Lecture Notes in Intelligent Transportation and Infrastructure
Series Editor: Janusz Kacprzyk

Elżbieta Macioszek
Nan Kang
Grzegorz Sierpiński *Editors*

Nodes in Transport Networks – Research, Data Analysis and Modelling

16th Scientific and Technical Conference "Transport Systems. Theory and Practice 2019", Selected Papers

Springer

Lecture Notes in Intelligent Transportation and Infrastructure

Series Editor

The series “Lecture Notes in Intelligent Transportation and Infrastructure” (LNITI) publishes new developments and advances in the various areas of intelligent transportation and infrastructure. The intent is to cover the theory, applications, and perspectives on the state-of-the-art and future developments relevant to topics such as intelligent transportation systems, smart mobility, urban logistics, smart grids, critical infrastructure, smart architecture, smart citizens, intelligent governance, smart architecture and construction design, as well as green and sustainable urban structures. The series contains monographs, conference proceedings, edited volumes, lecture notes and textbooks. Of particular value to both the contributors and the readership are the short publication timeframe and the world-wide distribution, which enable wide and rapid dissemination of high-quality research output.

More information about this series at http://www.springer.com/series/15991

Elżbieta Macioszek · Nan Kang ·
Grzegorz Sierpiński
Editors

Nodes in Transport Networks – Research, Data Analysis and Modelling

16th Scientific and Technical Conference "Transport Systems. Theory and Practice 2019", Selected Papers

Springer

Editors
Elżbieta Macioszek
Faculty of Transport
Silesian University of Technology
Katowice, Poland

Nan Kang
Faculty of Science and Technology
Tokyo University of Science
Noda City, Japan

Grzegorz Sierpiński
Faculty of Transport
Silesian University of Technology
Katowice, Poland

ISSN 2523-3440 ISSN 2523-3459 (electronic)
Lecture Notes in Intelligent Transportation and Infrastructure
ISBN 978-3-030-39108-9 ISBN 978-3-030-39109-6 (eBook)
https://doi.org/10.1007/978-3-030-39109-6

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Nodes, being either points or areas where several trajectories of traffic streams (vehicles, passengers, goods) intersect, more broadly understood as junctions of several transport routes, roads, railways, tram lines or air corridors, are frequently the bottlenecks of transport networks. Some of the main challenges connected with the efficient functioning of junctions of diverse types in different kinds of transport networks include their integration with other transport systems, increasing the availability and quality of the services rendered, improving safety and reducing their negative environmental impact.

This publication, entitled *Nodes in Transport Networks – Research, Data Analysis and Modelling*, provides an excellent opportunity to become familiar with the latest solutions and the efforts undertaken with regard to road and rail nodes, as well as the challenges they are currently facing. The book has been divided into four parts. These are:

- Part 1. Intersections as Bottlenecks of Transport Networks – Solutions for Low Capacity,
- Part 2. System Approach to Transport Nodes and Traffic Flows Modelling,
- Part 3. Modern Types of Intersections to Improve Traffic Safety,
- Part 4. Traffic Organization and Control at Transport Nodes.

The publication contains selected papers submitted to and presented at the “16th Transport Systems. Theory and Practice” Scientific and Technical Conference organized by the Department of Transport Systems and Traffic Engineering at the Faculty of Transport of the Silesian University of Technology, Katowice, Poland. The subjects addressed in respective papers include the current problems of research, data analysis and modelling of road and rail nodes in dense transport networks. Using numerous practical examples, the authors have analysed various opportunities for improvement of the current state of matters, bearing in mind the human well-being, sustainable development of transport systems and protection of natural environment.

We would like to make the most of this opportunity and express our gratitude to the authors for their substantial contribution to a discourse on the numerous challenges currently facing transport nodes, which perform a significant function decisive of the efficient operation of transport networks, as well as for rendering the results of their research and scientific work available. We would also like to thank the reviewers for their insightful remarks and suggestions which have made it possible to ensure high quality of the publication. With this in mind, we hope that readers find this book valuable.

September 2019

Elżbieta Macioszek
Nan Kang
Grzegorz Sierpiński

Organization

16th Scientific and Technical Conference “Transport Systems. Theory and Practice” (TSTP 2019) is organized by the Department of Transport Systems and Traffic Engineering, Faculty of Transport, Silesian University of Technology, Poland.

