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Simplified model of children-pedestrian crossing speed at signalized crosswalks

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Abstract

Road accidents are one of the main causes of child mortality, and research results show that children do not have an adequate perception of traffic risks and are prone to insecure and impulsive reactions in traffic situations. The data clearly show that educational and restrictive measures need to be complemented by engineering measures that shape pedestrian transport infrastructure (especially crosswalks) according to the needs of vulnerable traffic users. The influence of children's age, gender, group movement, supervision, distractions and the influence of traffic infrastructure has been widely studied.
In articles previously published by the authors, on the basis of field research involving child pedestrians at zebra crosswalks in the vicinity of primary schools in two Croatian and one Italian city, several parameters were identified as significant for the development of the linear regression model for the speed of child pedestrians. Statistical analysis showed that the statistically significant parameters are related to the design of the conflict zone of the transport infrastructure, as well as traffic regulation. As the developed model is considered complex with regard to the number of parameters, a simplified model will be developed in the following of this article. In the first phase, a simplified model with exclusively infrastructural parameters will be developed that would allow a simple application in solving various engineering and planning problems in traffic infrastructure, and its accuracy will be tested. In subsequent phases, models including other main/simple parameters will be developed and tested and the models will be compared. The simplified models thus developed could be used in the early stages of planning by professionals to test or plan pedestrian traffic infrastructure or traffic signals in corridors that are regularly used by children on the basis of easily definable parameters - considering the infrastructure elements and basic data on children.

Keywords: children pedestrians; crosswalks; model development; influencing parameters

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1. Introduction

Children-pedestrians are one of the most vulnerable road users. According to the WHO data (WHO, 2015) in high-income countries children-pedestrians account for 5-10% of all road traffic deaths of pedestrians and in low and middle-income countries the percentage is up to 30-40%.

Different studies aimed to establish factors that influence children behavior and consequently their traffic safety and also locations on road and especially urban road network where children get injured mostly in order to produce conclusions that can help in making traffic infrastructure more in line with children's needs especially on corridors used by them regularly.

As locations where children get mostly involved in traffic accidents different studies pointed similar locations – those on which children walk regularly independently – on the corridors leading to schools, near parks or playgrounds (Abdel-Aty et al., 2007; Ferenchak et al., 2017). Interesting fact is that intersections and pedestrian crosswalks, both signalized and non-signalized, in the intersection area and also mid-block crosswalks are locations potentially dangerous for children independent moving.

As parameters influencing children pedestrian behavior in most of the research their age, gender, way of moving and presence of potential distractors are detected. Age is almost universally detected as influential parameter that influences children behavior (Ampofo-Boateng et al., 1991; Gitelman et al., 2019; Schwebel et al., 2018; Wang et al., 2019). Research pointed that younger and children (5-11) and those over 14 years are mostly in danger. Analyses of impact of children's gender had different conclusions during time and depending on where there were done, recently however most of this type of analyses pointed boys potentially more in risk for traffic accidents than girls (Gitelman et al., 2019; Holm et al., 2018.). Way of moving (independent or in a group) can be seen as certain distractor because many analyses concluded that walking in the group has effect on children behavior, for example children tend to walk slower when in the group than when they walk alone, the same conclusions are made also for use or talking to mobile phone (Deluka-Tibljaš et al., 2021.).

There are also other parameters detected as very important for children traffic behavior like infrastructural, environmental and traffic parameters (Li et al., 2013; Muley et al., 2018.; Maria Cielsa, 2021). Among analysed parameters crosswalk length and width, green time duration, traffic volume, number of lanes and road environmental complexity were mostly analysed.

Establishment of parameters influencing children pedestrian behavior is basis for development of children behavior models. Analyses of existing models describing pedestrian behavior done by the authors (Deluka-Tibljaš et al., 2022.) show that mostly used methodology to develop those models are linear or multiple linear regression and that also neural network models exist. Most off the developed models are intended for general population of pedestrians even children have their specifics in those models they are not taken into account. Potential advantage of models developed on the basis of parameters specific for children is that they can be used in phase where traffic infrastructure regularly used by children is planned or designed without affecting their safety. Important is to use reliable models that correspond to analysed situation well.

