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Control and allocation at an intersection with traffic lights

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Abstract
Managing road infrastructure in highly urbanized areas during the Industry 4.0 era poses a significant technological challenge for traffic engineers. Steadily growing traffic volume, both of motor vehicles and pedestrians, cyclists or scooters, necessitates the development of advanced traffic control algorithms and systems. Improvement of the efficiency and capacity of intersections without any intervention into the physical structure of roadways is one of the two aspects of today's traffic engineering. In this paper, however, emphasis is placed on the aspect of coordination of conflicting flows of motorized and pedestrian traffic. Consideration is given to ensuring that each traffic light phase at an intersection is maximally utilized while maintaining the required safety factor. The empirical part of the study consists in identifying inefficiencies in the traffic light cycle. The analysis of traffic phases has revealed that there were certain periods in the cycle during which pedestrians were given the right of way while, in fact, it was not necessary. The study proposes a solution to optimize the green signal timing for conflicting vehicular and pedestrian flows in real-time. By eliminating delays in traffic signal phases as a result of not having to give a green signal for pedestrians, the proposed solution will improve the efficiency of urban networks with respect to an aspect whose potential has not been exploited so far. Coordination and adaptation of each light phase to the most effective extent is a feasible answer to the needs and requirements of modern urban areas.

Keywords: traffic signal, tram button, pedestrian crossing.

INTRODUCTION

This article is the second in a series of articles addressing issues related to the rationalization of traffic in congested urban networks by better allocation of conflicting traffic flows. The first article, titled "Improving the capacity of signalized intersection. Using smart traffic control systems supported by innovative beam sensors" described the influence of signals received from vehicle detectors on optimizing the flow of vehicles through intersections. Algorithms and methods of traffic signal control by advanced traffic control systems were analyzed, with particular attention given to establishing real-time traffic signal frameworks. This article considers the effect of pedestrians and cyclists on the length of traffic signal phases and on the optimization of intersection capacity.

The participants of road traffic include motor vehicle drivers, as well as cyclists, motorcyclists, people hauling bicycles, and pedestrians traveling along the roadway or traversing it. Each year, the volume of traffic generated by each of these categories of traffic participants increases, which compels traffic infrastructure management to continuously readapt the existing infrastructure, to improve and to develop it. There are two primary reasons why this is necessary – the need to streamline traffic flow in the streets and intersections to reduce congestion, and the need to isolate different categories of traffic to ensure a higher level of safety for conflicting traffic flows. It appears essential to use advanced algorithms and sensors to transmit information to the traffic management system to coordinate the flow of motorists and pedestrians, while ensuring the greatest possible degree of safety, as well as the efficiency and smooth flow at point elements in road infrastructure (consisting of at least a pedestrian crossing and traffic lights). According to TOM TOM's ranking, on average, in the 12 most congested cities in Poland, the volume of traffic increased by an average of 1.25% over a one-year period (from 2017 to 2018), with an average level of congestion of approx. 33% (Okurowski, 2019). Additionally, with greater traffic congestion, pedestrian crossing-related fatalities have also increased. According to the Traffic Bureau of the Police Headquarters, from January through November 2019, 190 people were killed at crosswalks in 2,864 accidents ("Komenda Główna Policji", 2019). In view of these statistics, different measures should be taken to improve the overall level of road safety. One of them is greater use of traffic lights separating pedestrian traffic from that of vehicles, segmenting that flow relative to the phases of traffic lights. One particular approach to increasing safety on this front is, among others, to increase the duration of the intervals between green phases. Consequently, a driver who drives through a crossing on a yellow or even a red light should not come into conflict with a pedestrian who, thanks to the long inter-green interval, has to wait a sufficiently long time to be given the right of way. On one hand, this definitely improves road safety by introducing an intelligent system which "thinks" for the driver and the pedestrian. On the other hand, however, it is also the main reason for bottlenecks, inefficient use and prolongation of the interval between green phases. Therefore, the question to consider is how to use the interval between green phases to optimize the flow of vehicles and pedestrians while maintaining a high level of safety. Signalized pedestrian crossings across multi-lane roads with public transportation stops in-between the carriageways appear to be a particularly relevant site from the perspective of the need to ensure safety and the potential to improve efficiency.

