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Assessment of selected traffic calming measure on the example of the Armii Krajowej street in Cracow[1]

Streszczenie: W artykule przedstawiono porównanie zachowań kierowców przed i po wprowadzeniu środka uspokojenia ruchu na przejściu dla pieszych na ulicy Armii Krajowej w Krakowie. W tym miejscu dochodziło do wielu wypadków z udziałem pieszych, dlatego zdecydowano się na nietypowe rozwiązanie – gumowe słupki pomiędzy pasami ruchu przed przejściem dla pieszych, uniemożliwiające zmianę pasa ruchu, jak również mające na celu zredukowanie zachowań, które powodują większość wypadków w tym miejscu, czyli wyprzedzania i omijania na przejściu dla pieszych oraz nadmiernej prędkości. Ze względu na krótki czas od momentu wprowadzenia zmian nie było możliwe porównanie statystyk wypadków, dlatego też skupiono się, poprzez analizę nagrań wideo, na obserwacji zachowań kierowców, takich jak osiągana przez nich prędkość oraz popełniane wykroczenia, np. wyprzedzanie lub omijanie w rejonie przejścia dla pieszych.
Słowa kluczowe: uspokojenie ruchu, środki uspokojenia ruchu, badanie skuteczności uspokajania ruchu.

Introduction: Aspects of functioning of traffic calming

Every day thousands of people get killed, hurt or damaged in road traffic. Therefore a standardized traffic safety is required. A vast set of actions are undertaken to improve the level of traffic safety and decrease the number of accidents and injuries. One of the methods to increase the safety level is traffic calming, which gives a set of solutions for road designers and road administrations.

According to a definition by Institute of Transportation Engineers [1] traffic calming is a set of measures, the purposes of which are to reduce the negative effects of motor vehicle use, alter driver behaviour and improve conditions for non-motorised street users. That includes reduction of traffic volume, thus noise and air pollution, improvement of road safety level, and the quality of life.

The effects of traffic calming depend on the spatial scale of implemented solutions. O'Brien [2] defines three scales of influences:

- Level I – local scale, where traffic volumes and capacities are not important.
- Level II – actions to restrain traffic impacts at a corridor, where traffic conditions are important but only inside the corridor, not really at the network level.
- Level III – actions at macro-level where restraints are introduced in a greater area and traffic volumes, capacities and levels of service are important in a city-wide scale.

Local scale implementation includes point traffic calming which are measures that are placed at specific points on the road, for example: speed humps, speed cushions, elevated pedestrian crossings, narrowing of the street, chicanes, etc.

In this article, an innovative traffic calming measure has been assessed to answer the question if it improves the safety level. Implemented measure is a set of flexible traffic bollards installed between the lanes of the Armii Krajowej street in the approach area of the pedestrian crossing, Instead of comparing the statistics, what was impossible due to the short time from the introduction of the measure, the behaviour of drivers was compared.

Examples of traffic calming impact on road traffic safety

During the years was made a lot of different analysis assessing different measures of traffic calming impact on safety. History of traffic calming reaches the times of the expansion of the car usage. The basic aim of the traffic calming was to reduce the vehicle speed. Traffic safety analysis are based on the assessment of the effectiveness of speed reduction and driver behaviour changes for particular traffic calming measures. There are numerous studies comparing the before and after data on speed, driver behaviours and accident reduction. Most widely used parameters for evaluating the effect of traffic calming are mean speeds and 85 percentiles of speeds on the road sections and its surroundings. In a slightly greater scale, also travel times and driver behaviours are examined.

The vast majority of traffic calming measures has already been examined considering various local conditions. For example speed cushions were investigated by Layfield and Parry [3]. A comparison of effectiveness of speed humps, speed slots and speed cushions was described by Johnson and Nedzesky [4]. Another construction measures, including bulbouts – intersection narrowings, refuge islands and elevated crossings and intersections, were examined widely by Cynecki and Huang [5]. More detailed analysis provide also the data on precise speed profiles of vehicles on testing road section. Such research was conducted by Garcia et al. [6] were speed profiles were derived and compared on the road section containing of median strip, roundabout, speed hump and speed tables.

Detailed data on the impact of traffic calming measures is presented on the basis of literature review in German conditions. The comparison of the vehicles' speed before and after the introduction of traffic calming was presented in the table 1.