The authors of this paper, in previously published work (Ištoka Otković et al., 2021), presented a developed complex model for the prediction of children crossing speed on signalized pedestrian crosswalks, whose application is realistic and possible in the case of reconstruction of transport infrastructure when there is a possibility of data collection on site. The aim of this paper is to develop a simpler model, exclusively with infrastructural parameters, which would enable simple planning of pedestrian infrastructure (largely used by children) in the early planning phase. If such a model does not have sufficient accuracy and applicability, inclusion of other non-infrastructural parameters as qualitative variables is necessary.

2. Model develoment

Complex field research involving child pedestrians at 18 signalized pedestrian crosswalks in the vicinity of primary schools and kindergaden, in two Croatian and one Italian city was done in May and June 2019. The research was done by video recording the pedestrian crosswalks and children, without them being aware of it. All 18 crosswalks were located on primary roads, within intersections. Althogether 480 crossing was recorded, 300 in Osijek (Croatia), 120 in Rijeka (Croatia) and 60 in Enna (Italy). The same methodology was used to collect the data in matching conditions (location, type and position of crosswalk in road network) in the each of three cities.

The movements of each child were analyzed from the recordings as well as the estimation of their age and gender. The recordings were made during one or two working days for every location, during the same period of the day, in the morning, from 7.15–9.00 a.m., in the expected time of arrival of children in schools and kindergartens. Children were recorded in familiar circumstances, on their usual/daily way to school and at the crosswalks they use regularly. This way, it was presumed to record reliable children's traffic behavior which can serve as valuable input for future interventions in traffic systems or infrastructure.

From the recordings, it was possible to analyze / determine the crossing time required for the child to cross the pedestrian crosswalk and the parameters that affect the speed of the child's movement such as: supervision (by adults), movement in a group, age, gender, risk behavior and mobile use. In the case of estimating the child's age, children were classified into groups up to 11 years (approximately primary school), into the group from 11 to 14 years (middle school) and older children (high school). Running over a pedestrian crosswalk was considered risky behavior, and mobile use was considered typing on a mobile phone or talking. The impact of certain infrastructural parameters on the children's movement speed - the length and the width of pedestrian crosswalk and the duration of pedestrian green time were also analysed.

The crossing speed (which is correlated with the crossing time) is a parameter that has a significant impact on traffic infrastructure, such as the introduction of a central pedestrian island or/and on traffic regulation, such as the duration of green time for pedestrians. This is why the pedestrian crossing speed parameter was chosen as it has direct engineering implications.

1.1. Complex linear regression model

Authors Ištoka Otković et al. in their work (Ištoka Otković et al., 2021) presented a complex children pedestrian speed model of linear regression, based on recorded data on children's pedestrian crosswalks recorded in the city of Osijek. Although at each pedestrian crosswalk, for each children's crossing, the time required for the child to cross the crosswalk was recorded, due to the different geometric characteristics of the pedestrian crosswalks where data were collected, the average children crossing speed was chosen as a dependent model variable.

In addition to several infrastructural parameters, the model includes a large number of other parameters related to the behavior of children when crossing pedestrian crosswalks. Individual parameters were analyzed in detail (age of children through 6 categories, movement in the group depending on the number of children in the group, etc.) and as such were analyzed during the development of the model. Nevertheless, the final multiple linear regression model out of a total of 22 analyzed parameters included 13 of them as significant, which certainly places it in a rather complex model. The adjusted coefficient of determination R^2 = 0.84 for the developed model confirms that 84% of the relationship between the children crossing speed at signalized pedestrian crosswalks and the parameters included in the model is explained by the developed linear regression model.