The research problem addressed in this study, formulated on the basis of a literature review, is expressed in the form of a research question, the answer to which achieves the purpose of the article. The question is as follows: "Is it possible to expedite the entry of vehicles into an intersection, passing through a pedestrian crossing where the green light is on while maintaining a high level of safety?".

The relevance of the research problem to be verified is substantiated by the fact that, on many occasions, there are no pedestrians passing walking through the crossing, which, in view of the fact that the green light is on, delays the activation of the green light for vehicles.

To make the answer to the research problem quantifiable and statistically describable, two research hypotheses were formulated and tested in the study, i.e:

1. There are traffic light cycles during which the green signal is activated at the pedestrian crossing even if no pedestrian crosses it or crosses only part of the road.
2. There are unused time resources of the cycle phases on account of the green signal for pedestrians being activated for parts of the roadway where no pedestrian crosses.

The research hypotheses listed above were specified as a result of the previous studies conducted by the authors on the management, coordination, and optimization of traffic at intersections of conflicting flows of traffic participants.

1. THE POLISH ROAD TRAFFIC LAW AS APPLICABLE TO THE ISSUE IN QUESTION

No road can be considered to be properly designed and implemented without properly organized, i.e. safe and efficient, pedestrian traffic (Brzeziński et al., 2013). These two aspects should be taken as the starting point for planning and design activities. By definition, a pedestrian crossing is a place where a conflict arises between vehicles driving along the axis of the road (a privileged position due to speed and force) and pedestrians (a subordinate position due to low mass and force generated by pedestrian traffic) crossing the road in a direction perpendicular to its axis (Michalski et al., 2014). Areas where there are conflicting vehicle and pedestrian routes should be arranged so as to ensure the highest possible level of safety for traffic participants and to maximize their flow ("Prawo o ruchu drogowym", 2020).

The Polish law defines a pedestrian as a person who is outside a vehicle on the road and who does not perform any type of roadwork or road activities as provided for in separate regulations. A person riding, pulling or pushing a bicycle, a moped, a pram, a pushchair or a wheelchair, a person in a wheelchair, as well as a person under 10 years of age riding a bicycle under the supervision of an adult are also classified as pedestrians ("Prawo o ruchu drogowym", 2020). Under the same provisions, a pedestrian crossing is an area of a roadway, a cycleway or a railway track intended for crossing by pedestrians, marked with appropriate road signs, both horizontal and vertical ("Prawo o ruchu drogowym", 2020). A distinction is made between non-synchronized pedestrian crossings, which are not separated from the conflicting traffic of other traffic participants, and those with different phases signaled with traffic lights (Jamroz, 2017). Pedestrian crossings can be situated both at intersections (usually) as well as in areas that are not intersections; e.g., access routes to public transportation stops located between road lanes. Pedestrian traffic signals are located at pedestrian crossings, across roadways, or tram tracks. Further, they can be fixed-time, variable-time (adaptive), or actuated. At pedestrian crossings, light signaling should be augmented with audible signaling (Jamroz, 2017). The basic elements for the planning and design of signaling systems at pedestrian crossings include control devices and control procedures, together with algorithms for the programming and operation of traffic lights (Gondek, 2011). Control devices include all kinds of local controllers, detectors, and sensors, whereas control procedures for traffic lights include all kinds of technical (placement, operation) and organizational considerations (actual need, implementation costs, safety) that assure proper functioning of this element of the infrastructure. The procedures for the control and assignment of the green signal to conflicting traffic flows are determined, among other things, by the interval required between the green phases. In other words, pairs of conflicting flows that may be given the right of way at the same time (vehicles going straight ahead at the intersection or turning right and pedestrians going in parallel through the crosswalks) should be controlled so that the flow with the permissive green (vehicles turning right) should not be able to reach the point of conflict (pedestrians crossing the lane into which the vehicles are turning right), earlier than the flow with the priority green (pedestrians or cyclists at the crossing).

