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Effects of countdown timers on traffic safety at signalized intersections

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ABSTRACT: *Improving safety is one of the most important tasks of traffic engineering. In the road network, intersections are the places where conflicts most often occur. Therefore, these objects are of particular interest to engineers, designers and researchers. The possibilities of using modern technologies give a chance not only to achieve greater traffic efficiency, but also to ensure safe passing for all road users.*

One of such solutions are countdown timers, i.e. support devices for traffic lights which show the time (in seconds) remaining before the currently displayed signal on traffic light change. In some Polish cities those devices are installed on a growing number of intersections. However, the introduction of such new solutions without prior examination of their impact on safety is not recommended. The use of countdown timers at signalized intersections changes the way traffic control signals are perceived by drivers.

To compare the impact of the device on the behavior of drivers, three different intersections have been selected depending on the function of the intersection in the transportation network. The measurements were made in two periods of research: for a week with enabled and disabled countdown timer devices. This article is a continuation of the previous research work carried out by the authors on determining the impact of the countdown timers on traffic conditions. The aim of this article is to show results of the analysis of the time distribution of vehicles entering the crossroads during the red signal for different type of the intersections. The results of the case study show that the countdown timer devices improve safety. Depending on types of intersections during the research with the enabled countdown timers from 22,65% to 32,03% less of the vehicles drove into the crossroads in a prohibited period.

KEYWORDS: *countdown timers, traffic safety, signalized intersection, driver behavior*

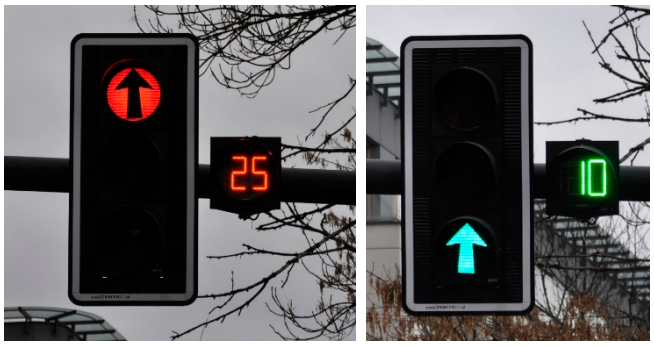
1. INTRODUCTION

Traffic safety is a crucial factor for transport (Oskarbski, 2016; Rudyk, Szczepański, & Jacyna, 2019). Depending on the country there are laws governing proper movement on roads. Several factors influence the level of road safety. The most notable of these are speed, organization of road traffic, condition of road infrastructure, user behavior, and technical condition of vehicles. Researchers from around the world and traffic safety professionals are trying to find new solutions to improve road safety. Over the years new technologies have been introduced in transport with different effects on safety (Hamandi, 2013; Wawrzyński & Jacyna, 2015; Nosal Hoy, Solecka, & Szarata, 2019). One of the categories of such technologies are the Intelligent Transport Systems (ITS), which contain a lot of useful tools (e.g. variable-message sign, collision avoidance systems) to improve level of the safety (Ganin, Mersky, Jin, & Kitsak, 2019; Żochowska & Karoń, 2016; Macioszek, 2014). The major task for the traffic lights is to give proper information to road users. New technology and services from ITS allow to faster and more accurate information to be provided (Meyer, 2016). The variable message signs are examples of such devices. The law in some countries is not ready for the new technologies, which should be tested under real conditions (Wengel & Okos, 2019).

Devices may affect the road users differently, depending on various factors e.g. traffic flow, localization, location of pedestrian's facilities. The introduction of new solutions and devices for road use requires particular attention to be paid to the safety of road users. The new device or solution connected to the current infrastructure without prior examination of their impact on safety is not recommended (Wolshon & Pande, 2016).