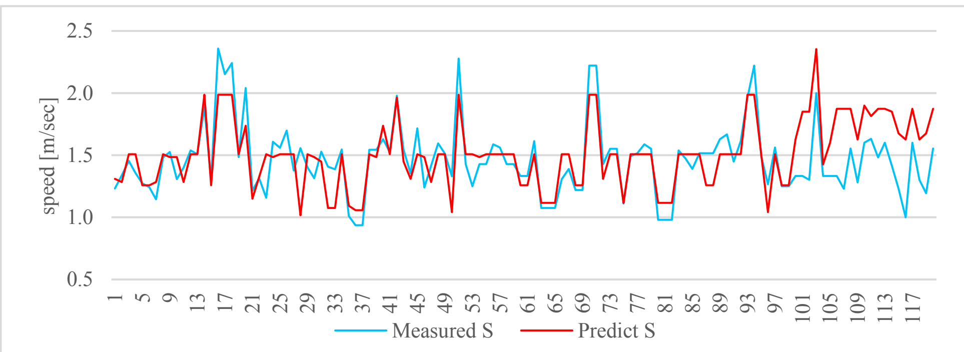

Figure 1. Validation of the complex LR model for the crossing speed measurement database in Rijeka (Ištoka Otković et al, 2021).

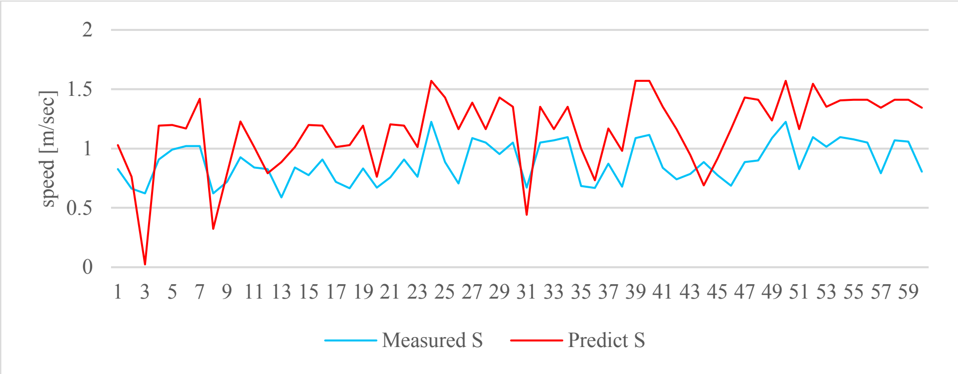

Figure 2. Validation of the complex LR model for the crossing speed measurement database in Enna (Ištoka Otković et al, 2021).

Model validation was performed on data collected by the same methodology in the city of Rijeka (Figure 1) and the city of Enna (Figure 2). While Rijeka and Osijek are cities with similar populations, but with significantly different spatial and urban conditions (the city of Rijeka is in very complex topographic conditions and has a high population density, the city of Osijek has a very favorable position and population), Enna is a smaller city by population (about 30,000 inhabitants) and therefore with a significantly different transport system and habits. The validation results show that the multiple linear regression model developed for Osijek can be used for preliminary assessment of children pedestrian's speed in real traffic conditions in Rijeka but, however, is not applicable in Enna.

Due to the previously mentioned differences in traffic systems and habits of children at pedestrian crosswalks in 3 analysed cities, which resulted in the inapplicability of the developed model, in this paper, authors tried to develop a multiple linear regression model of children crossing speed, but this time combining the databases of all 3 cities, both for development and for model validation. Out of a total of 480 recorded children crossings in all 3 cities, 300 of them were used for model development, while the remaining 180 crossings were used for model validation.

1.2. Simple linear regression model with only infrastructural parameters

In the first step, the authors tried to develop a simple linear regression model based on the available infrastructural parameters: the length and width of the pedestrian crosswalk and the duration of the pedestrian green time at the pedestrian traffic light.