Organizing Committee

Organizing Chair

Grzegorz Sierpiński	Silesian University of Technology, Poland

Members

Marcin Staniek
Renata Żochowska
Ireneusz Celiński
Grzegorz Karoń
Marcin J. Kłos
Krzysztof Krawiec
Aleksander Sobota
Barbara Borówka
Piotr Soczówka

The Conference Took Place Under the Honorary Patronage

Ministry of Infrastructure
Marshal of the Silesian Voivodeship

Scientific Committee

Stanisław Krawiec (Chairman)	Silesian University of Technology, Poland
Rahmi Akçelik	SIDRA SOLUTIONS, Australia
Tomasz Ambroziak	Warsaw University of Technology, Poland
Henryk Bałuch	The Railway Institute, Poland
Werner Brilon	Ruhr-University Bochum, Germany
Margarida Coelho	University of Aveiro, Portugal

Boris Davydov	Far Eastern State Transport University, Khabarovsk, Russia
Mehmet Dikmen	Baskent University, Turkey
Domokos Esztergár-Kiss	Budapest University of Technology and Economics, Hungary
Zoltán Fazekas	Institute for Computer Science and Control, Hungary
József Gál	University of Szeged, Hungary
Anna Granà	University of Palermo, Italy
Andrzej S. Grzelakowski	Gdynia Maritime University, Poland
Mehmet Serdar Güzel	Ankara University, Turkey
Józef Hansel	AGH University of Science and Technology, Cracow, Poland
Libor Ižvolt	University of Žilina, Slovakia
Marianna Jacyna	Warsaw University of Technology, Poland
Ilona Jacyna-Gołda	Warsaw University of Technology, Poland
Nan Kang	Tokyo University of Science, Japan
Jan Kempa	University of Technology and Life Sciences in Bydgoszcz, Poland
Michael Koniordos	Piraeus University of Applied Sciences, Greece
Bogusław Łazarz	Silesian University of Technology, Poland
Michal Maciejewski	Technical University Berlin, Germany
Elżbieta Macioszek	Silesian University of Technology, Poland
Ján Mandula	Technical University of Košice, Slovakia
Sylwester Markusik	Silesian University of Technology, Poland
Antonio Masegosa	IKERBASQUE Research Fellow at University of Deusto Bilbao, Spain
Agnieszka Merkisz-Guranowska	Poznań University of Technology, Poland
Anna Meżyk	Kazimierz Pulaski University of Technology and Humanities in Radom
Maria Michałowska	University of Economics in Katowice, Poland
Leszek Mindur	International School of Logistics and Transport in Wrocław, Poland
Maciej Mindur	Lublin University of Technology, Poland
Goran Mladenović	University of Belgrade, Serbia
Kai Nagel	Technical University Berlin, Germany
Piotr Niedzielski	University of Szczecin, Poland
Piotr Olszewski	Warsaw University of Technology, Poland
Enrique Onieva	Deusto Institute of Technology, University of Deusto Bilbao, Spain
Asier Perallos	Deusto Institute of Technology, University of Deusto Bilbao, Spain
Hrvoje Pilko	University of Zagreb, Croatia
Antonio Pratelli	University of Pisa, Italy

Dariusz Pyza	Warsaw University of Technology, Poland
Cesar Queiroz	World Bank Consultant (Former World Bank Highways Adviser), Washington, DC, USA
Andrzej Rudnicki	Cracow University of Technology, Poland
František Schlosser	University of Žilina, Slovakia
Grzegorz Sierpiński	Silesian University of Technology, Poland
Jacek Skorupski	Warsaw University of Technology, Poland
Aleksander Sładkowski	Silesian University of Technology, Poland
Wiesław Starowicz	Cracow University of Technology, Poland
Andrzej Szarata	Cracow University of Technology, Poland
Tomasz Szczuraszek	University of Technology and Life Sciences in Bydgoszcz, Poland
Antoni Szydło	Wrocław University of Technology, Poland
Grzegorz Ślaski	Poznań University of Technology, Poland
Paweł Śniady	Wrocław University of Environmental and Life Sciences, Poland
Andrew P. Tarko	Purdue University, West Lafayette, USA
Frane Urem	Polytechnic of Šibenik, Croatia
Hua-lan Wang	School of Traffic and Transportation, Lanzhou Jiaotong University, Lanzhou, China
Mariusz Wasiak	Warsaw University of Technology, Poland
Adam Weintrit	Gdynia Maritime University, Poland
Andrzej Więckowski	AGH University of Science and Technology, Cracow, Poland
Katarzyna Wegrzyn	Wolska: Engineering School of Digital Science Villejuif, France
Adam Wolski	Polish Naval Academy, Gdynia, Poland
Olgierd Wyszomirski	University of Gdańsk, Poland
Elżbieta Załoga	University of Szczecin, Poland
Stanisława Zamkowska	Kazimierz Pulaski University of Technology and Humanities in Radom, Poland
Jacek Żak	Poznań University of Technology, Poland
Jolanta Żak	Warsaw University of Technology, Poland