Countdown timers are support devices for traffic lights which show the time (in seconds) remain-

ing before the currently displayed signal on a traffic light changes (Miłaszewicz, 2018). These devices are used in Poland on a growing number of intersections. Figure 1 presents the example of such a device in two cases. Fig. 1a shows the example for the time counted down to the end of the red signal and the Fig. 1b shows the time counted down to the end of the green signal.



a) b)

Figure 1. Examples of the countdown timers functioning at the intersections in Poland. Source: Own research

Displaying the countdown time on the device causes an apparently shorter waiting time until the change of light signal. The introduction of countdown timers at signalized intersections changes the way traffic control signals are perceived by drivers (Felicio, Grepo, Reyes, & Yupingkun, 2015, Huang, Fujita, & Wisinee, 2017; Rijavec, Zakovšek, & Maher, 2013). Depending on the nature of the driver this may be a source of stress or motivation to act too quickly when the lights change, and could be the reason for dangerous incidents such as entries onto the intersection at red signals or rear end collisions (Devalla, Biswas, & Ghosh, 2015; Napiah, Koh, & Che Long, 2007, Botzoris, Papakatsikas, Profillidis, & Galanis, 2017; Fu, Zhang, Qi, & Cheng, 2016; Biswas, Ghosh, & Chandra, 2017).

The use of these devices raised many controversies connected with low knowledge of their impact on safety. The public perceptions of the devices on the examined intersections were positive, many of drivers praised the new solution (Kempa & Bebyn, 2014). This positive attitude to the device comes from the drivers feeling during waiting to the change of the signal. Drivers who know the time until signal change are more relaxed. Similar research has been conducted in Bangkok by analyzing the perceptions of drivers. Close to 95% of the respondents said that they felt a positive impact of the device (Limanond, Prabjabok, & Tippayawong, 2010).

The methodology to determine the influence of the function of the intersection with countdown timers in the urban transportation network on the level of safety of the intersection has been presented in the article (Sobota, Karoń, Żochowska, & Kłos, 2018). The study of safety has been prepared only for a comparison of the number of vehicles passing the stop line when displaying the red signal on the traffic light, in two periods of time – for one week with the countdown timer on and one week when the device was off. It showed that at each of the examined intersections more vehicles crossed the stop line during the red signal when the countdown timers were off than when they were on (482 more illegal passing through the stop line have been recorded).

The results of previous studies on traffic volumes and the structure of vehicle types at various intersections conducted by the authors confirmed the validity of the functional division of the examined intersections into the following types (Sobota, Karoń, Żochowska, & Kłos, 2018):

- intersections with non-urban traffic,
- intersections with urban traffic,
- intersections with mixed traffic.

This classification of the intersections is also used in this paper, so the data presented here were collected at the same intersections.

Countdown timer devices are described in the literature and used in many places in the world (Felicio, Grepo, Reyes, & Yupingkun, 2015). One of the important factors connected with countdown timer device is the type of work. There are three types of the same device, which differ by the way the time is displayed (Islam, Hurwitz, & Macuga, 2016). The first group shows only the time counted down to a red signal, the second is only for the green signal, and the third is for both signals (Chiou & Chang, 2010). These three approaches to giving information to drivers have different impacts. Displaying information about the green signal improves safety by reducing emergency braking at the last moment during changing of the signal. Information about ending of the red signal could cause unsafe situations, where vehicles enter the intersection during the last seconds of the signal. The countdown timer devices analyzed in this article belonged to the third group and had one display, which showed the time for green and red signals in turn.

Device could also have impact on the conditions of traffic. The analysis presented in (Yu & Shi,

2015) shows the impact of the countdown timer on the queue of vehicles in the inlet of the intersection. Drivers change their behavior with the additional information, and made faster decisions, which improved the quality of traffic. The queues of vehicles at the intersection with countdown timers has also been examined by (Wenbo, Zhapcheng, Xi, & Feifei, 2013). The device has the biggest impact on the first two vehicles in the queue. Based on the results from (Lum & Halim, 2006) the display of the red signal could reduce early entering onto intersection by vehicles at the beginning of the queue. The thesis that using a countdown timer only for displaying red signal is more efficient for safety than other settings. The authors also stated that using devices, which display green signal time is only good solution for roads with low traffic. This statement was based on results where for the intersection with heavy traffic many violations of traffic law were observed.