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Tabela 1

Changes of the velocity with different traffic calming measures source			
Model Area	Esslingen	Ingolstadt	Mainz
Before: Tempo 50; After: Traffic-Calmed Sector			
Measuring Point Number	-	-	1
average velocity (before) [km/h]	-	-	36
average velocity (after) [km/h]	-	-	30
Difference [km/h]	-	-	-6
Before: Tempo 50; After: Tempo 30 with constructional measures			
Measuring Point Number	3	1	5
average velocity (before) [km/h]	45	42	51
average velocity (after) [km/h]	33	34	38
Difference [km/h]	-12	-8	-13
Before: Tempo 50; After: Tempo 30 without constructional measures			
Measuring Point Number	1	3	3
average velocity (before) [km/h]	37	39	46
average velocity (after) [km/h]	32	35	40
Difference [km/h]	-5	-4	-6
Before: Tempo 50; After: Tempo 50 with constructional measures			
Measuring Point Number	3	-	5
average velocity (before) [km/h]	49	-	51
average velocity (after) [km/h]	45	-	44
Difference [km/h]	-4	-	-7
Before: Tempo 50; After: Tempo 50			
Measuring Point Number	3	1	2
average velocity (before) [km/h]	45	49	51
average velocity (after) [km/h]	43	46	48
Difference [km/h]	-2	-3	-3

Source: [7]

The following table shows, that the implementation of traffic calming measures, gives the bigger effect on speed reduction, compared to using only traffic signing. Another safety analysis have been undertaken in a matter of traffic safety improvement through traffic calming. Therefore, the overview of the selected safety assessments is shown in the table 2.

Tabela 2

Effects of traffic calming in a matter of road traffic safety		
Measure	Change	Source
Introduction Tempo-Limit 30 instead of Tempo-Limit 50	- Reduction of vm of unhindered driving vehicles by circa 1.3 % from 41.5 km/h to 38.2 km/h - Less traffic conflicts (-20%)	Measurements in 10 model areas („Flächenhafte Verkehrsberuhigung" = areal traffic calming)
Conversion of the priority to give way	- Reduction of the velocity in junction areas by up to 20 km/h - Stabilization of the traffic flow	„Stadtverkehrsplanung – Methoden, Grundlagen, Ziele" = city traffic planning – methods, basics, targets [8]
Introduction of speed reduction areas	- Increase in safety - Decrease in number of accidents with personal injury by about a fourth	GDV (German Insurance Association) – Effects of the design of traffic calming areas on casualties (=Auswirkungen von verkehrsberuhigten Maßnahmen auf das Unfallgeschehen)
Radar control and introduction of tempo-limit 30 zones	- Decrease of the average maximum velocity by 7.5 km/h (-11.4%) - Reduction of the 85-%-velocity by 10 % to 43.3 km/h - Arithm. mean decreases by 11.5% to 36.3 km/h	Verkehrsentwicklungsplan Stadt Erlangen, Referat für Stadtplanung und Bauwesen (=traffic development plan, city Erlangen, project for city planning and building trade)
Introduction of Tempo-limit 30 in cities	- Decrease of accidents by 9 % with constant amount of accidents - Decrease of accidents in lines (longitudinal) by 12 % - Halve the stopping distance on dry road-surface - Risk for pedestrian-fatalities decreases by 12.5 %	FGSV 210/1 „Wirkung von Maßnahmen zur Umweltentlastung" Teil 1 (= part 1: Effects of measurements to relieve the environment)

Indicators related to the road traffic safety

The study area was chosen by the road administration for implementing an innovative traffic calming measure because of numerous accidents on the pedestrian crossings. Flexible traffic bollards were implemented on two pedestrian crossings which were high-risk sites for pedestrians. In the table 3 accident data for those crossings were gathered showing the number of accidents and injuries in last 5 years. From the police data which collects information on accident and collisions, cases of pedestrian accidents and rear impacts were derived. Pedestrian accidents show how many pedestrians were hit each year on the pedestrian crossing. Rear impacts are shown because they occur on the site in situations when a car stops in front of the crossing to let the pedestrian in and another vehicle hits the preceding car due to too high speed and lack of attention.