Referees

Rahmi Akçelik
Przemysław Borkowski
Tony Castillo-Calzadilla
Ireneusz Celiński
Jacek Chmielewski
Piotr Czech
Magdalena Dobiszewska
Michal Fabian
Barbara Galińska
Anna Granà
Róbert Grega
Mehmet Serdar Güzel
Katarzyna Hebel
Peter Jenček
Nan Kang
Peter Kaššay
Jozef Kuĺka
Michał Maciejewski

Elżbieta Macioszek
Krzysztof Małecki
Martin Mantič
Paola di Mascio
Silvia Medvecká-Beňová
Maria Mrówczyńska
Vitalii Naumov
Katarzyna Nosal Hoy
Ander Pijoan
Hrvoje Pilko
Michal Puškár
Alžbeta Sapietová
Grzegorz Sierpiński
Izabela Skrzypczak
Marcin Staniek
Dariusz Tłoczyński
Andrzej Więckowski
Grzegorz Wojnar
Adam Wolski
Ninoslav Zuber

Contents

Intersections as Bottlenecks of Transport Networks – Solutions for Low Capacity

Empirical Analysis of Gap Acceptance Parameters at Roundabouts Located in Tokyo (Japan) and the Tokyo Surroundings

Elżbieta Macioszek(✉)

Faculty of Transport, Silesian University of Technology, Katowice, Poland
elzbieta.macioszek@polsl.pl

Abstract. The article comments upon results of an empirical analysis of psychotechnical parameters of vehicle drivers (i.e. critical gaps and follow-up times) at roundabouts located in Tokyo and the Tokyo surroundings. The analysis in question was conducted as a part a project entitled "Analysis of the applicability of the author's method of roundabouts entry capacity calculation developed for the conditions prevailing in Poland to the conditions prevailing at roundabouts in Tokyo (Japan) and in the Tokyo surroundings" financed by the Polish National Agency for Academic Exchange.

Keywords: Roundabouts · Psychotechnical parameters · Driver behaviours · Road traffic engineering · Transport

1 Introduction

Transport in Japan is very highly advanced in technological terms as well as remarkably developed. The sector clearly stands out for its energy efficiency, as it consumes less energy per capita than any other country. As claimed in papers [1–3], this is possible owing to the high share of rail transport in general. While comparing the costs and characteristics of Japanese transport with the costs and characteristics of transport worldwide, the former appears to be among the most expensive in the world which stems from the fact that the users of means of transport are charged with actual transport costs, and these are reflected in various fees and taxes.

Two documents entitled *Basic Plan on Transport Policy* [4] and *White Paper on Land, Infrastructure, Transport and Tourism in Japan* [5] define three basic directions for the development of the country's transport policy. They are as follows:

- realize user-friendly transport that contributes to the rich lives of the citizens,
- build up the inter-regional/international passenger transport and logistics networks that create a foundation for growth and prosperity,
- create a foundation of sustainable, secure and safe transport.

Detailed objectives have also been set up under each of the above primary goals. As for the first goal, i.e. to "realise user-friendly transport that contributes to the rich lives of the citizens," they have been defined as follows:

E. Macioszek et al. (Eds.): TSTP 2019, LNITI, pp. 3–15, 2020.
https://doi.org/10.1007/978-3-030-39109-6_1

- reconstruct the regional transport networks under local governments' initiatives, coordinating with town planning policies,
- encourage deployment of various transport services taking into account local circumstances,
- make barrier-free transport more familiar,
- further raise the service levels for passenger transport and logistics.

With regard to the second primary goal, i.e. to "build up the inter-regional/ international passenger transport and logistics networks that create a foundation for growth and prosperity," the objectives are to:

- strengthen competitiveness of Japan's international transport network,
- boost regional flow of people and goods,
- enhance coordination with tourism policies toward receiving 20 million foreign visitors,
- expand transport infrastructure & services worldwide using Japanese technology and know-how.

