestrian crosswalks at 2 intersections in Osijek. The basic traffic and geometric features of the analysed pedestrian crosswalks are shown in Table 1 and the typical design of pedestrian crosswalk for each of the cities is given in Figure 1.

The width of the pedestrian crosswalk was also measured, but since in the previous analyses it was determined that it does not affect the speed of pedestrians [6, 23] it was not shown. It is observed that the length of pedestrian green times is significantly different within the same city, depending on whether it is a pedestrian crosswalk at a major or minor direction.

Field measurements were performed during May and June 2019 during several days on each of the pedestrian crosswalks, in the morning hours when children are arriving at school, between 7.15 and 8.00 a.m. when classes normally start. Days with stable weather conditions and without rain have been selected to provide as objective data as possible on the movement of pedestrian children. Children were recorded without being aware of being recorded, usually from the back, and the time measured from the first step on the pavement until the first step on the sidewalk on the opposite side of the street was considered as the crossing time. There was no significant share of other pedestrians at the analysed pedestrian crosswalks, so the stated parameter was not taken into account.

3.2. Data Analyses. Children's movement speed was calculated according to the time they spent on pavement, which, together with the measured length of the pedestrian crosswalk, was the basis for the calculation of the walking speed.

Based on the analysis of the common speeds used to analyse the pedestrian movement and to define the recommendations for transport infrastructure design, the following indicators of the movement speed were analysed:

(i) The V_{mean} speed, which represents the average (mean) speed of movement of the analysed group (hereinafter V_{mean})

(ii) The V_{15} speed, up to which 15% of children in the analysed group data move (hereinafter V_{15})

(iii) The V_{50} speed, up to which 50% of children in the analysed group data move (hereinafter V_{50})

(iv) The V_{85} speed, up to which 85% of children in the analysed group data move (hereinafter V_{85})

Speed V_{15} is used as the relevant speed when designing transport infrastructure for pedestrians, so it is also emphasised in these analyses.

From the video records, we measured, observed, or estimated the predefined parameters according to which the speeds were later analysed and compared: children's sex, age of children divided into several categories, moving in a group or individually, with or without adult supervision, and presence of distracters (mobile phone use).

Considering the age, the children were grouped in 3 categories regarding the level of primary education, thus avoiding major mistakes in determining the age of children assessed by visual inspection of the video recordings.

Analysed age categories of children:

(i) AG 1: up to 7 years—the usual age when children start attending school

(ii) AG 2: 8–11 years—in Croatia, 11 years is the limit for the transition to a higher level of primary education

(iii) AG 3: 12–15 years—higher levels of primary education, 15 years of age is when children generally transfer to secondary education

Table 1: Basic geometric and traffic characteristics of the analysed pedestrian crosswalks.

City/country	Location code	Crosswalk length (m)	Cycle (s)	Pedestrian green time (s)	Clearance time (s)	Min. pedestrian speed expected (m/s)	
						Green time	Clearance time
Osijek, Croatia	O-1	7	90	50	7	NR	1.0
	O-2	10.5	90	20	9	0.525	1.16
	O-3	9.3	90	50	7	NR	1.3
	O-4	10.5	90	20	9	0.525	1.16
	O-5	14	90	13	10	1.1	1.4
	O-6	9.2	90	42	21	NR	NR
	O-7	14	90	13	10	1.0	1.4
	O-8	9.2	90	42	21	NR	NR
Rijeka, Croatia	R-1	16	80	12	6	1.33	2.7
	R-2	16.5	80	12	6	1.3	2.75
	R-3	7	100	13	25	0.54	NR
	R-4	10	100	13	6	0.78	1.7
	R-5	10	80	9	11	1.11	0.9
	R-6	10	80	9	11	1.11	0.9

NR, not relevant; green time enables walking speed ≤ 0.5 m/s.

(a) (b)

Figure 1: Example of a typical pedestrian crosswalk in Osijek (a) and in Rijeka (b).

In addition, the movement speed of children was analysed depending on certain infrastructure parameters that were shown to be significant in the previous analysis of parameters affecting the speed of movement, i.e., the length of stay in the pedestrian crossing zone [10, 23]. Thus, the movement speed of children was analysed with regard to the length of the pedestrian crosswalk and to the length of green time for pedestrians (listed in Table 1).

Table 2 provides basic data on the structure and behaviour of children in two abovementioned cities, which is important for further speed analysis.

4. Results and Discussion

4.1. Data Analyses and Descriptive Statistics. The analysis of the measured speeds of pedestrian children includes an analysis of the overall database for each of the abovementioned cities as well as analysis and comparisons according to the selected speed indicators and according to the selected relevant parameters as outlined above.