Tabela 3

Accident data in the preceding 5 years on analysed crossings						
Year	Pedestrian accident	Severely injured	Slightly injured	Rear impact	Severely injured	Slightly injured
2013	3	1	2	50	1	9
2014	11	6	5	63	0	3
2015	7	3	2	64	2	5
2016	8	1	4	72	0	6
2017	15	8	6	69	0	6

For a better understanding of the accident purposes, typical conditions were analysed to mark when the highest risk for accident or collision on the site occurs. This data is shown in the table 4 and presents that most accidents occur in perfect weather conditions on working days in rush hour when the traffic volumes are high and most people finish their jobs crossing the road by foot or driving their cars.

Tabela 4

Highest accident rate based on accident data in the preceding 5 years								
	by month		by day of the week		by hour		Weather conditions	
Highest accident rate	December	11,7	Wednesday	18,3	18.00-19.00	8,8	Good	47
	June	9,3	Tuesday	17,1	13.00-14.00	8,3	Rain	26
	April	9,1	Monday	16,4	16.00-17.00	8,1	Cloudy	24
	October	9,1	Thursday	15,5	14.00-15.00	7,9	Snow	2

Because of the short time from introducing the new traffic calming measure, it was not possible to compare the long term safety and accidents statistics. Instead, the emphasis was put on the observation of the traffic through the video recording. To obtain a proper observation area, the drone (UAV) with aerial camera device was used.

Regarding the activity on streets, there are four main subjects which can be responsible for accidents. Each component of the loop system "Driver-Vehicle-Surrounding" has some influencing variables while the part of surrounding can be divided up into two separate topics. "Setting" more refers to the surrounding conditions like weather or the behaviour of other traffic participants. The term "road" is more an indicator which is important for the street itself, e.g. considering the surface conditions or the alignment.

In a comparison example with two drone recordings of the same road section before and after introducing a traffic calming measurement a drone can only gain data via traffic recordings from the sky. With these videos it can measure distances, average velocities or accelerations of vehicles and pedestrians.

Indicators measurable with the drones are:

- The velocity of each vehicle or pedestrian,
- The lengthwise acceleration,
- The distance to other traffic participants or obstacles in the vehicles driving direction,
- The amount of surrounding traffic participants of each vehicle,
- The velocity and de-/acceleration of traffic participants,
- The width of the road and its lanes and
- The number of lanes

To evaluate if a road section is safer or not the following questions should be answered:

- Are safety distances observed?
- Is there now a more fluent traffic occurred or is it more unstable?

Due to the measured velocity and distances and referring to this formula, the drone-recordings can evaluate if a situation on the road is safer and compare it to other situations. The videos can also figure out some critical situations which are dangerous but solved without some real happened accidents.

Area description – accidents data, traffic flow data

The area analysed in this paper is the Armii Krajowej Street in Cracow. It is located in the Bronowice area, in the north-western part of the city. It is a two-roadway street with two lanes on each roadway. The street is a collector street connecting Rondo Ofiar Katynia (main node of outlet routes in north-western Cracow) and main north-south transit route – Aleja Trzech Wieszczów). The Armii Krajowej street is a part of the corridor serving Bronowice residence area, and AGH University of Science and Technology campus and students' dormitory. Six public transport bus lines operate on this street for various destinations throughout the city.

Analysed pedestrian crossing is placed near multi-storey buildings with various functions: office, hotel and apartments. The office buildings generate a great pedestrian traffic to the public transport stops, which includes crossing the street.

Due to numerous accidents between pedestrians and vehicles, causing deaths and injuries, the traffic calming measure was installed in the area of pedestrian crossings on this street. It is a set of flexible traffic bollards between the lanes, together with narrowing the lane width, before the pedestrian crossing – as seen in photo 1. Its aim is to reduce

Fig.1. Traffic calming measure on the analysed area.
Source: http://krakow.wyborcza.pl

the amount of accidents with pedestrians caused by not giving the way to pedestrians on the pedestrian crossing through overtaking and exceeding the speed limit.

Collection of traffic flow data derived from the city continuous count stations was used to determine the volume of traffic and its variability on the Armii Krajowej street. The annual average daily traffic in the testing site is around 25 000 vehicles daily in both directions. During peak hours the highest traffic volumes reach about 1 200 vehicles per hour in one direction. The capacity of the street is limited by adjacent signalized intersections on both ends of the examined section.

For the analysis before and after the implementation, there were chosen the periods of the similar traffic flow, in the afternoon peak hour, around 3 PM. The traffic volumes – expressed in vehicles per hour and in the pedestrian per hour crossing the street, were shown in the table 5.