For pedestrian crossings in conflict with the flow entering the intersection controlled by the signal permitting the vehicles to turn in the direction indicated by the arrow, the signal for the vehicles must not be given earlier than 2 seconds after the green signal for the conflicting pedestrian group (Jamroz 2017). In practice, that time is extended according to the characteristics of a given intersection and pedestrian flows so as to ensure the highest possible level of safety. One disadvantage of that solution is the need to intervene, e.g., at those locations where pedestrians cross only half of the intersection in the direction to a public transportation stop located between the carriageways. Here, in at least two further areas of the intersection, vehicular traffic in the conflicting directions is held up for several seconds over the time required by regulations as the green signal is activated for each carriageway in each direction for a single pedestrian crossing (while only a single green light is actually necessary for a single carriageway) ("Stowarzyszenie Akcja Miasto", 2017).

The duration of the green signal for pedestrians is not regulated by law. However, the minimum recommended green phase should allow a pedestrian to cross the entire crosswalk at a speed corresponding to a quantile of 15% of the actual speed of pedestrians at that crossing (Jamroz et al., 2017). The duration of the flashing green light is 4s. The minimum length of the continuous green light at a crossing must not be shorter than 4s and is calculated with the formula 1 (Jamroz, 2017):

$$Gp_{min} = \frac{Lp}{Vp} - 2$$

Fig. 1. Formula for the minimum length of the continuous green signal

Source: National Road Safety Council, Kazimierz Jamroz (ed.), Published by the Ministry of Infrastructure and Development, Warszawa 2017

where:

Gp_{min} - the minimum duration of the continuous green signal for pedestrians (s),

Lp - time to cross (m),

Vp - pedestrian crossing speed, which should be adopted according to the following principle:

- 1,2 m/s for a general purpose pedestrian crossing,
- 1,0 m/s for a special pedestrian crossing for children,
- 0,7 m/s for a special pedestrian crossing for people with disabilities.

A pedestrian crossing across more than one carriageway may be regarded as two separate crossings if the width of the traffic island separating the carriageways is longer than 2m and allows the pedestrian to stop safely. This applies to junctions with traffic signals as well as to those without priority control. It is also irrelevant whether or not there is a public transportation stop between the lanes nor whether it is a crossroads or a facility other than a crossroads (Jamroz et al., 2017). If the traffic island does not provide the required level of pedestrian safety or is shorter than 2m, the crossing shall be regarded as a single pedestrian crossing ("Prawo o ruchu drogowym", 2020).

2. SENSORS AND PREDESTRIAN DETECTION SYSTEMS, SIGNAL CONTROL ALGORITHMS

Both pedestrians and motorized users are subject to detection for statistical and traffic coordination purposes to improve the allocation of the right of way. This is directly related to ensuring the safety of each traffic participant and to optimizing the efficiency of traffic flow to minimize congestion. Pedestrian detection is also performed to determine the need to activate the green signal phase for a given pedestrian crossing. When no pedestrians wanting to cross the road are detected, the green phase for motor vehicles in the (usually) parallel direction can be activated about 1-5 seconds sooner.

The currently used push buttons for pedestrians are installed according to certain standards and rules. It is recommended that they should be capable of generating auxiliary audible signals to allow the blind and visually impaired to locate the crossing and the button. Pedestrian push buttons should be mounted on a post or a traffic signal pole, at a height of 1.2 to 1.35 m above the ground level. When the push button is attached to a separate post, its height should be at least 1,5 m. The location of the push buttons should be decided after examining the directions from which pedestrians access the crossing. Access to the push button must be free of any obstacles (Jamroz, 2017). In addition, the protection rating of the enclosure must be at least IP54, which means that the push button cannot be quickly dislodged or damaged, but also that it is protected against dust and water ("Rozporządzenie Ministra Infrastruktury", 2013)

A great advantage of traditional push buttons is their reliability and clarity of the messages they convey. Furthermore, the latest ones produce audible sound and vibration signals so that the blind or visually impaired can easily take advantage of this functionality when trying to cross the street (Jamroz, 2017). Moreover, it may be appropriate to place a tactile diagram of the intersection on the push button (which is not always the standard) (Bielecki, 2004) to assist a visually impaired person in identifying the nature of the pedestrian crossing, and by touching the push button, to actuate the signal indicating the intention to cross the road at the same time.