The distribution of the values of the calculated speeds for the analysed environments is given in Figure 2.

If we consider 1.2 m/s as the designed speed for green and clearance time, quick analyses of data from locations considered in this study show that in Osijek around 30% of children walk slower than 1.2 m/s and in Rijeka only 10% of children walk slower than that. The results obtained in Rijeka can be related to the fact that on some of the analysed pedestrian crosswalks due to lower clearance time, higher crossing speeds than 1.2 m/s are expected, so children are forced to walk faster (See Table 1).

4.2. Analyses of Children's Pedestrian Speed. Before performing the statistical analysis and determining the relevant movement speeds, the data on individual speeds in each of the databases were analysed. Mean movement speeds (V_{mean}) as well as baseline descriptive statistics for each database was analysed (Table 3). It was established that they do not follow the normal distribution, and the Mann–Whitney test [35, 36] confirmed that the mean speeds of children's movement across the entire base are statistically significantly different (P value smaller than 0.0001).

The comparison of mean speed results and speeds V_{15}, V_{50}, and V_{85} for the total sample in both bases is given in Figure 3.

The analysis on the total sample of children shows that children in Rijeka are moving faster and their V_{15} speed is within the limit of the usually applied speed. The speed calculated for the total sample of children pedestrians in Osijek is lower, the V_{15} is 1.04 m/s when the entire base is

Table 2: Main features of analysed samples.

Database	Gender	Crossing in a group/individual	Supervised by adults	Children age groups (years)		Using mobile phone
Osijek	52% F 48% M	75% individual 25% group	94% no 6% yes	AG1 (<7) AG2 (8–11) AG3 (12–15)	8% 29% 63%	86% no 14% yes
Rijeka	47% F 53% M	65% individual 35% group	89% no 11% yes	AG1 (<7) AG2 (8–11) AG3 (12–15)	6% 39% 55%	96% no 4% yes

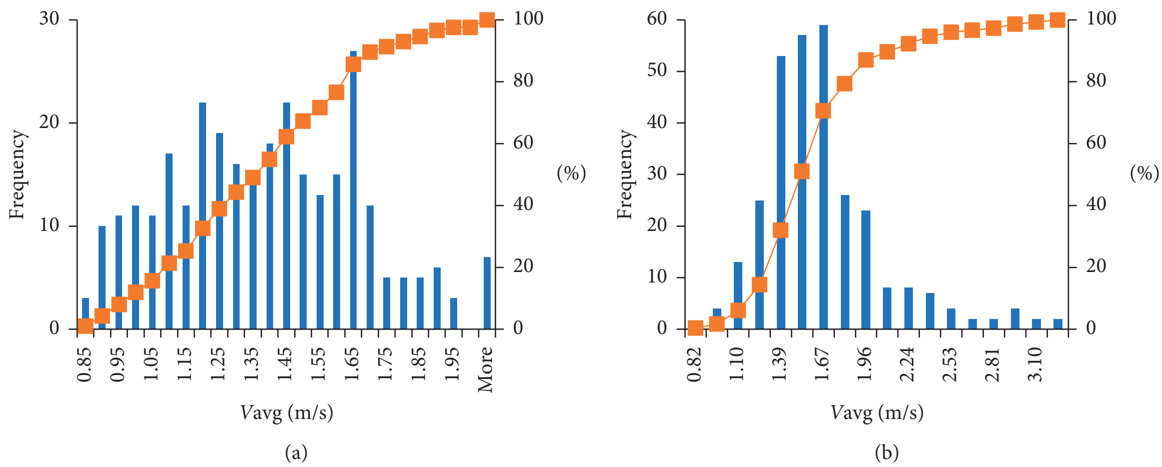

Figure 2: Frequency of mean speed distribution: Osijek (a) and Rijeka (b).

Table 3: Descriptive statistics and Mann–Whitney test results for speed difference for the whole database and for each city.