The impact of the countdown timers on traffic parameter connected with the queue of the vehicles was also analyzed. The first driver on the inlet could have a big influence on the rest of the vehicles in the queue. Giving accurate information about signals could improve the reaction of the first driver in the queue. An example of this has been presented in a paper about Kuala Lumpur city (Ibrahim, Karim, & Kidwai, 2008), where this impact was tested. The authors checked the average time interval between vehicles. The time was 10% shorter when the device was on. In another approach, the author (Małecki & Iwan 2019) analyzed the impact of countdown timers by using simulation. The results show that the device reduces delay time of vehicles in the queue in the inlets of the intersection.

The aim of this article is to show the results of the analysis of the time distribution of vehicles entering the crossroads during a red signal. This article presents research on determining the impact of countdown timers on traffic safety at three different intersections differentiated by the function of the intersection in the transportation network. The results of the research are highly valuable for consideration of the impact of the countdown timer device on traffic safety at signalized intersections.

2. METHODOLOGY

During the analysis of the exact time of the described phenomena drivers' behaviors was divide into two group. The first group is for drivers who cross the stop line at the beginning of the signal, and the second one is for those who break the law because they know that the green signal is almost coming (Anjana & Anjaneyulu, 2015). In order to examine the impact of countdown timers' devices on safety at signalized intersections authors proposed methodology, which shows step-by-step how to prepare studies to obtain accurate time data to check the impact of the devices on safety. The general scheme of the proposed methodology has been presented in figure 2.

The developed method was divided into five main stages:

- identification of signalized intersections equipped with countdown timer,
- determination of the function of the intersections in the transportation network,
- selection of the intersection and assigning it to the proper group,
- analysis of the results of measurements,
- assessment of the impact of countdown timer devices on road safety.

The first step of the methodology is connected with identification of signalized intersections equipped with the countdown timer devices. Based on the selected infrastructure data for the Poland country authors obtained list of the specific intersections related to the research problem. The input data of this step was also geoinformation data, which contain location of the intersections in transportation network. Preliminary location analysis made it possible to narrow down the search for the suitable research objects.

Before starting next step, it is necessary to select analysis interval time, which should be related to the morning and afternoon traffic peak hours. The second step describes measurements aimed to looking for research objects different by the function in the transportation network. That approach allows to consider impact of the countdown timer on the road users in different traffic condition. The input data for those analysis was both traffic flow distribution in time and vehicles types structure distribution in time. The functionality of the intersections could be divided into three main groups: non-urban traffic, urban traffic and mixed traffic. That functionality could be assessed by analyzing the structure of the network (Karoń & Żochowska, 2015).