Tabela 5

Pedestrian and vehicle flow per hour in the analysed period – the measurement before and after the change

		Before	After
Vehicles	Eastbound	1182	1040
	Westbound	1095	1120
Pedestrians	Southbound	359	343
	Northbound	36	4

The 'before' study was conducted during typical workday and the 'after' study was conducted during the holiday period. Despite this fact, traffic volumes were similar in both cases. Based on the continuous counts average traffic flows in afternoon peak hour were derived for the comparison to the results from the research. In the figure 2 the comparison of traffic flows is shown. Data from 05.2017, 07.2017 and 05.2018 are for the 'before' situation and data from July 2018 were collected after the implementation. The month of May is used for the comparison with the holiday month of July and data from year 2017 is shown to compare with the current conditions.

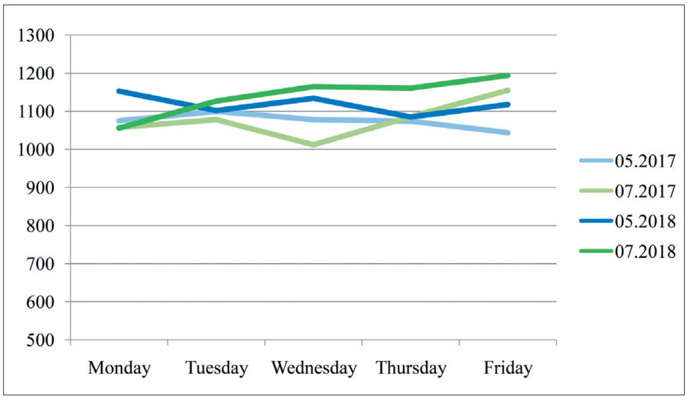

Fig. 2. Comparison of average traffic flows during afternoon peak hour per direction on testing site during typical week [veh/h]

As it is shown in the figure the variation of traffic flows is not significant. Average peak hour traffic volume is also similar with data counted during the observation with the drone.

Descriptions of measurement methods

To observe the changes of drivers' behaviour and interaction between drivers and pedestrians with a high level of precision, and to ensure the continuity it was necessary to have the motion recorded by a video camera. To provide undisturbed image, the video was taken from the drone hovering above the analysed area (95 meters above ground level), covering circa 130m of road length.

In order to ensure continuity in the observation of every vehicle and pedestrians, video recording can be used. Previously, analysis of the video and identification of the vehicles trajectories were performed manually and this was a very time-consuming task. Nowadays, with the use of deep machine learning through creating classifiers, it is possible do detect vehicles automatically, trace them, and produce trajectories.

The area which can be recorded depends on the angle of the camera and the obstacles which covers the traffic, as well as the shape of the road, which can limit the size of the area that can be recorded. The optimal solution is to position the camera in such a manner that it is recording from above in order to minimize the amount of obstacles, as well as to simplify the trajectory calculations. This would mean installing the camera at a point high above the street or to record from the air. To provide coverage of a great area, when only low buildings are present, an unmanned quadcopter was used, hovering 95 meters above ground level, and recording the traffic along an approximate length of 130 meters of road. The quadcopter used is able to fly for around 25 minutes, which, taking into account a safe reserve of battery time, take off, positioning above the street and landing, leaves around 15-20 minutes of traffic recording at any one time. Recordings were made at a high definition of 1920*1080 pixels resolution, and 40 frames per second.

The trajectories from the video were processed by the company DatafromSky [9]. The result of processing is delivered in two files – one of these is the file for the DatafromSky viewer software which is used to visualise the results, and the other is the csv file with all the data, containing timestamp, coordinates, object ID, and object type (car, heavy vehicle, bus, bicycle, pedestrian). The screenshot of the DatafromSky viewer software is presented in the figure 3.

Types of dangerous situations

The Armii Krajowej street, due to presence of non-signalised pedestrian crossings, has a high rate of pedestrian--car accidents. It is a result of the great amount of car and pedestrian traffic, 50 km/h speed limit, which is exceeded by the drivers, overtaking the cars on pedestrian crossing or even omitting the car that stops to give the way to the pedestrian.