Database	Description	Sample	Mean speed	Stand. dev.	Min	Max	Mann–Whitney	
							U-test	P value
Osijek	Whole base	300	1.36	0.30	0.53	2.37	30382	<0.0001
Rijeka	Whole base	300	1.59	0.41	0.82	3.24		

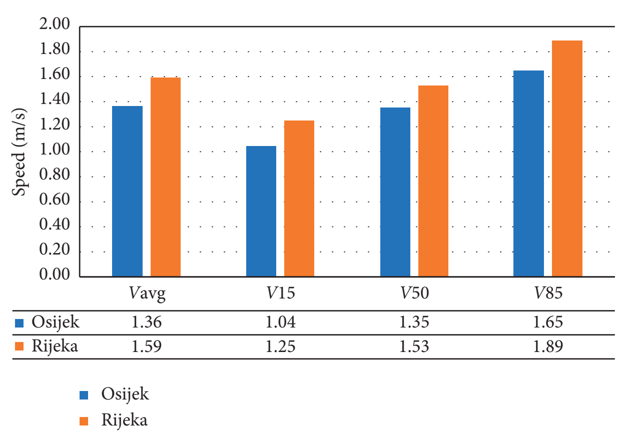

Figure 3: The relevant speeds of children for both cities on the whole sample.

observed, and it is below the usually expected speed of pedestrians at pedestrian crosswalks.

4.3. Analysis of Children's Movement Speed Depending on the Children's Characteristics. The speeds of children depending on their age and sex are analysed below. Age-based analysis included children in 3 age groups according to their level of primary education as explained in methodology. The average speeds of children of the same age groups by cities and the relevant movement speeds for all groups in both analysed environments were compared.

In Table 4, descriptive statistics and results of the Mann–Whitney test used to determine the significance of speed differences with respect to the same age of children in different databases are shown.

According to the results of the nonparametric test (Mann–Whitney) shown in Table 4, the speeds measured at pedestrian crosswalks in Rijeka and Osijek differ significantly between the age groups for all age categories.

Table 5 shows the comparison of mean speeds and speeds V_{15}, V_{50}, and V_{85} of the same age groups per city.

The relevant speeds for dimensioning of pedestrian crosswalks, V_{15}, for all age categories in Rijeka are higher than the usually applied 1.2 m/s, while for Osijek the values are lower, i.e., 15% of the slowest children move well below this standard and even slower than 1 m/s.

The speeds of children per gender are analysed below. The speeds between boys and girls in each of the analysed cities were compared as well as the speeds of boys and girls in two different cities. Table 6 shows the descriptive statistics and results of the Mann–Whitney test used to determine the significance of speed differences with respect to the children's gender.

According to the results of the nonparametric test (Mann–Whitney) presented in Table 6 at the pedestrian crosswalks in Rijeka and Osijek, no statistically significant difference between the speed of girls and boys was identified. There is a statistically significant difference, as expected, only when the speed of girls in Rijeka and Osijek and the boys in Rijeka and Osijek is compared (Table 7).

4.4. Analyses of Children's Pedestrian Speed Depending on Children's Behaviour at Crosswalks. Given below is the analysis of the speeds of pedestrian children at signalized pedestrian crosswalks depending on children's behaviour: crossing the street independently, in pairs or groups (all without parental supervision), and mobile phone use. The results provide an insight to the impact of these parameters on the children's movement speed.

4.4.1. Analysis of the Impact of the Group on Children Pedestrian's Speed of Movement at Signalized Pedestrian Crosswalks. An analysis of the impact of the movement in the group on the children's speed at nonsignalized pedestrian crosswalks was carried out for three scenarios: Children's independent movement, children's movement in pairs, and group movements.

A Mann–Whitney test was performed for various combinations of children. Results are presented in Table 8.

According to the test results, it is evident that there are statistically significant differences comparing the average speeds for the analysed manner of movement (individually, a pair—group of 2 children, a group—three or more children) in both analysed environments.

Table 9 shows the relevant speeds considering the number of children in the group for both cities.

The analysis of the speed of children who walk independently (individually) across the pedestrian crosswalk depending on their age, separately for Rijeka and Osijek, is given in Table 10.

According to the results of the nonparametric test (Mann–Whitney) shown in Table 10, the speeds measured at the pedestrian crosswalks in Rijeka and Osijek for the individual crossing of the pedestrian crosswalk depending on the age of children differ significantly between them, except when comparing children in Rijeka, at the age of 8–11 and 12–15 years, where there is no statistically significant difference.

In Table 11, the average speeds of individual crossings of children considering their age, for both cities, are given.

4.4.2. Analysis of the Impact of Using a Mobile Phone on the Speed of Children Pedestrians at Signalized Pedestrian Crosswalks. An analysis of the impact of using mobile devices on the crossing speed at signalized pedestrian crosswalks was analysed on a sample of measurements from Osijek where it was possible to carry out the analysis on a sample of 41 children using a cell phone while crossing a street. In Rijeka, the share of children using a mobile phone was insufficient to carry out the analysis (11 children).