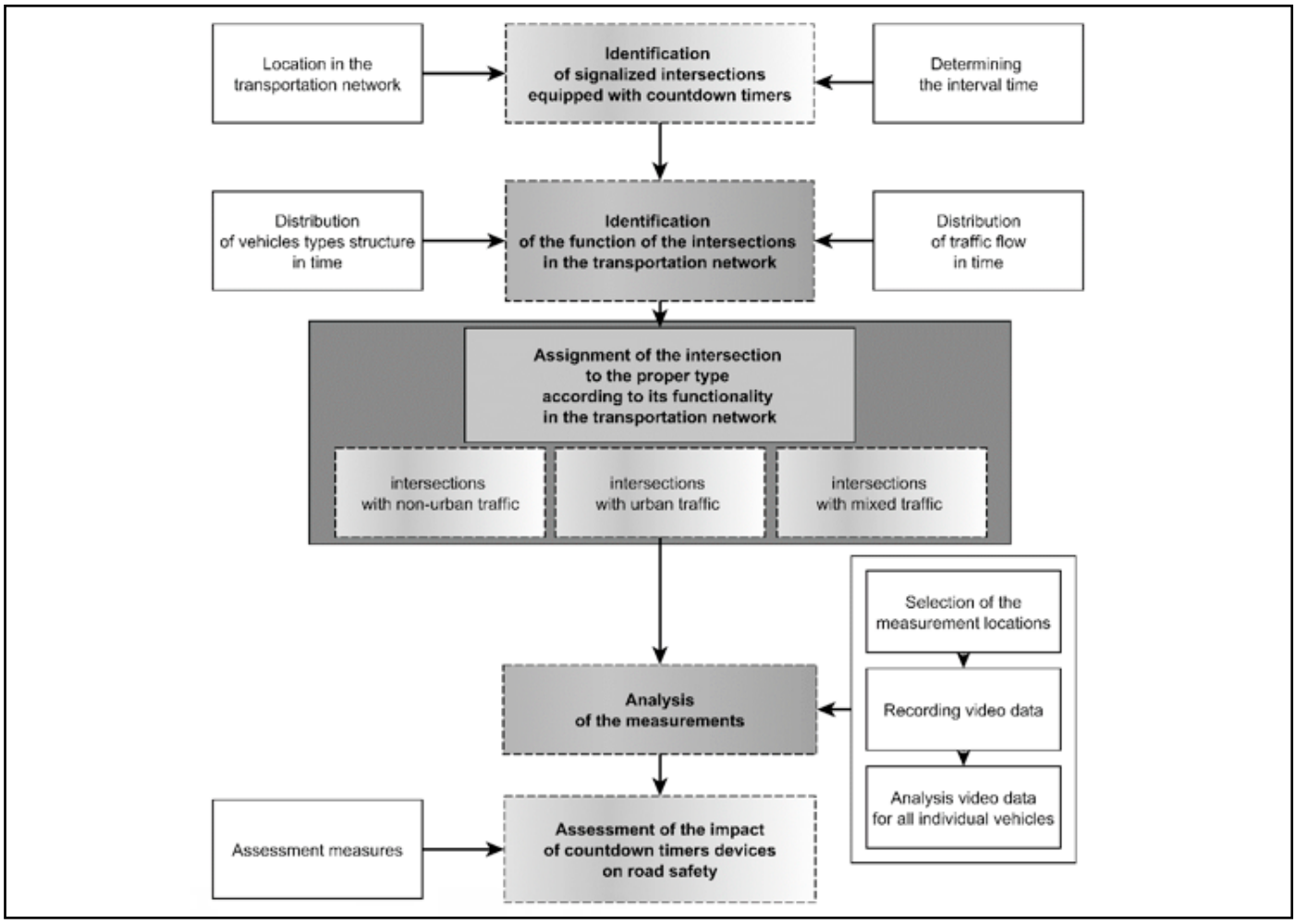


Figure 2. The general scheme of the proposed method: analysis of the countdown timer device impact on safety. Source: Own research

In the next step authors should choose the intersections different by the functionality for further research. In this article it was necessary to choose intersections different in terms of their functionality in the transportation network. The analysis of this step is presented in chapter 3.

The fourth step of the presented methodology is concerned about development and analysis of the measurements for examine impact of the devices on safety. The first element for preparing measurement is selection the proper device to investigate the phenomenon under research. Safety could be estimated based on recorded data with different devices for example with unmanned aerial vehicle, speedometer, video camera. In this paper authors used video camera. In the next sub step is necessary to choose proper location for the inspect devices. It was assumed that location of the video camera was proper only when the camera had a record range of vehicles and the signal from countdown timer device. Recording the video data was performed for two periods: one week with the countdown timer on and one week when the device was off. The data indicated made it possible to compare the real impact of the devices on safety.

The last step is the assessment of the impact of countdown timer devices on traffic safety. The most important element of this step is defining assessment measures, which could be different depending on the type of the analysis. In this article the exactly time of the vehicles crossing the stop line during the red signal has been chosen as the measure.

3. RESULTS OF MEASUREMENTS

The functionality of the intersections in Poland depends by classes of the road and road categories. The categories of the road are related to the technical aspects of the road. The examples of the technical parameters are lane width of the road, radius of turn. The other parameters which involve on the type of intersections is traffic flow and vehicles type struc-

ture. That type of the analysis was also presented in (Kłos, 2016). In the article author focus on the intersection located at the arterial road with non-urban traffic. Data collection and visualization of the data was complex for that type of research. Good example of collecting data was presented in (Kłos, Sobota, Żochowska, & Soczówka, 2019).