Unfortunately, traditional pedestrian push buttons have come under a lot of criticism. Opponents of this detection method mainly focus on the fact that pedestrians are discriminated against in favor of vehicles (Wierciński, 2014). They argue that drivers of motor vehicles are detected automatically, e.g., by induction loops, while pedestrians are required to push the button. This inequality can be redressed by automatic pedestrian detection, which can be performed with the aid of special radars placed adjacent to pedestrian crossings, video recorders, and induction loops. Unfortunately, like any mechanical device, these solutions suffer from a certain functional defect; or else, related to that, a lack of functional integrity. What this means primarily is that automatic detection sensors cannot identify the direction of pedestrian movement, require mechanical adjustment, and may be adversely affected by the movement of other bodies. An induction loop can be used as an automatic traffic detector, but only for electrically conductive vehicles (detection of bicycles, but not those with carbon frames). A relatively highly efficient, but definitely the most expensive solution would be to use hybrid systems, combining both traditional mechanical or touch buttons and automatic pedestrian and cyclist detection sensors. However, at this point the following questions should be addressed: what is the purpose of this solution, and what will be its added value if it is successfully implemented into the traffic control system? Perhaps a good starting point for the development of a new type of solution is to study the time gaps that occur in the correlation between pedestrian traffic and conflicting motor vehicle traffic and the unused interval between green phases, or the failure to segment pedestrian crossings in multi-lane roads with public transportation stops between them. By combining new or existing sensors, applying appropriate algorithms and neural networks, it is possible to reconcile the elimination of the time gaps between green phases and the correlation of traffic participants' movement, thus primarily increasing the benefit in terms of a reduction in the cost function of delays and stoppages of motor vehicle traffic and improved pedestrian safety. The range of motion detection sensors is complemented by light and sound signals used at pedestrian crossings. The first of these are color signals for pedestrians in the form of two light signals – green and red. The green signal allows a pedestrian to enter the zebra crossing (unless it is a flashing green, indicating that it will soon be forbidden to do so) while the red signal disallows crossing (Szczuraszek et al. 2005). These signals are accompanied with a lenticular yellow flashing light signal (with a clearly marked silhouette), oriented towards drivers turning right to clearly indicate that the driver needs to pay attention to the zebra crossing they are about to pass through (Zalewski 2011). Apart from light signals, modulated sound signals are also used. They are mainly intended for persons with disabilities to inform them whether it is possible to cross the street. They are aligned with traffic lights ("Polski Związek Niewidomych", 2009).

3. RESEARCH METHODOLOGY AND DESCRIPTION OF SUBJECT

The research for this publication was conducted with the use of the quantitative etic approach (Zakrzewska-Bielawska, 2019). It was partial and non-random. The general population consisted of phases in traffic light cycles, while the statistical unit was each phase in the traffic light cycles within a selected time period. Traffic signal phases are units typical (Zakrzewska-Bielawska, 2019) to the entire network of urban intersections in Łódź included in the Area Traffic Control System (Pl.: "Obszarowy System Sterowania Ruchem"). The decisive criterion, however, was that of accessibility (Depta et al., 2010). Observation and participatory measurement methods were used (Bronk, 2006). The research tool was a designed form, where the results obtained with the measuring instrument – a stopwatch – were recorded. The statistical feature measured during the study was the period when the green light for pedestrians was on (no vehicles were allowed to pass through the pedestrian crossing) yet no one used the crossing, or those who did, only crossed one carriageway.