Table 1. Correlation matrix between parameters for simple infrastructure model

	Width of crosswalk	Pedestrian green time	Length of crosswalk	Average children speed
Width of crosswalk	1	0,321	-0,084	0,032
Pedestrian green time	0,321	1	-0,873	-0,310
Length of crosswalk	-0,084	-0,873	1	0,406
Average children speed	0,032	-0,310	0,406	1

From Table 1 it can be seen that the best correlation is between the speed and length of the pedestrian crosswalk while the weakest is with the width. In the simple infrastructure model, 2 out of 3 analyzed parameters were included, the length of the crosswalk and the pedestrian green time (Table 2).

Table 2. Simple infrastructure model parameters

source	value	standard error	t	pr > |t|	lower bound (95%)	upper bound (95%)
Intercept	0,494	0,215	2,298	**0,022**	0,071	0,918
Width of crosswalk	0,000	0,000				
Pedestrian green time	0,004	0,002	1,632	0,104	-0,001	0,008
Length of crosswalk	0,073	0,014	5,099	**<0,0001**	0,045	0,101

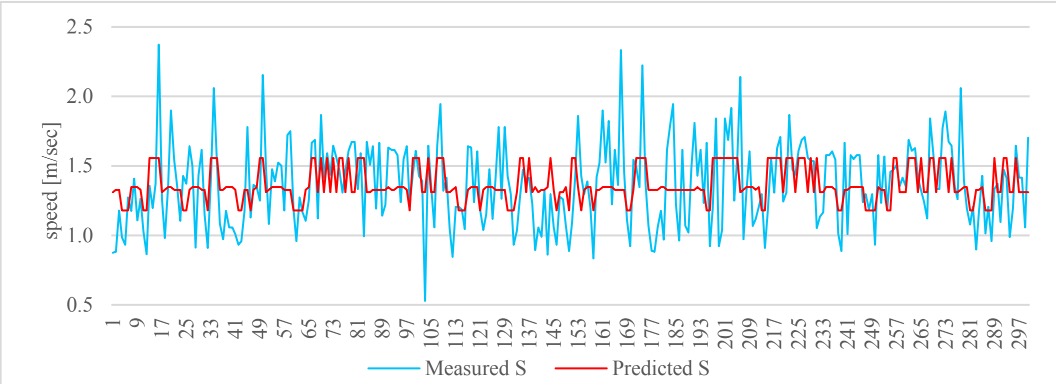

Figure 3. Comparison of measurements and simple infrastructure model prediction for children crossing speed

The adjusted correlation coefficient of the model (Figure 3) is only $R^2 = 0.11$, which shows that only 11% of the relationship between the dependent variable and the independent variables is explained by the model.

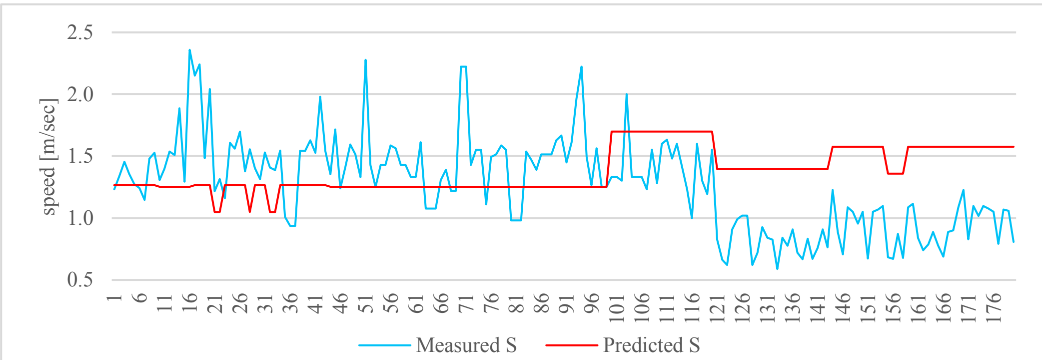

Figure 4. Validation of the simple infrastructure model for children crossing speed

The validation of the model ($R^2 = 0.1$) also showed very poor applicability of the model and the need for additional parameters (Figure 4).