According to the measurements before the introduction of traffic calming, per 100 cars, the 3.7 cars in the direction eastbound and 4.6 cars direction westbound were overtaking on, or just before the pedestrian crossing. Apart from that, 1.5% of cars direction eastbound and 1% of cars direction westbound, omitted the other car giving a way to the pedestrian, which affected 7.3% of pedestrians. On the

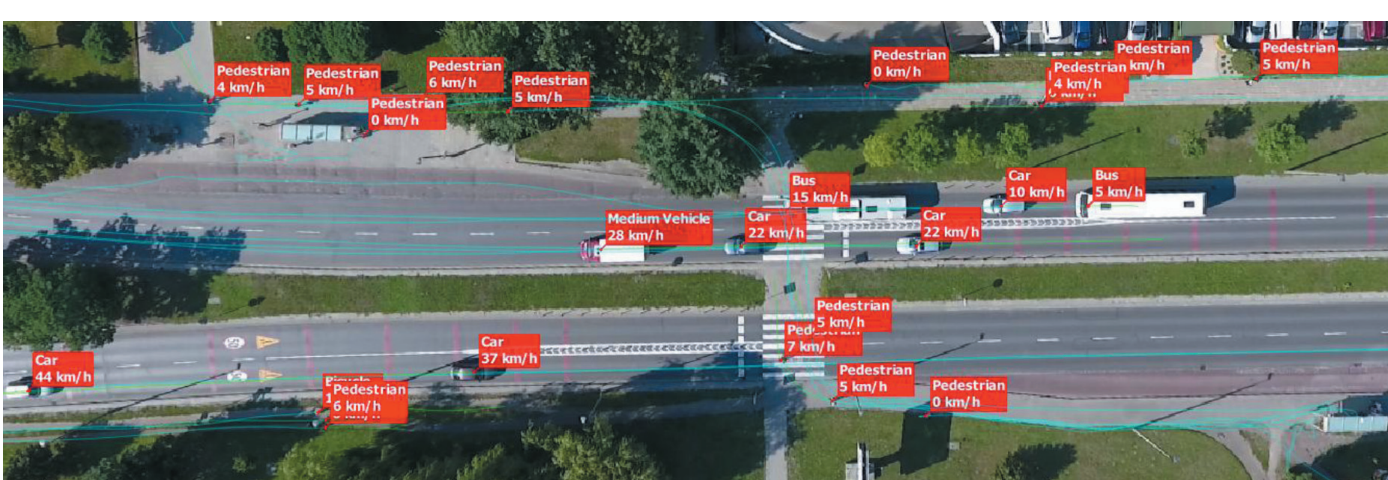

Fig. 3. DatafromSky viewer software screenshot with car detection and trajectory data displayed
Source: own

pedestrian crossings, maximal measured speed is around 70 km/h, but only around 5% of cars travels faster than 50 km/h in that area.

Comparison of speed, and number of overtaking, number of conflicts, waiting times to cross the road, frequency of cars stopping and other aspects

The vehicle motion data were processed in order to extract the instantaneous velocities in the resolution of 0,1m. The street was then divided into parts, shown on the figure 2 in order to extract the speed distributions in the characteristic areas.

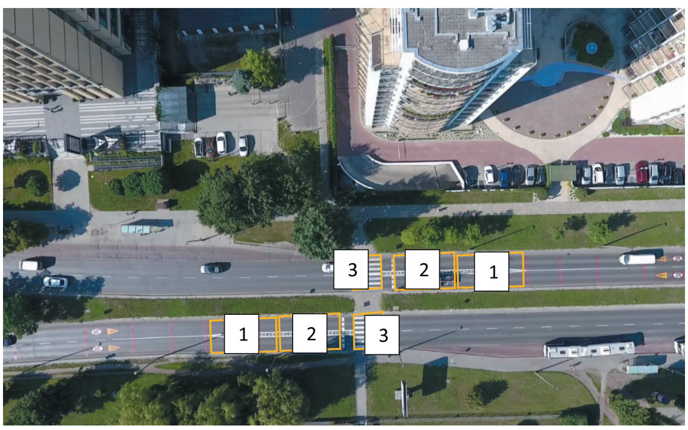

Fig. 4. Map of the analysed streets with marked characteristic areas

In all the figures, the speeds, located on the vertical line are given in kilometres per hour. The orange bar on the distribution or line in cumulative distribution pictures the behaviour before the change, and the blue ones – after.

The first characteristic area is located in the biggest distance from the pedestrian crossing – on the beginning of the traffic bollards. The charts are shown in the figure 5.