And under the third primary goal, i.e. to "create a foundation of sustainable, secure and safe transport," the following objectives have been established:

- take the most prudent course for large-scale disasters & deterioration of transport facilities,
- enhance transport business foundation for stable & safe operation,
- secure and foster human resources in the transport sector,
- proceed with further low carbonization & energy conservation.

Roundabouts are not particularly popular intersections in Japan. Nevertheless, the interest in this road junction type increased after the earthquakes that struck east Japan in the recent years. This is when they revealed their undeniable advantage, namely the capacity to function properly without traffic lights under different terrain conditions. In European countries, in Australia and in the USA, to the contrary, roundabouts are popular and frequently implemented street intersection types. In these countries, a significant number of scientific publications (including [6–32]) have already been dedicated to these infrastructural components sometimes in the main role, and sometimes as a side study topic. This article comments upon results of an analysis of psychotechnical parameters of drivers at roundabouts in Tokyo (Japan) and in the Tokyo surroundings. Empirical studies have been conducted at six single-lane roundabouts.

2 Gap Acceptance Parameters

In the models used to estimate the flow capacity of entry legs, based on the theory of gap acceptance in the main vehicle stream, the basic parameters which characterise the behaviour patterns of drivers at roundabout entry legs as they attempt to enter the main circulatory roadway are as follows:

- critical gap (t_g),
- follow up time (t_f).

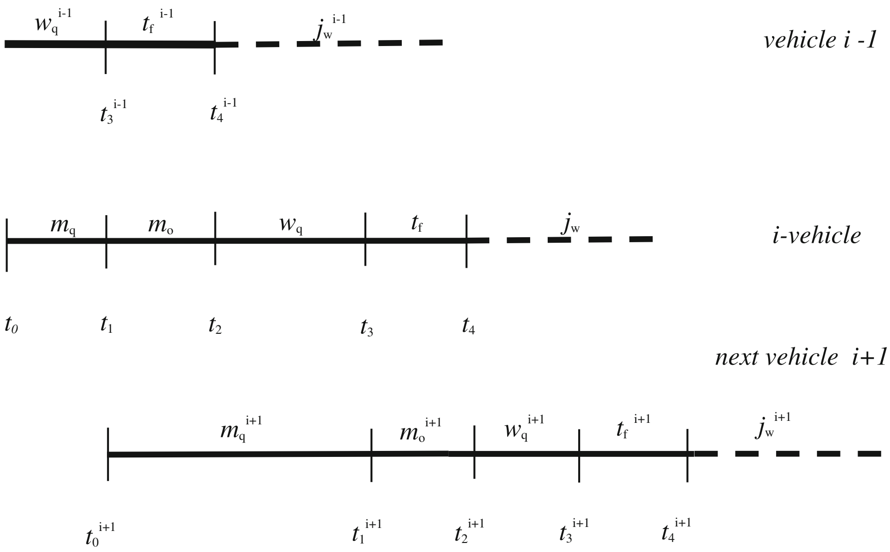
The critical gap for drivers of vehicles at an entry leg (t_g) is such a value of time interval between vehicles in the higher rank stream of vehicles on the main circulatory roadway at which each interval of equal or higher value will be used to perform a manoeuvre of entry to the main circulatory roadway by a statistically average driver from a lower rank stream, while every such interval of a lower value (preventing drivers from performing the intended manoeuvre) does not provide an entry opportunity which can be used. The critical gap is not a fixed quantity. It assumes different values for different drivers and for each individual driver at different times. The critical gap is also a random variable whose value depends on the characteristics of a human-vehicle system as well as on geometric and motional conditions of the given roundabout, and which can be characterised using probability distributions.

The follow-up time, on the other hand, i.e. the time interval between vehicles entering the roundabout from an entry leg queue (t_f), represents the time between the passing of the circulatory roadway edge by the first minor stream vehicle from the entry leg and the passing of a successive vehicle using the same gap in the roundabout stream. If the roundabout stream gap time enables further vehicles to enter the roundabout, they pass through the circulatory roadway edge at follow-up intervals of t_f one after another. On a very low flow rate of the roundabout stream, the t_f follow-up times mainly determine the entry leg capacity.