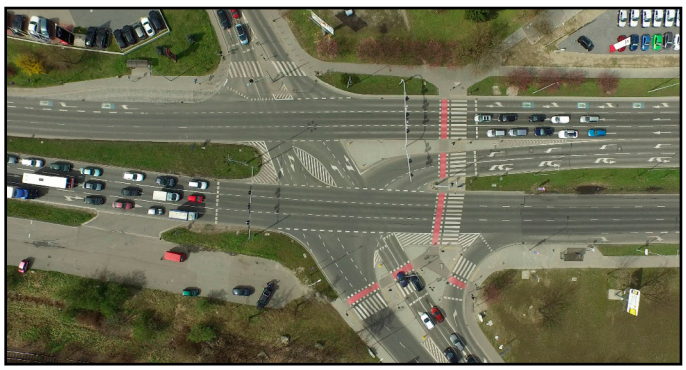
The data in this article was results of the project (Krawiec, Mitas, & Sobota, 2015), collected by the standard video camera. This approach allows to record in the same time vehicles and signal at the countdown timer device. The research work was chosen based on previous research (Sobota, Karoń, Żochowska, & Kłos, 2018) and conducted on three different types of intersections divided by the functionality in the transportation network:

- intersections with non-urban traffic – Wrocław city (figure 3c),
- intersections with urban traffic – Zabrze city (figure 3a),
- intersections with mixed traffic – Opole city (figure 3b).

The figure 3 shows the images from the unnamed aerial vehicle with the chosen intersections for the analysis of the impact of countdown timer devices on safety.

a)

b)



c)

Figure 3. Examples of the countdown timers functioning at the intersections in Poland: a) Zabrze city, b) Opole city, c) Wrocław city. Source: Own research

The table 1 shows the location of the intersections and characteristics of the functionality in the transportation network of them.

Table 1. Characteristics of the chosen intersections for the analysis of the impact of countdown timer devices on safety.

Intersection – city and names of crossing roads	Number of lanes at the intersection	Description
Zabrze - De Gaulle'a and Roosevelta	8	urban traffic most often districts and municipal roads characterized by the dominant and high share of passenger cars as well as delivery trucks in traffic
Opole - Obrońców Stalingradu, Mieszka I and Jagiellonów	8	mixed traffic mostly major and district roads characterized by the presence of trucks, trucks with trailers and passenger cars
Wrocław - Aleja Karkonoska, Zwycięska and Jeździecka	12	non - urban traffic most often national and other major roads with a high proportion of trucks and trucks with trailers

The measurements have been carried out in two periods with the devices switched on and off. The studies were conducted for working days between the hours of 7:00 to 19:00 for all objects. The time, elapsed between the moment the red signal is displayed on the traffic light and the vehicle passing the stop line, was recorded. The distribution series for these times have been drawn up, the number of vehicles passing the stop line when displaying the red signal for each time interval was obtained. The

chosen period of time contains the morning and the afternoon traffic peak hours for the all selected intersections. The table 2 presents the results for comparison of the traffic flow within a 60-hour measurement period with the diversification to the group of the vehicles and the number of vehicles passing the stop line when red signal was displayed for two periods of time (Sobota, Żochowska, Karoń & Kłos, 2019). The analysis also includes the function of the intersection in the transportation network.

Figures from 4 to 6 presents the time distribution in the intervals of vehicles entering the intersections on red signal. The behaviors of the drivers were changed depending on countdown timer device on/off and with the intersections function in the all research objects.

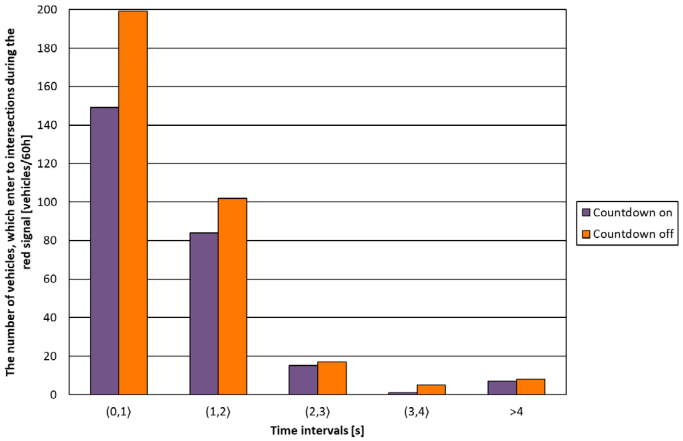


Figure 4. Zabrze – urban traffic site - number of entries vehicles at intersection during the red signal. Source: Own research

In the urban traffic site (figure 4 - Zabrze city), drivers enter significantly more often the intersection during red signal in the first two intervals for both cases of the device use (on/off). More drivers break the law with the turned off countdown device. During the research with the enabled countdown timers the 22,65% less of the vehicles drove into the crossroads in a prohibited period.