The use of a mobile phone was shown to be a significant distracter and has a significant impact on the speed of children, so the average speed of children using a mobile phone when crossing the street is 1.23 m/s compared to the speed achieved by the population of children who do not use the mobile phone while crossing, which is 1.38 m/s, and speaking about V_{15}, this speed is 0.99 m/s for children using a mobile phone, and 1.06 m/s for the rest of the observed population.

4.5. Analyses of Children's Pedestrian Speed Depending on Infrastructural Elements. The length of the crosswalks and duration of pedestrian green time were analysed in this study as infrastructural elements that can influence children's behaviour while crossing the street. Pedestrian crosswalks on two-lane, three-lane, and four-lane roads were analysed for each base (city) separately.

4.5.1. Children's Pedestrian Speed Depending on Crosswalk Length. In the carried-out field study, the represented pedestrian crosswalks were from 7 to 14 m long. The width of the pedestrian crosswalks analysed varied from 7 m when it was a two-lane road, 9.2–10.5 m when it was a three-lane road, and 14 m and more when the four-lane roads were analysed.

By analysing the speed of children at pedestrian crosswalks of different lengths, we sought to determine the influence of this parameter on the mean speed of movement of the total sample of children.

According to the results of the nonparametric test (Mann–Whitney) presented in Table 12, the speeds measured at pedestrian crosswalks of the same length in Rijeka and Osijek differ significantly except for the crosswalks longer than 14 m where no statistically significant differences were identified. Comparing the speeds of children within the same city, on the basis of the results obtained in the city of Osijek, it

Table 4: Descriptive statistics and Mann–Whitney test results for speed difference according to the children's age.

Database	Description	Sample	Mean speed	Stand. dev.	Min	Max	Mann–Whitney U-test	Mann–Whitney P value
Osijek	≤7 y	23	1.23	0.34	0.86	2.37	115.5	0.008
Rijeka		19	1.45	0.29	1.14	2.32		
Osijek	8–11 y	88	1.37	0.36	0.83	2.33	3336	<0.0001
Rijeka		116	1.62	0.44	0.98	3.24		
Osijek	12–15 y	189	1.38	0.26	0.53	2.06	11040.5	<0.0001
Rijeka		165	1.58	0.40	0.82	2.99		

y, years old.

Table 5: The speed of children depending on age, for both cities.

Database	Description	Sample	V_{avg}	$\mathbf{V_{15}}$	V_{50}	V_{85}
Rijeka	≤7 y	19	1.45	**1.22**	1.33	1.72
Osijek		23	1.23	**0.87**	1.18	1.41
Rijeka	8–11 y	116	1.62	**1.25**	1.54	1.96
Osijek		88	1.37	**0.97**	1.36	1.78
Rijeka	12–15 y	165	1.58	**1.25**	1.53	1.88
Osijek		189	1.37	**1.08**	1.39	1.65

y, years old; bold values denote speed adopted as relevant for children pedestrians (v_{15}).

Table 6: Descriptive statistics and Mann–Whitney test results for speed difference according to the gender.

Database	Description	Sample	Mean speed	Stand. dev.	Min	Max	Mann–Whitney U-test	Mann–Whitney P value
Osijek	Male	143	1.34	0.03	0.53	2.37	10378.5	**0.259**
	Female	157	1.38	0.02	0.83	2.33		
Rijeka	Male	158	1.60	0.03	0.94	2.96	11658.5	**0.557**
	Female	142	1.57	0.04	0.82	3.24		
Osijek	Male	143	1.34	0.03	0.53	2.37	6908	<0.0001
Rijeka		158	1.60	0.03	0.94	2.96		
Osijek	Female	157	1.38	0.02	0.83	2.33	8192.5	<0.0001
Rijeka		142	1.57	0.04	0.82	3.24		

Bold values denote no statistically significant difference.

Table 7: The speed of children depending on gender, for both cities.

Database	Description	Sample	V_{avg}	$\mathbf{V_{15}}$	V_{50}	V_{85}
Osijek	Male	143	1.34	**1.03**	1.35	1.64
	Female	157	1.38	**1.06**	1.37	1.67
Rijeka	Male	158	1.60	**1.25**	1.53	1.96
	Female	142	1.57	**1.23**	1.53	1.87

Bold values denote speed adopted as relevant for children pedestrians (v_{15}).

was shown that the speeds of children differ significantly with respect to the length of the pedestrian crosswalk, while the results from the city of Rijeka showed that there is no statistically significant difference between the speeds of children at different lengths of pedestrian crosswalks.

Table 13 shows the relevant speeds considering the length of the pedestrian crosswalk for both cities.