Pursuing the assumed objective: revealing the shortcomings of the traffic control system and identifying a possible improved configuration of the traffic lights timing, empirical examination of the pedestrian crossing in Aleja Włókniarzy in Łódź (national road DK 91), in the vicinity of the Concert Hall of the Academy of Music in Łódź, was conducted. The crossing runs through a three-lane dual carriageway (three lanes on each of the two carriageways). The carriageways are separated by tram tracks and public transportation stops. On the west side, the crossing borders the “Żubardź” residential area; and on the east side, mostly green areas. High pedestrian traffic takes place between the public transportation stops and the residential area. Only a small fraction of those using the pedestrian crossing cross the western carriageway. The traffic islands and tram stops between the carriageways are of an adequate size so that the pedestrian can stand safely between the carriageways for a longer moment, exactly as when waiting for a tram.

4. EXAMINATION OF SELECTED PEDESTRIAN CROSSINGS

Following the observations of the intersection, it was decided to identify the main deficiencies in the traffic light timing, and from there, to propose corrective measures. The guiding principle was to ensure maximum use of the green light for motor vehicles, which would consequently mitigate bottlenecks leading to traffic congestion. Pedestrian crossings at non-intersection locations with public transportation stops between multiple-lane areas were selected, and a detailed analysis was done of the pedestrian crossing of Aleja Włókniarzy at Żubardzka in Łódź, referred to earlier. It is a dual carriageway, with 3 lanes in each direction, separated by tram tracks. The facility has traffic lights, a zebra crossing and tram stops, but it is not at an intersection. The situation is illustrated in Fig. 2.

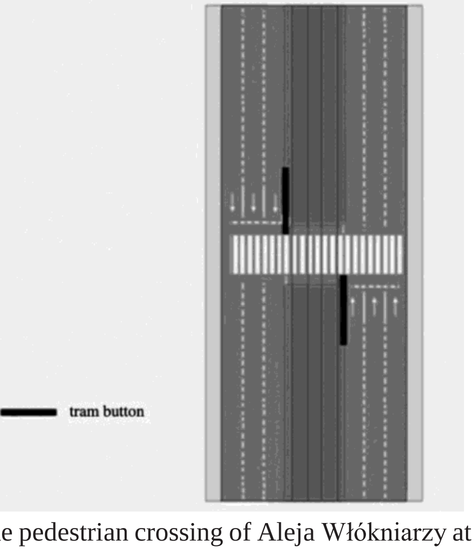

Fig.2. Diagram of the pedestrian crossing of Aleja Włókniarzy at Żubardzka in Łódź

Source: compiled by the authors

Unfortunately, the transportation infrastructure engineers did not consider the option of a green split for pedestrians at this location. As a result, each pedestrian wanting to access the tram stop from the west side (and they are a considerable majority), by pushing the pedestrian button, brings the vehicles on each of the carriageways to a halt, regardless of the fact that actually it would only be necessary to stop the traffic going in just one direction – only across one of the carriageways.

During the analysis of pedestrian traffic, another inadequacy of the pedestrian light signal control was noticed. Despite the fact that three tram routes run along DK 91, the intervals between individual trams usually range from two to as long as ten minutes (in off-peak hours and at night, the intervals are up to twenty minutes). A pedestrian wanting to get to the tram stop, pushes the pedestrian button causing the vehicles going in both directions to stop, even though the next tram does not leave for another few minutes. The same happens with all other public transportation users when actually getting to the public transportation stop is pointless at that moment. It is certainly wrong to assume that all or most pedestrians arrive at a zebra crossing at exactly the time of departure of a public transportation vehicle or just before it.

The following are among the identified reasons for pedestrians having vehicles stop too frequently:
1. wanting to cross only part of the road, i.e. to get to or from a tram stop,
2. wanting to get to a public transportation stop when the next service is not expected to arrive for another several minutes.