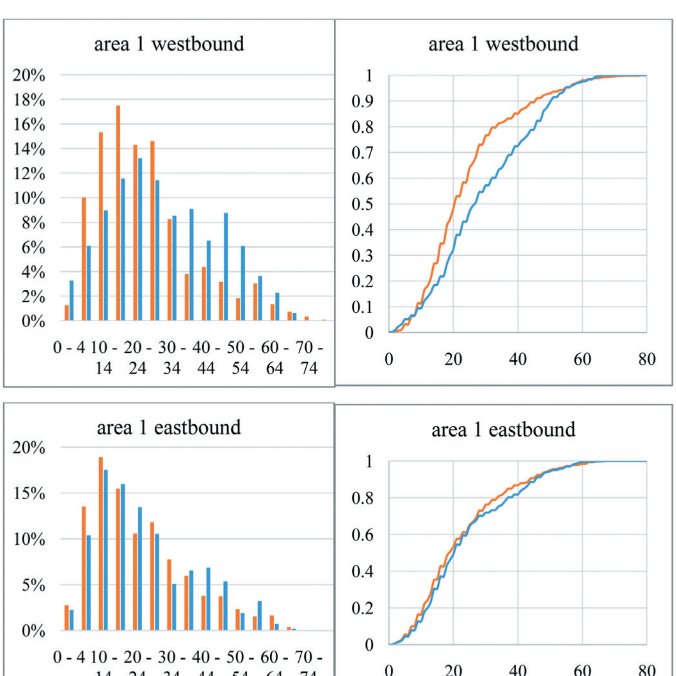

Fig. 5. Speed distributions of the area on the beginning of the traffic bollards

On that charts we can see quite similar speed distributions for both situations – before and after with the slightly greater speeds after the change. Average speed changed from 24 km/h to 29 km/h westbound and from 22 km/h to 24 km/h eastbound. That means that in that area the traffic calming didn't affect the speed.

The second area is located just before the stop line – before the pedestrian crossing. The distributions are shown on the figure 6.

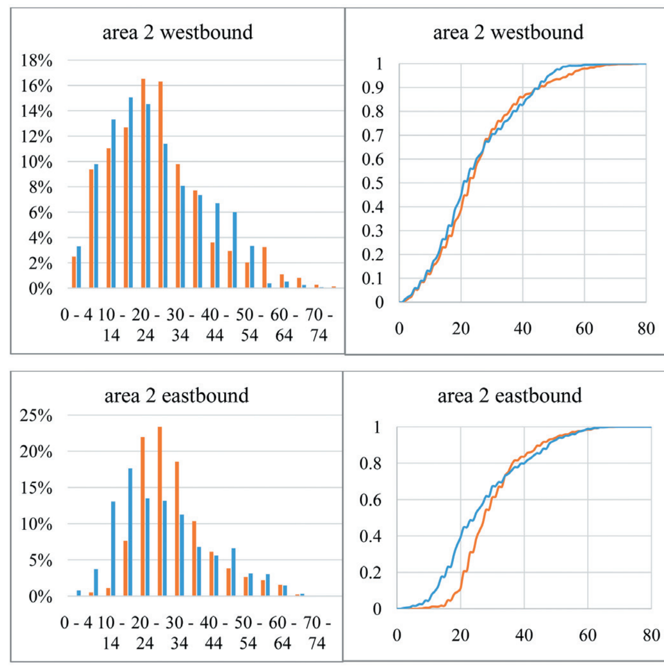

Fig. 6. Speed distributions of the area on the beginning of the traffic bollards

On the charts shown above, it is shown, that for the direction westbound, the speeds does not differ before and after the change. For the direction eastbound, the speed slightly decreases after the change. The average speeds in the direction westbound decreases from 25.6 to 24.7 km/h. and in direction eastbound – from 26.2 to 24 km/h.

Finally, the third area, where the distributions were showed, is the pedestrian crossing. The speed distributions of this six-meter-long area are shown in the figure 7.

After the change, for both directions, the speed after the change is slightly lower. For the direction westbound, it falls from 32 to 30.8 km/h and for the direction eastbound – from 31.5 to 30.4 km/h.

The analysis of the Armii Krajowej street pedestrian crossing shows, that the used traffic calming measure does not have the significant influence on speed – only the minor speed decrease was noted. The positive effect is, that in spite of noting higher speeds far from the pedestrian crossing, which could happen because of the random seed of the traffic caused by filming in the different days, the speeds near the pedestrian crossing got lower.