The passing through a roundabout by each vehicle consists of several stages. When vehicle drivers reach the roundabout entry leg and are forced to queue, they lose time by queuing at the entry leg as well as on account of the vehicle handling actions they must perform. The vehicle drivers who have arrived at the roundabout entry without being forced to queue, on the other hand, suffer time losses resulting only from the vehicle handling process itself (thus losing no time queuing or advancing to the first place in the entry leg queue). Hence the total time of driving through the roundabout comprising four stages (Fig. 1):

- stage 1: $m_{\mathrm{q}} = t_1 - t_0$ - queuing time from the moment of arriving at the entry leg queue end (t_0) to the moment when the preceding vehicle accepts the gap and leaves the entry leg by entering the circulatory roadway (t_1),
- stage 2: $m_0 = t_2 - t_1$ - time required to advance to the first place in the entry leg queue. It is the time interval between the moment when the preceding vehicle left the entry leg and when the vehicle in question takes the first place in the entry leg queue. Starting from time t_2, the vehicle driver begins to observe the gaps between the vehicles already in the circulatory roadway,
- stage 3: $w_{\mathrm{q}} = t_3 - t_2$ - waiting time at the first place in the queue directly at the entry leg stop line until time t_3 when the driver accepts the gap,
- stage 4: $t_{\mathrm{f}} = t_4 - t_3$ - time required for the vehicle at the first place in the entry leg queue to enter the roadway around the roundabout's central island.

The time required for the i^{th} vehicle to enter and the time of advancing in the queue to the first place and crossing the entry leg stop line by the $i + 1^{th}$ vehicle overlap, and consequently time instants t_3 and t_1^{i+1} overlap as well. The time required to handle the



where:

t_o^{i-1}, t_0, t_o^{i+1} - moment of arrival of a vehicle (*i-1*, *i* and *i*+1, respectively) at the entry leg's queue,

t_1^{i-1}, t_1, t_1^{i+1} - moment when the preceding vehicle accepts the gap and begins leaving the entry leg by entering the circulatory roadway,

t_2^{i-1}, t_2, t_2^{i+1} - moment when the driver of a vehicle (*i-1, i* and *i+1*, respectively) begins to observe the gaps between the vehicles already in the circulatory roadway,

t_3^{i-1}, t_3, t_3^{i+1} - moment of gap acceptance by a vehicle (*i-1*, *i* and *i*+1, respectively),

t_4^{i-1}, t_4, t_4^{i+1} - moment when the entry manoeuvre is completed by the vehicle (*i-1*, *i* and *i*+1, respectively) entering from the first place in the entry leg,

m_q^{i-1}, m_q, m_q^{i+1} - time of queuing by a vehicle (*i-1*, *i* and *i*+1, respectively),

m_0^{i-1}, m_0, m_0^{i+1} - time required for a vehicle (*i-1*, *i* and *i*+1, respectively) to advance to the first place in the entry leg queue,

w_q^{i-1}, w_q, w_q^{i+1} - time of waiting at the first place in the queue directly at the entry leg stop line until the vehicle (*i-1*, *i* and *i*+1, respectively) accepts the interval (gap),

t_f^{i-1}, t_f, t_f^{i+1} - time of entering the circulatory roadway by the vehicle (*i-1*, *i* and *i*+1, respectively) at the first place in the entry leg,

j_w^{i-1}, j_w, j_w^{i+1} - time required for a vehicle (*i-1*, *i* and *i*+1, respectively) to move around the central island and reach the intended exit. The value of this quantity depends on the chosen driving direction (right, straight, left, turn).

Fig. 1. Successive stages in which a vehicle passes through a roundabout

vehicle (S) does not comprise the entire interval of [t_1, t_4], but it constitutes a sum of two times:

$$S = w_q + t_f \ [s] \tag{1}$$

The vehicle handling starts at time t_2, i.e. when the driver begins observing gaps between vehicles on the circulatory roadway, and it ends upon completing the circulatory roadway entry action. The handling of the next vehicle ($i + 1$) begins at time t_4 with observation of the gaps in the circulatory roadway (Fig. 1).

Models based on the theory of gap acceptance in the main stream are generally founded on the assumption that the vehicle drivers at the entry leg begin their effective and efficient observation of the gaps on the main circulatory roadway from the moment of arrival at the first place in the queue. This assumption stems from the fact that the observation of the gaps in the main circulatory roadway by a queuing driver cannot begin until the moment when it is physically possible on account of the preceding vehicles. Hence the assumption that the handling of non-queuing vehicles cannot start before the lapse of m_{o} units of time after the previous vehicle handling operation was completed. If a time gap of a value higher than that of the critical gap occurs in the main circulatory roadway in time t_1, the decision to accept this gap is made by the vehicle driver at the entry leg.