The above factors are the main reasons for congestion, the necessity to brake and start driving again; and, consequently, difficulty for integrated traffic control systems to appropriately time vehicle stopping times and shift green phases for motor vehicles (including public transportation). The pedestrian crossing under consideration was examined in great detail and subsequently also subject to a rationalization process. The results are shown in the table below.

Table 1. Pedestrian flow through the pedestrian crossing - research results

Phase number	Number of pedestrians going to and from the tram stop per a unit of time	Number of pedestrians crossing both carriageways, per a unit of time	Number of people arriving together, per a unit of time, at the pedestrian crossing on the west and the east side	Tram arrival	Light signal change in the original system	Light signal change in the proposed model, without light signal split	Light signal change in the proposed model, with light signal split
1	2	0	2				
2	1	0	1		Change		
3	0	1	1				
4	0	1	1	Tram	Change	Change	Change
5	4	0	4				
6	3	0	3		Change		
7	0	2	2				
8	1	2	3		Change	Change	Change
9	1	3	4	Tram		Change	Split
10	0	1	1		Change		
11	2	0	2			Change	Change
12	2	1	3		Change		
13	1	1	2			Change	Change
14	0	2	2		Change		
15	0	0	0			Change	Change
16	0	1	1				
17	2	0	2		Change	Change	Change
18	3	1	4				
19	4	1	5		Change	Change	Change
20	2	0	2	Tram		Change	Split
21	0	0	0		Change		
22	1	0	1				
23	2	1	3		Change		
24	1	2	3			Change	Change
25	1	1	2		Change		
26	1	1	2			Change	Split
27	2	0	2		Change		
28	0	0	0				
29	0	0	0				
30	2	0	2				
31	1	0	1		Change		
32	1	1	2				
33	2	0	2		Change	Change	Change
34	1	1	2				
35	0	1	1		Change	Change	Change
36	0	0	0				
37	2	0	2				
38	0	1	1		Change		
39	0	1	1			Change	Change
40	0	2	2	Tram	Change		Split
41	1	1	2			Change	
42	1	4	5		Change		Change
43	0	1	1			Change	
44	2	0	2	Tram	Change		Change
45	0	0	0				
46	1	2	3				
47	2	2	4		Change	Change	Change
48	1	0	1				
49	3	0	3		Change		
50	1	1	2				
51	1	0	1		Change	Change	Split
52	2	0	2				
53	0	1	1		Change		
54	0	4	4			Change	Change
55	1	1	2		Change		
56	2	2	4	Tram		Change	Change
57	1	1	2		Change		
58	0	1	1			Change	Change
59	1	0	1		Change		
60	2	0	2				

In the table above, the phase number represents the consecutive 30-second phase from time 0, when the survey started, to the 30th minute, when the survey ended. In each of the phases, the number of individuals was determined according to the criterion of the purpose of the journey – getting to the stop or crossing the whole road from the east side to the west side and vice versa. The word "Tram" in the column "Tram arrival" means the phase when the flow of passengers was possible between the stops and a public transportation vehicle or between public transportation vehicles. The word "Change" in the column " Light signal change in the original system" shows towards the end of which phase of the traffic light cycle the green light for pedestrians lighted up (at this stop, it is programmed in such a way that it goes on up to 60 seconds after the initial actuation of the sensor – the pedestrian push button). The column "Light signal change in the proposed model, without light signal split" shows the end of the phase during which pedestrians are given the green signal and the right of way once the rationalization has been implemented. The last column, "Light change in the proposed model, with light signal split" shows the predicted results that could be obtained once the improvement has been implemented and with the possibility to split the green light for pedestrians, individually for the traffic in each direction at the examined pedestrian crossing.

The traffic at the selected pedestrian crossing was surveyed within consecutive short time frames, each lasting 30 seconds (the total duration of the survey of the crossing was 30 minutes). The investigation was conducted from 20-24 Feb. 2020, between 16:00 and 16:30 each day. Table 1 shows the averaged data from the entire survey period. The survey was conducted based on the selected criteria (i.e. the number of traffic participants, time of arrival at the survey location, and motor vehicle travel times through the surveyed pedestrian crossing), using a stopwatch as the measurement tool. Measured times shorter than 2 seconds were disregarded in the study. The authors consider these instances to represent a measurement error, the reaction of the pedestrian or another traffic participant, and therefore should be excluded from the test so as not to distort the actual road and pedestrian crossing conditions.