1.3. *Simple linear regression model with infrastructural parameters and additional parameters of children's behavior*

As the simple model with exclusively infrastructural parameters proved to be extremely poor for the purpose of estimating the children crossing speed at signalized crosswalks, in addition to infrastructural parameters, other parameters related to the characteristics of children (gender, age), the manner of movement (alone or in a group, supervised by an adult), risky behaviors (running, mobile use) were also analysed.

In order to use such a model in the case of transport infrastructure planning, when it is necessary to assume certain parameters, some collected data were presented in the form of "dummy" qualitative variables, which are included in the model using binary variables (value 1 for presence of a parameter or value 0 for the absence of a parameter). Therefore, in addition to the 3 infrastructure parameters (quantitative variables), the following dummy variables were analyzed in the model:

- gender
- children up to 11 years of age (corresponding to the completion of primary elementary school)
- children over the age of 11 (secondary elementary school)
- movement in a group
- supervision of adults
- use of mobile phone (talk or text)
- risky behavior (possible running).

Using the forward stepwise linear regression method from the initially analyzed 11 parameters, a model with 7 parameters was developed, two of which are the infrastructure parameter.

Table 3. Correlation matrix between children pedestrian speed and selected parameters for planning model

	width	pedestr. green time	length	gender	running	supervision	age till 11y	age more then 12	move ment in a grou p	mobile use
V_{av}	0,210	-0,470	0,188	0,033	-0,545	0,309	0,135	-0,135	0,345	0,250

From Table 3 it is evident that the best (negative) correlation is between the speed and pedestrian green time, while of the other parameters, running, movement in a group and supervision also have a significant impact.

Table 4. Planning model parameters

source	value	standar d error	t	pr > |t|	lower bound (95%)	upper bound (95%)
intercept	1,297	0,113	11,521	**<0,0001**	1,076	1,519
pedestr.green time	-0,006	0,001	-7,752	**<0,0001**	-0,007	-0,004
length	0,018	0,006	3,102	**0,002**	0,006	0,029
run-0	-0,647	0,053	-12,141	**<0,0001**	-0,752	-0,542
supervision-0	0,188	0,037	5,003	**<0,0001**	0,114	0,261
age till 11y.-0	0,082	0,027	3,091	**0,002**	0,030	0,134
movement in a group-0	0,275	0,026	10,390	**<0,0001**	0,223	0,327
mobile use-0	0,257	0,038	6,683	**<0,0001**	0,182	0,333

the mark 0 next to the parameter indicates the absence of that parameter

From the values of the model parameters (Table 4), it can be concluded that a longer duration of pedestrian green time at a pedestrian crosswalk reduces the speed of children. Conversely, the speed of children at the pedestrian crosswalk will be higher if there is no adult supervision, if there are only children over the age of 11 at the pedestrian crosswalk who do not move in a group and do not use a mobile phone. If running is expected over a pedestrian crosswalk, or if it is a longer pedestrian crosswalk, the speed will be higher.

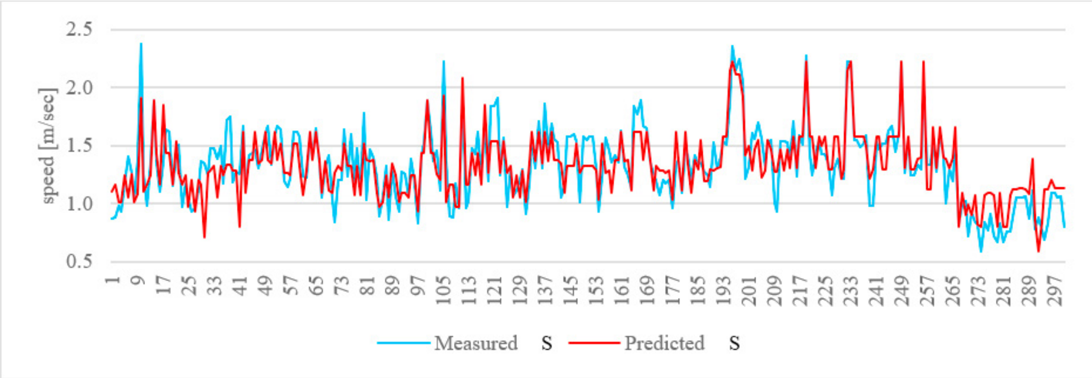

Figure 5. Comparison of measurements and planning model prediction for children crossing speed