4.5.2. Speed of Children Pedestrians Depending on the Duration of Pedestrian Green Time. In the field study, 14 pedestrian crosswalks analysed had the length of the green light for pedestrians from 9 to 50 seconds. The influence of the duration of the pedestrian green light on the children's movement speed, within the reference frame of each city, is given in Table 14).

According to the results of the nonparametric test (Mann–Whitney) shown in Table 15, the speeds measured at pedestrian crosswalks within the Osijek reference frame, where the duration of green light for pedestrians is up to 13 seconds, are statistically significantly different from the speeds at pedestrian crosswalks where green light for pedestrians lasts longer than 20 seconds. Based on the reference frame of the city of Rijeka, it was determined that there

Table 8: Descriptive statistics and Mann–Whitney test results for speed difference according to the individual or movement in a group.

Database	Description	Sample	Mean speed	Stand. dev.	Min	Max	Mann–Whitney U-test	Mann–Whitney P value
Osijek	Individual	225	1.43	0.02	0.53	2,33	7617	<0.0001
	Group of 2	45	1.22	0.04	0.91	2,37		
	Individual	225	1.43	0.02	0.53	2.33	6006.5	<0.0001
	Group with ≥3	30	1.04	0.03	0.83	1,51		
	Group of 2	45	1.22	0.04	0.91	2,37	1053	<0.0001
	Group with ≥3	30	1.04	0.03	0.83	1,51		
Rijeka	Individual	195	1.71	0.03	1.05	3.24	9130	<0.0001
	Group of 2	68	1.45	0.03	0.82	2.25		
	Individual	195	1.71	0.03	1.05	3.24	6386	<0.0001
	Group with ≥3	37	1.23	0.04	0.94	1.78		
	Group of 2	68	1.45	0.03	0.82	2.25	1969.5	<0.0001
	Group with ≥3	37	1.23	0.04	0.94	1.78		

Table 9: The speed of children depending on the number of children in a group for both cities.

Database	Description	Sample	V_{avg}	$\mathbf{V_{15}}$	V_{50}	V_{85}
Osijek	Individual	225	1.43	**1.13**	1.44	1.67
Rijeka		195	1.71	**1.33**	1.60	2.11
Osijek	Group of 2	45	1.22	**1.05**	1.22	1.36
Rijeka		68	1.45	**1.25**	1.45	1.65
Osijek	Group with ≥3	30	1.04	**0.88**	0.99	1.18
Rijeka		37	1.23	**1.01**	1.20	1.40

Bold values denote speed adopted as relevant for children pedestrians (v_{15}).

Table 10: Descriptive statistics and Mann–Whitney test results for speed difference of children's individual crossing according to age.

Database	Description	Sample	Mean speed	Stand. dev.	Min	Max	Mann–Whitney U-test	Mann–Whitney P value
Osijek	Individual/≤7 y	18	1.21	0.24	0.88	1.86	163	<0.0001
	Individual/8–11 y	52	1.56	0.32	0.92	2.33		
	Individual/≤7 y	18	1.21	0.24	0.88	1.86	691	≤0.001
	Individual/12–15 y	155	1.42	0.25	0,529	2.06		
	Individual/8–11 y	52	1.56	0.32	0.92	2.33	4900	0.020
	Individual/12–15 y	155	1.42	0.25	0.53	2.06		
Rijeka	Individual/≤7 y	15	1.44	0.31	1.14	2.32	279.5	0.003
	Individual/8–11 y	74	1.76	0.47	1.05	3.24		
	Individual/≤7 y	15	1.44	0.31	1.14	2.32	394.5	0.002
	Individual/12–15 y	105	1.71	0.40	1.05	2.99		
	Individual/8–11 y	74	1.76	0.47	1.05	3.24	4140	**0.456**
	Individual/12–15 y	105	1.71	0.40	1.05	2.99		

y, years old; bold value denotes no statistically significant difference.

Table 11: Crossing speeds of children moving individually considering their age, for both cities.

Database	Description	Sample	V_{avg}	$\mathbf{V_{15}}$	V_{50}	V_{85}
Osijek	≤7 y	18	1.21	**0.93**	1.18	1.41
	8–11 y	52	1.56	**1.19**	1.52	1.90
	12–15 y	155	1.42	**1.15**	1.44	1.67
Rijeka	≤7 y	15	1.44	**1.22**	1.33	1.72
	8–11 y	74	1.76	**1.33**	1.64	2.17
	12–15 y	105	1.71	**1.38**	1.59	2.06

y, years old; bold values denote speed adopted as relevant for children pedestrians (v_{15}).