The survey data clearly show that the moment at which the pedestrian signals to cross the road is usually inadequate to the actual traffic situation. In most of the examined traffic light phases, the pedestrian, by pushing the pedestrian button, sends a signal to the traffic control system requesting a green light for pedestrians. Within 60 seconds of that signal, motor vehicles on both carriageways going in either direction were stopped – whereas in reality it only was necessary to stop the traffic on one carriageway alone (to enable access to the public transportation stop between the carriageways) or it was not necessary to stop the traffic for another few minutes before the public transportation service would be approaching. It can be concluded from the collected data that it would be possible to reduce the number of vehicular stops on one or on both carriageways if the green light timing for pedestrians was optimized in correlation with public transportation services and pedestrian demand (information relayed to the system whether a pedestrian wishes to cross the entire road or part of it). Thus the capacity (number of vehicles passing through) at the respective pedestrian crossing location would be increased and traffic light settings at subsequent intersections could be predicted with greater accuracy. Currently in Łódź, no light signal splitting is used to enhance vehicular flow and reduce traffic congestion at any intersection or non-intersection with a pedestrian crossing and traffic lights.

The specific details of the proposed improvement will be discussed in the next section of the study.

5. DESIGN AND DEVELOPMENT IMPLEMENTATION; ADVANTAGES OF A NEW SENSOR

The most prevalent device for pedestrians to signal crossing is the “yellow button” mounted on traffic light poles or on auxiliary poles located in the immediate vicinity of the pedestrian crossing. Once pressed, it triggers a green signal for the pedestrian (as soon as possible after the pedestrian’s request) and a red signal for drivers of vehicles going in the directions conflicting with the pedestrian. Unfortunately, it fails to allow pedestrians to signal their intention to cross only half of the road, e.g., to reach a public transportation stop located between the lanes with traffic in opposite directions.

For the purpose of the conducted simulations and the attempt to facilitate the flow of traffic, an additional button was developed, referred to by the research group as the “tram button”. The device operates on the same principle as conventional pedestrian buttons. In the proposed version, the device is blue and features the image of a tram or a bus. It is mounted on the existing infrastructure above, below or next to the yellow pedestrian push buttons. The solution can be used at locations where there are public transportation stops between carriageways, or where there is a reasonable need for pedestrians or cyclists to cross only part of the road, and the island or the stop separating the roadways is more than 2 meters wide and guarantees the safety of pedestrians. A graphic visualization of the sensor is shown in the Fig. below.

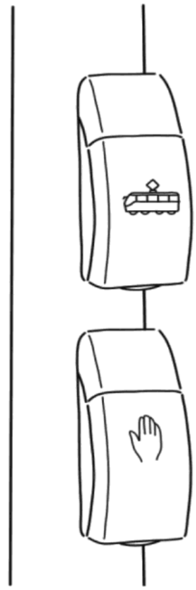

Fig. 3. Diagram of the placement of the "tram button" on the traffic signal pole
Source: compiled by the authors

The tram push button allows information to be transmitted to the traffic control system that a pedestrian wishes to cross only one of the carriageways, without having to stop vehicular traffic traveling in both directions. This is achieved by placing the device in appropriate locations at the crossing. An example of the location of this additional item of infrastructure is illustrated in the Fig. 4.

The traffic control system into which the "tram button" has been implemented will receive the information that the pedestrian traffic participant only wants to get to the tram stop. As a consequence, vehicular traffic will stop only on one of the two carriageways, making it possible for the pedestrian to get to the desired destination without stopping all traffic. The proposed solution may or should be correlated with GPS signals of track bound vehicles (it is currently universally applied and used in managing information displayed to pedestrians – e.g. next tram / bus service waiting time). As a result, a user wishing to get to a public transportation stop, in the absence of an approaching public transportation service, will not be able to cross the road and thus stop and delay vehicular traffic. The green light in this case will go on during only one of the several cycles preceding the arrival of the track bound vehicle (unless another pedestrian has already signaled to the system that s/he intends to cross the entire road).