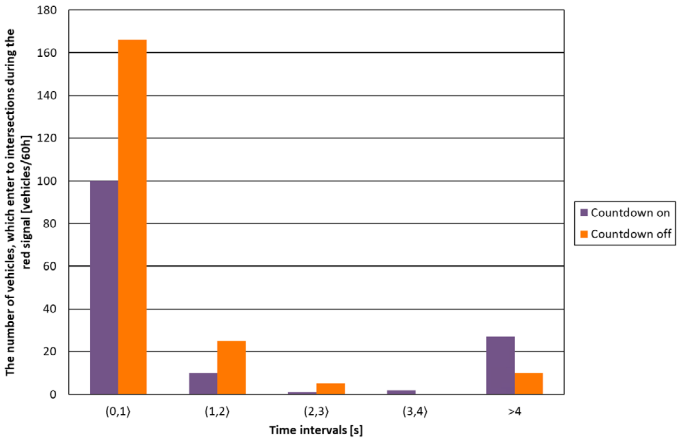


Figure 5. Opole – mixed traffic site - number of entries vehicles at intersection during the red signal. Source: Own research

For mixed traffic site (figure 5 – Opole city) the first time intervals have the highest numbers of the vehicles, which enter to the intersection during red signal. More drivers break the law with the turned off countdown device. Only for the last time interval observed more vehicles entering to the intersection during the red signal with the countdown timer was on. During the research with the enabled countdown

Table 2. Number of vehicles passing the stop line when displaying the red signal with the countdown timers switched on and off at the intersections.

		Vehicles entering the intersection during the red signal						
	Total traffic volumes	Car	Delivery truck	Minibus	Truck	Bus	Motor and bike	Σ
Zabrze								
Countdown ON	32 560	233	14	1	3	3	1	255
Countdown OFF	32 361	288	11	3	3	15	0	320
Opole								
Countdown ON	26 741	116	11	15	4	1	0	147
Countdown OFF	26 316	164	9	10	13	2	0	198
Wrocław								
Countdown ON	53 354	278	17	6	2	3	0	306
Countdown OFF	53 769	617	35	9	3	7	1	672

timers the 32,03% less of the vehicles drove into the crossroads in a prohibited period.

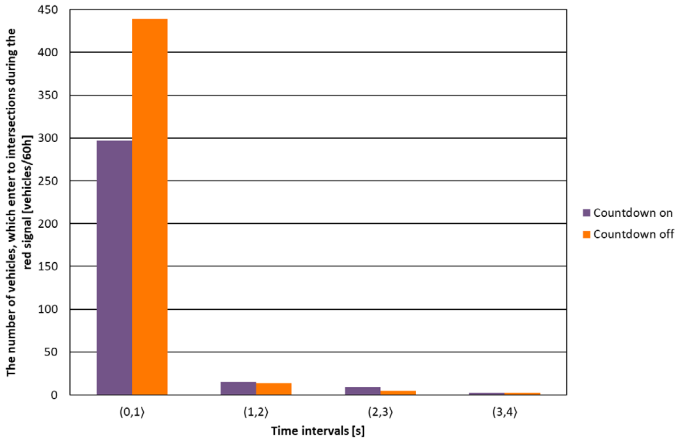


Figure 6. Wrocław– non-urban traffic site - number of entries vehicles at intersection during the red signal. Source: Own research

The last type – non-urban traffic intersection (figure 6 – Wrocław city) has the highest number of the vehicles which broke the law in the first time interval. The same like other research objects, more vehicles break the law with the turned off countdown device. The biggest traffic flow from the research objects and the big percentage share of the truck caused little number of vehicles, which entering the intersection during red signal in the last time interval. During the research with the enabled countdown timers the 29,78% less of the vehicles drove into the crossroads in a prohibited period, than in the case when the devices were off.