Table 12: Descriptive statistics and Mann–Whitney test results for speed difference according to the length of pedestrian crosswalk (number of traffic lanes of the road).

Database	Description	Sample	Mean speed	Stand. dev.	Min	Max	Mann–Whitney U-test	Mann–Whitney P value
Osijek	Up to 7 m	46	1.12	0.03	0.83	1.67	213	0.001
Rijeka		20	1.47	0.12	0.82	3.24		
Osijek	9.2–10.5 m	179	1.35	0.02	0.53	2.33	12721	<0.0001
Rijeka		211	1.59	0.03	0.94	3.13		
Osijek	>14 m	75	1.53	0.03	0.92	2.37	**2281**	0.221
Rijeka		69	1.61	0.04	1,00	2.96		
Osijek	Up to 7 m	46	1.12	0.03	0.83	1.67	2090.5	<0.0001
	9.2–10.5 m	179	1.35	0.02	0.53	2.33		
	Up to 7 m	46	1.12	0.03	0.83	1.67	360	<0.0001
	>14 m	75	1.53	0.03	0.92	2.37		
	9.2–10.5 m	179	1.35	0.02	0.53	2.33	4386	0,221
	>14 m	75	1.53	0.03	0.92	2.37		
Rijeka	Up to 7 m	20	1.47	0.12	0.82	3.24	**1719**	**0.172**
	9.2–10.5 m	211	1.59	0.03	0.94	3.13		
	Up to 7 m	20	1.47	0.12	0.82	3.24	**492**	**0.052**
	>14 m	69	1.61	0.04	1.00	2.96		
	9.2–10.5 m	211	1.59	0.03	0.94	3.13	**6462**	0.162
	>14 m	69	1.61	0.04	1.00	2.96		

Bold values denote no statistically significant differences.

Table 13: The average crossing speeds of children considering the length of the pedestrian crosswalk, for both cities.

Database	Description	Sample	V_{avg}	$\mathbf{V_{15}}$	V_{50}	V_{85}
Osijek	Up to 7 m	46	1.12	**0.92**	1.11	1.30
	9.2 to 10.5 m	179	1.35	**1.06**	1.35	1.63
	More than 14 m	75	1.53	**1.28**	1.51	1.84
Rijeka	Up to 7 m	20	1.47	**0.87**	1.41	1.75
	9.2 to 10.5 m	211	1.59	**1.24**	1.52	1.96
	More than 14 m	69	1.61	**1.33**	1.60	1.84

Bold values denote speed adopted as relevant for children pedestrians (v_{15}).

Table 14: The average crossing speeds of children given the duration of the green light at the pedestrian crosswalk, for both cities.

Database	Description	Sample	V_{avg}	$\mathbf{V_{15}}$	V_{50}	V_{85}
Osijek	PG = 13 s	75	1.53	**1.30**	1.51	1.84
	PG = 20 s	73	1.35	**1.01**	1.30	1.67
	PG = 42–50 s	152	1.28	**0.99**	1.26	1.58
Rijeka	PG = 9 s	124	1.58	**1.24**	1.48	1.92
	PG = 12-13 s	176	1.59	**1.27**	1.55	1.88

Bold values denote speed adopted as relevant for children pedestrians (v_{15}).

Table 15: Descriptive statistics and Mann–Whitney test results for speed difference according to the duration of pedestrian green time.

Database	Description	Sample	Mean speed	Stand. dev.	Min	Max	Mann–Whitney U-test	Mann–Whitney P value
Osijek	PG = 13 s	75	1.53	0.28	0.92	2.37	3621.5	0.001
	PG = 20 s	73	1.36	0.33	0.85	2.33		
	PG = 13 s	75	1.53	0.28	0.92	2.37	8507.5	<0.0001
	PG = 42–50 s	152	1.28	0.26	0.53	2.14		
	PG = 20 s	73	1.36	0.32	0.85	2.33	**6168.5**	**0.175**
	PG = 42–50 s	152	1.28	0.26	0.53	2.14		
Rijeka	PG = 9 s	124	1.58	0.44	0.98	3.13	**9890**	**0.167**
	PG = 12-13 s	176	1.59	0.39	0.82	3.24		

PG, pedestrian green time; bold values denote no statistically significant differences.

is no statistically significant difference between speeds at pedestrian crosswalks, regardless of the duration of the green light for pedestrians.