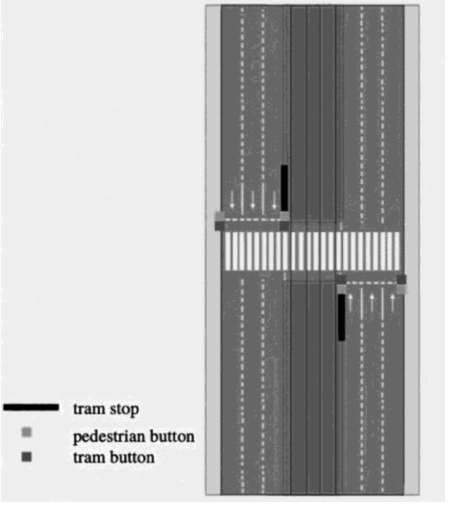

Fig. 4. Diagram of the location of the "tram button" at a pedestrian crossing
Source: compiled by the authors

The results presented in Table 1, in the column labelled "Light signal change in the proposed model, without light signal split" refer to the use of the "tram button" in combination with GPS on public transportation vehicles. This allows the green signal not to be activated for pedestrians who only want to access the stop although no bus or tram is approaching. During the light signal change simulation, it was possible to reduce the proportion of green light phases for pedestrians from 27 to 21 over a half-hour period, thereby reducing the total number of phases when vehicular traffic was forced to stop by more than 22%. The last column of the table shows an example of the traffic light signal change scheme for pedestrians, taking into account the division of the pedestrian crossing (light signal for one half of the pedestrian crossing is switched on at the end of the phase referred to as the "Split") into individual carriageways. This would allow the number of times the traffic was to stop on both carriageways to be reduced from 27 to 17 times per half hour, thereby resulting in a reduction of over 37% in the number of vehicular traffic stops on both carriageways should the solution be implemented in the traffic control system.

Appropriate correlation and management of pedestrian flows at pedestrian crossings would reduce the number of vehicular stops and thus improve the flow of traffic – a key parameter for optimization of vehicle flows and reduction of traffic congestion. The green light split for pedestrians, adjusted to accommodate the pedestrian's needs and road infrastructure, could reduce the number of stops by up to 37% compared to the current situation. In the absence of a tool that would allow pedestrians to communicate their intention to the system, it is not possible to effectively adjust when and where vehicular traffic should stop. Therefore, an additional device is needed to provide the system with the information required to effectively manage traffic lights and the flow of pedestrians and motor vehicles.

CONCLUSION

Effective traffic management at intersections is determined by a number of sensors, detectors, by efficient traffic control systems and by the behavior and interaction of those using the road infrastructure. With traffic in the streets of Polish cities intensifying year by year, it is time for the city traffic management to seek new and improved solutions. It is necessary to approach such changes holistically – starting from the analysis of the occurrence of bottlenecks, time gaps, through system optimization, to the study of the needs of pedestrians, cyclists, as well as motor vehicle drivers. The time gaps and bottlenecks that are identified need to be regarded as the basis for designing solutions that will allow systems to be more intuitive and smarter. One effective way to increase capacity by streamlining traffic flow at intersections is to allocate pedestrian and vehicular traffic appropriately in time. However, it will not be possible unless additional sensors are introduced to provide the traffic management system with information that so far has not been available to it. Therefore, the introduction of a `tram sensor' is necessary so that pedestrians can communicate their thoughts as it were – their actual need to cross one or more carriageways – to the traffic control system. This will increase efficiency, effectiveness, and safety for both motorized and non-motorized traffic participants. Environmental concerns and machine wear-and-tear are an additional advantage of the proposed improvements.

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