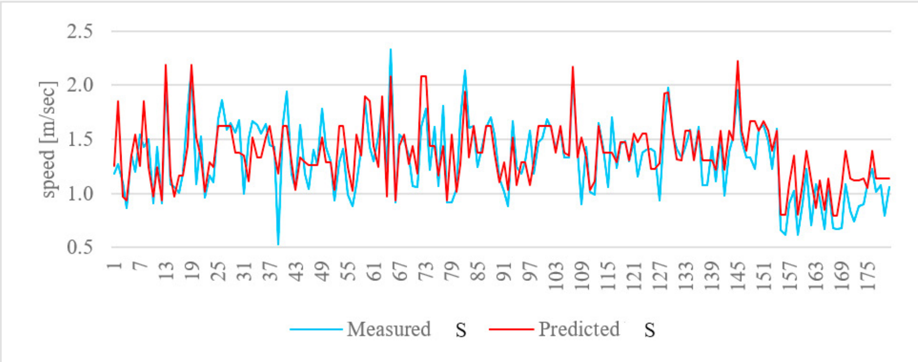

Figure 6. Validation of the model for children crossing speed

The adjusted correlation coefficient of the model is $R^2 = 0.69$, which shows that 69% of the relationship between the dependent variable and the independent variables is explained by the model (Figure 5). The same is confirmed by model validation (Figure 6).

2. Conclusion

The results of many studies have confirmed that children are among the most vulnerable users in transport, and therefore it is necessary to pay special attention to the planning and reconstruction of transport infrastructure in places where we expect an increased number of such users. Pedestrian crosswalks near schools are places that children use regularly / daily on the way to school.

Many authors have developed models for predicting pedestrian crossing speed at signalized pedestrian crosswalks, without taking into account the specifics of children's movement and behaviour at such crosswalks.

For this reason, the authors of this paper, in their previously published work, developed, based on extensive collected data, a rather complex model for predicting the speed of children at pedestrian crosswalks. Children speed was used as one of the possible parameters that describe children behavior from which some specifics of children traffic behavior can be detected. Also, the children pedestrian speed is directly correlated to the time that, in this case children-pedestrians, spend on the conflict area of crosswalk (e.g. on the traffic lines where possible conflict with vehicles is likely to happen). Although this complex model proved to be very reliable ($R^2 = 0.84$), considering the number of parameters required for the application of the model, it can be classified as a rather complex model. As such, it can certainly find its application in the case of reconstruction of transport infrastructure, when it is possible to collect the required number of parameters through field research. Another disadvantage of the developed complex model is somewhat poorer applicability to a significantly different transport system network and children pedestrian habits of those for which the model was developed.

In order to enable better applicability of the model on the transport networks of all 3 cities, the authors used a unified database of all 3 cities to develop the model. Out of a total of 480 recorded child crossings, 300 were used to develop a simple model and 180 to validate. In the first step, a very simple infrastructure model was developed, the accuracy of which is too low to be applicable ($R^2 = 0.11$), which indicates that the speed of children at pedestrian crosswalks is affected not only by infrastructure parameters but also by a number of other parameters. Therefore, in the next step, with the use of "dummy" variables, still a relatively simple model, including 2 infrastructure and 5 other parameters was developed. As the model has sufficient accuracy and applicability ($R^2 = 0.69$), its simple application is possible at an early stage of transport infrastructure planning or reconstruction.

In the further research, it is recommended to try to connect models for predicting the children crossing speed (simplified model) with microsimulation traffic modelling in the analysis and evaluation of alternative transport infrastructure solutions used by children in their environment.

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