5. Discussion

Relevant pedestrian speeds of children pedestrians (V_{avg}, V_{15}, V_{50}, and V_{85} speed) analysed in two cities in Croatia showed that there is a significant regional difference in the behaviour of children under 15 years of age in traffic, although analysed cities have a similar number of inhabitants and the children have the same general traffic education since the cities are located in the same country (Croatia, the EU). In this case, the speed of children was determined and analysed in detail with regard to their gender, age, and manner of movement (individually or in a different group size) and with regard to the infrastructure features—the length of the pedestrian crosswalk and of the green light for pedestrians, considering that these parameters were proven to be influential for defining the children's movement speed [23, 37, 38]. All speeds were determined in circumstances where children did not know that they were subjects of an experiment, which is a method, as previous studies show, to determine the objective speed of children [31].

The V_{15} speed, at which up to 15% of pedestrians move, is usually taken as relevant when designing the traffic lights, which is usually a speed of 1.2 m/s, i.e., 1.0 m/s, according to certain recommendations for the elderly people. The authors did not find special standards that would treat children as a sensitive category and adapt the functioning of the pedestrian traffic lights according to their needs.

In this study, the speeds of pedestrian children were determined at a total of 14 pedestrian crosswalks on pedestrian corridors at the approach of primary schools in 2 cities in Croatia. Preliminary analysis showed that for 2 of 14 crosswalks, the expected pedestrian speed during the green light for pedestrians is greater than 1.2 m/s, and when analysing the expected speed of pedestrians in the "clearance time," it was shown that on 6 out of 14 pedestrian crosswalks the children should cross the street at a speed higher than 1.2 m/s. The problem is more pronounced in the city of Rijeka than in Osijek, where the pedestrian times are generally shorter for the same length of the pedestrian crosswalk. It can be assumed that due to the abovementioned, the speed of children (expressed through several indicators) in Rijeka is higher than the speed of children in Osijek; the difference is proven to be statistically significant observing the whole sample and even when children by age and sex were analysed.

The influence of children's gender on movement speed has not been unambiguously defined as significant in previous studies of children's pedestrian speed [31, 32] and the data analysed in this study confirmed that there is no significant difference in the speed of movement of boys and girls under the age of 15 in either of the two analysed cities in Croatia.

In this research, the children were categorized into 3 age groups that match the level of primary education in Croatia (just started attending school, first level, second level of elementary school) and are fairly independent in traffic, since most of the children that are accompanied by an adult are in the first age group, up to 7 years old; in the second group are younger children in lower classes of elementary school; and the last group had children that are 100% independent, but it is very common for them to walk in pairs or groups. Comparison of the results from this study with the one conducted in similar conditions (children being unaware of being recorded while crossing the street) carried out by [31] shows some similar trends but also differences in established speeds. What is common is that social interaction—walking in pairs or in a group—slows down young pedestrians when walking. As for the age, in this study, the speed increases up to 12 years of age while in the study carried out by [31] the age up to which the speed increases is 8 years for boys, and 10 years for girls. The impact of the group has shown to be very important in this study (as well as in the one carried out by [31]), and the speeds of crossing the road individually are higher than the ones when children walk in a group or in a pair. General comparison of the results of these two studies shows that walking speeds of boys and girls in this study are higher than those established for children in Canada conducted 20 years ago in the same manner, which is in line with the conclusion reached by [29] that pedestrian speed increased in last decades due to improvement in traffic conditions and infrastructural facilities.

As for the impact of using a mobile phone—the speeds established for children using mobile phones in comparison with those not using it show significant difference in mean and V_{15} speed on relevant sample of children in Osijek. The V_{15} speed of children using the mobile phone was 0.99 m/s while for the others it was 1.06 m/s.

To ensure that children walk safely to school, it is important to consider their needs and limitations also when basic infrastructural elements of crosswalks are considered—like pedestrian green time, length of crosswalk, and crosswalk equipment. In this study, all of the crosswalks had a typical "design," with traffic lights for vehicles and pedestrians, and marked crosswalks. The analysis of pedestrian green light duration suggested that children walk faster (sometimes also run) when they have less time at their disposal for crossing the street. This fact was established in Osijek because in Rijeka the difference between analysed green lights was too small to enable proper analysis. As the children were recorded on their usual routes to, school it can be presumed that they have experience of the same crosswalks and so they adjust their walking speed. However, in Osijek, 7 of 8 crosswalks do have pedestrian green light duration that enables children to walk at V_{15} speed and in Rijeka only 4 out of 6 have the same when the whole sample is considered. The pedestrian speed expected at the analysed crosswalks is, however, not adjusted to the needs of younger children and those who walk in a group or in pairs in Osijek, and for those who walk in a group in Rijeka.