Another analysed aspect was the number of overtaking on, or before the crossing and omitting the car which gives the way for the pedestrian. Overtaking on or before

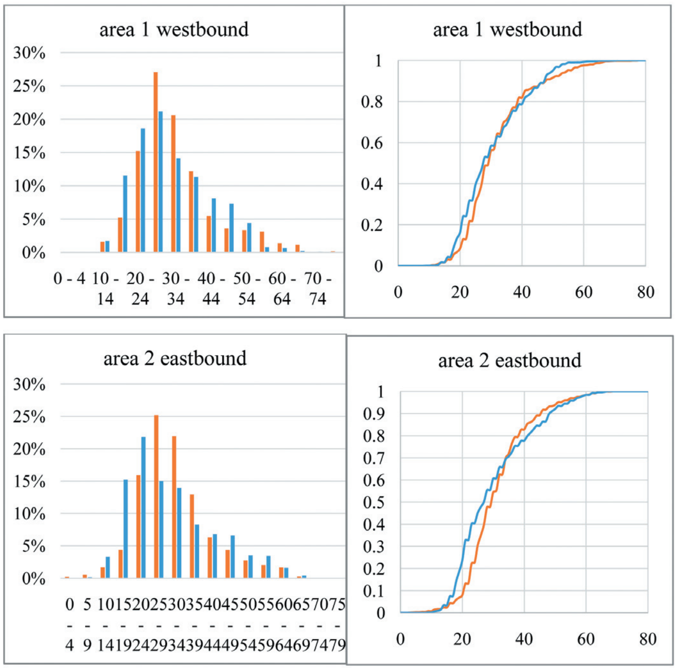

Fig. 7. Speed distributions on the pedestrian crossing

the pedestrian crossing was counted when the front of one vehicle passed the front of another vehicle, on the pedestrian crossing or in the area of continuous line. Omitting the car was counted, when one vehicle stopped on the stop line to give the way to pedestrians, while the other drives by.

As written before, in paragraph 6, before the change, per 100 cars, the 3.7 cars in the direction eastbound and 4.6 cars direction westbound were overtaking. Apart from that, 1.5% of cars direction eastbound and 1% of cars direction westbound, avoided the other car giving a way to the pedestrian, which caused 7.3% of total number of pedestrians slow down or stop in the middle of the street.

After the change, the number of overtaking per 100 vehicles fell to 2.9 vehicles direction eastbound and to 2 vehicles direction westbound. The number of cars omitting another on the crossing fell to 0.72% direction eastbound and 0.67% direction eastbound and affected 4.3% of pedestrians.

The last, there was counted the percentage of pedestrians, who were given the way without stopping, compared with that, who had to stop before crossing the street. Before the change, direction westbound, 65% of pedestrians could cross the street without stopping, whereas, after the change, that amount rose to 90%. On the opposite direction, values rose from 50% to 78%. On both of the directions, there is a significant growth visible, which is a positive result.

These statistics shows that the traffic calming solution installed on the Armii Krajowej street reduced a very dangerous behaviour of overtaking or omitting on, or before the pedestrian crossing. In future this could contribute in the decrease of number of accidents and possibly reduction of injured pedestrians crossing the Armii Krajowej street.

Summary and further research suggestions

This paper contained a short assessment of the very new and non-typical traffic calming measure, which aim was to improve the pedestrian safety on the pedestrian crossing, especially through minimising the amount of vehicles overtaking and omitting before or on the pedestrian crossing. The paper presented the comparison of speed choices as well as overtaking and omitting behaviours in the surrounding of the crossing. The result showed the non-significant decrease of the speed in the area of the crossing, but the amount of overtaking and omitting had fallen by half, which is a promising result. That analysis, was made in the short time after the change. That means, the size of the drivers' behaviour database was limited – for more diversified results, a longer video material, taken in the bigger amount of days could have been recorded. The videos could also be repeated after the longer period of time, when drivers domesticate with the new solution, as well as after the school holiday time – that would help to observe the behaviour for a bigger and more similar, in the mean of trip motivations, traffic. For further research, the analysis of vehicle dynamics could be undertaken, in the matter of reaction time and distance from conflict, deceleration force, and the pedestrian waiting time to cross the road. Also, the observation of drivers' behaviour in smaller traffic flow could reveal the differences. Finally, the future will bring the accident statistics from the year after the change to compare the safety level with the situation before the installation. That would allow to make a classic accident-based analysis, to finally state if the safety improvement took place..

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