To assess the significance of the results obtained, a statistical analysis based on the parametric tests for two structure indicators at the significance level of 0.05 has been carried out. The shares of vehicles passing the stop line when displaying the red signal with the countdown timers switched on and off have been compared for each of the examined intersections. If the null hypotheses about the equality of these two structure indicators are true, then the test statistics Z_{emp} have approximately standard normal distributions. This means that the values of test statistics calculated on the basis of empirical data are compared with the critical values determined on the basis of the level of significance and on the distribution function of a random variable with a normal distribution. For the adopted significance level, the two-sided critical area has been designated as: $(-\infty, -1.96) \cup (1.96, +\infty)$.

Table 3 contains the values of the test statistics for all vehicles as well as for passenger cars. The remaining groups of vehicles were not analyzed due to insufficient share in the measured traffic flow.

Table 3. Statistical analysis results - values for the test statistics in the parametric tests for two structure indicators.

Intersection – city and names of crossing roads	Values for the test statistics for all vehicles	Values for the test statistics for passenger cars
Zabrze - De Gaulle'a and Roosevelta	-2.797	-2.404
Opole - Obrońców Stalingradu, Mieszka I and Jagiellonów	-2.904	-3.191
Wrocław - Aleja Karkonoska, Zwycięska and Jeździecka	-11.636	-11.321

The results presented in the Table 3 indicate that the differences between the shares of vehicles passing through the stop line while displaying the red signal with the countdown timers switched on and off in all cases are statistically significant. This statement applies both to all vehicles (without distinguishing by the type of vehicles) and to passenger cars. It means that these shares depend on the use of the countdown timers.

4. DISCUSSION

This research investigated how countdown timer's device impact on the road users at intersections in Poland. The measurements were made in two periods of research: for a week with on and off countdown timer's devices. This approach allows to compare the impact of the device on safety caused by the changing the behavior of the drivers. The time interval indication allows to check the impact on safety with different approaches.

The first approach is for the situation for the early red, which mean that drivers enter the intersection with the knowledge that the red signal was began. The part of drivers undertakes this type of decision based on the current speed and scared of the emergency braking. The other approach was connected with the drivers who began the move because the red signal was almost end. The results show that countdown timer could improve safety but a change in displaying should be taken into account. The result from Opole city shows that would be better if drivers do not know the exactly time for ending the red signal. For

example, countdown timer could only display counting of the rest of the signal without three last seconds (Fu, Zhang, Qi, & Cheng, 2016).

The results show that the functionality of the intersection has also impact on the road users. In urban intersection in Zabrze city buses are an interesting group, because 15 of them passed the stop line on red signal when the time for countdown timer is off. In opposite situation only 3 of them did the same. Distinguishing group for the mixed traffic intersection was truck, because 13 of that vehicles passed the stop line on red signal during the time for countdown timer is off. In opposite situation only 4 did the same. For the last type of intersection – non urban traffic – delivery truck was the distinguishing group around 50% more of delivery trucks passed the stop line on red signal during the countdown timer is off. In all of the research objects most cars passed the stop line during red signal.

Furthermore, the study (Pamuła, & Kłos, 2019) shows that the countdown devices on intersections may contribute to more drivers crossing the stop line compare to the situation, which devices were off. It could turn to increase probability of the red-light violations.

5. SUMMARY

This article presents methodology for preparing research of impact on new device on road safety. A case study of the usage of methodologies was described.

This study shows that at each of the examined intersections more vehicles crossed the stop line during the red signal for the countdown timers off. During the research with the countdown timers on, fewer vehicles drove onto the crossroads in a prohibited period. Checking the exact times for the entering of vehicles to the intersections during red signals with countdown timers' devices on and off, divided into intervals allow to examined impact on safety.

Based on results presented on the figure 4-6 and table 1, during the research, that approximately 0.6% of drivers had entered the intersection during the red signal when the countdown timers were on and about 0.8% of the drivers - when they were off.

Future work on countdown timers will include the development of simulation models to determine how the devices can be mapped in a simulation environment. In addition, available models of driver behavior will be tested and an attempt made to adapt them to the incorporates the use of countdown timers.

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