This study has shown that the length of the crosswalk is also an important parameter when measuring the speed of children pedestrians. In both environments, the longer length of the path causes faster movement of children, which indicates the need to introduce central pedestrian islands at places where children cross lengths of over 10 m, because in this case, their speed is higher than the average! If V_{15} is taken as the relevant value, the central island should be available when the road length exceeds 7 m, i.e., in any case when children are expected to cross more than 2 lanes, because then the speed of children is significantly higher, which can lead to the risk of falling during crossing of a conflict zone.

All of the analyses about children's pedestrian speed at signalized crosswalks pointed out to the need to establish a safe speed for the design of infrastructure regularly used by children.

According to the results of this study for corridors regularly used by school children in Croatia, the following project recommendations have been established:

(i) The pedestrian speed used during design should amount to 1.0 m/s

(ii) If school children younger than 11 years are expected to walk independently or are moving in a group in their usual manner of crossing the street, the design speed for signalized crosswalks near schools, parks, or sport facilities should be 0.9 m/s

(iii) The length of a crosswalk that a child has to cross without rest should not exceed 7.0 m

The suggested design pedestrian speeds should be used for the calculation of pedestrian green time as well as for clearance time at signalized crosswalks.

6. Conclusions

In order to encourage the children to walk to school every day, it is necessary to make their route safe—to educate them about acceptable behaviour in traffic and to adapt the infrastructure they use to their needs and constraints in order to prevent or mitigate the consequences of inadequate reactions or risky behaviour of the school-age children.

An analysis of available research and practices from two cities in Croatia shows that the specifics of children's movements are not sufficiently taken into account even when planning and designing the infrastructure they use on a daily basis, for example, near schools. It can also be concluded by analysing available studies that the behaviour of children in traffic is dependent on the overall transport culture and habits, and implies that there are general, and also specific, impacts on their behaviour which requires local analysis.

This paper presents a study that included school-age children from two cities in Croatia and analyses their speed at signalized pedestrian crosswalks near primary schools, based on parameters that are proven to be important in previous studies.

Analysis of children's pedestrian speed at signalized pedestrian crosswalks near primary schools in two different urban areas showed significant differences in these speeds. It was shown that the recommendations of relevant international institutions concerning the minimum walking speed used when designing green and protective pedestrian times are not tailored to the children's needs.

Children's pedestrian speeds are analysed depending on the characteristics of children (age, gender), infrastructural conditions (length of pedestrian crosswalks, duration of green pedestrian light), manner of movement of children (individually, in a pair, or in a group), and distracters (use of mobile phone) in order to determine impacts on walking speed under defined conditions.

The V_{15} speed was adopted as the relevant speed, based on the analysis of the available studies that dealt with this issue and the analyses carried out in this study. The results of this study suggested that it is important to take into consideration the speed of children younger than 11 years, crosswalks on which children walk in a group regularly, and crosswalks wider than 7 m.

In Croatia, for the calculation of the green time duration and the minimum protection time at pedestrian crosswalks where the movement of unaccompanied children is regularly expected, the recommended speed is 1.0 m/s as relevant V_{15} speed for design. Otherwise, the children are forced to walk quickly or run, which may pose a risk to their safety. It is necessary to take into account the length of the path, and wherever possible to provide a central pedestrian island for the children if the road is wider than 7 m or if there are more than two traffic lanes.

In addition, early and continuous education is required for children on the desired behaviour in traffic in order to reduce the number of children who show risky behaviours that affect their speed of travel at critical locations of pedestrian corridors—pedestrian crosswalks.

The results of the study only partly match the results of similar studies on children's movement speed and impacts on the movement of children at signalized pedestrian crosswalks carried out in the world, which is why it is suggested to locally check the infrastructure design parameters in order to ensure that they are child-friendly and to target the traffic education on the locally affirmed risky behaviour. In this paper, only in one of the environments (Osijek) the use of mobile phones was, given the sample size, relevant for analysis and showed a significant impact of mobile phone use on the speed of children. It is a distracter that should definitely be analysed in more detail in future research and the children should be made aware of desirable behaviour in traffic through education.

The research methodology in this paper proved to be very good for determining the real speed of children's movements because the children were not aware of being monitored and their behaviour was completely natural, and the determined speeds can be considered as precisely determined. However, this method of data collection did not allow accurate identification of the children's age, which is why they are categorized in only three age categories with a relatively wide range.

Further research shall be focused on the children's behaviour in traffic at other points within the transport network—unsignalised pedestrian crosswalks at the corridors where children go to school and pedestrian sidewalks that need to be made safe to encourage active and independent movement of children in the urban areas.

Data Availability

The data used to support the findings of this research are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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