From a mathematical point of view, the vehicle detection process is described as a point process, where each arrival is a point in a timeline. Each follow-up time is linked with a vehicle the detection of which ends the current time interval. At roundabouts, vehicle drivers at entry legs are considering the possibility of entering the higher rank stream during the time intervals corresponding to the gaps in the main circulatory roadway. Let us assume that a vehicle has arrived at the entry leg stop line in time τ, the preceding vehicle on the circulatory roadway passed through the collision area in time τ_i, while the following vehicle on the circulatory roadway passed through the collision area in time τ_{i+1}. The time between the moment of passing by the preceding vehicle and the moment of a vehicle's arrival at the minor entry leg stop line is an unused interval equalling to:

$$B(\tau) = \tau - \tau_i \tag{2}$$

The time between the moment of a vehicle's arrival at the minor entry leg stop line and the moment of arrival of the following vehicle on the circulatory roadway is an interval which equals to:

$$L(\tau) = \tau_{i+1} - \tau \tag{3}$$

The current follow-up time of τ is the follow-up time before vehicle $i + 1$, i.e.:

$$T(\tau) = T_{i+1} = \tau_{i+1} - \tau_i = B(\tau) + L(\tau) \tag{4}$$

where:
$T(\tau)$ - current follow-up time of τ.

The availability of gaps in the higher rank stream for the entry leg vehicles is described by the distribution of gaps in the higher rank stream. The cumulative distribution function of gaps determines the probability that a randomly chosen gap is not longer than the pre-set value:

$$F(t) = P\{T < t\} = \int_0^t f(g)d(g) \tag{5}$$

$$F(\infty) = P\{T < \infty\} = \int_0^\infty f(g)d(g) = 1 \tag{6}$$

where:
f(g) - probability density function.

Since the gaps do not assume negative values, the lower threshold equals zero in both these expressions. The probability of a randomly chosen gap being longer than the pre-set value is given by the negative cumulative distribution function of *R*(t):

$$R(t) = P\{T \geq t\} = \int_t^\infty f(g)d(g) = 1 - F(t) \tag{7}$$

The expected value of *E[T]* can be calculated as:

$$E[T] = \bar{t} = \int_0^\infty tf(t)dt \tag{8}$$

Where $t < 0$, then $f(t) = 0$, and therefore the expected value can also be expressed using a negative cumulative distribution function:

$$E[T] = \bar{t} = \int_0^\infty [1 - F(t)]dt = \int_0^\infty R(t)dt \tag{9}$$

The mathematical proof of the above equation can be found in paper [27]:

$$\int_0^\infty R(t)dt = \int_0^\infty \int_t^\infty f(g)dgdt = \int_0^\infty \left(\int_0^g dt \right) f(g)dg = \int_0^\infty gf(g)dg \tag{10}$$

For n consecutive gaps, the expected time of their duration is:

$$E[\tau_n] = n \cdot \bar{t} \tag{11}$$

Traffic intensity $\lambda = \frac{q}{3600}$ is the converse of average gap $\lambda = n(E[\tau_n])^{-1} = \bar{t}^{-1}$.

The intervals encountered by vehicles randomly arriving at the entry leg are characterised by a distribution different than that of gaps. If $R(u) = P\{T > u\}$ is the negative cumulative distribution function for the gap distribution and *E[T]* is the expected gap value, the probability density function of intervals may be expressed as the following equation of work [33]:

$$f_L(u) = \frac{R(u)}{E[T]} = \lambda \cdot R(u) \tag{12}$$

With reference to the above equation, one can calculate the negative cumulative distribution function for intervals [33]:

$$R_L(u) = \lambda \cdot \int_u^\infty R(y)dy \tag{13}$$

The expected interval value can be expressed as follows [33]:

$$\begin{aligned} E[L] &= \int_0^\infty u f_L(u)du = \frac{1}{E[T]} \cdot \int_0^\infty uR(u)du = \frac{1}{E[T]} \cdot \int_0^\infty u \int_u^\infty f(y)dydu \\ &= \frac{1}{E[T]} \cdot \int_0^\infty \left(\int_0^y udu \right) f(y)dy = \frac{1}{E[T]} \cdot \int_0^\infty \frac{y^2}{2} f(y)dy = \frac{E[T^2]}{2E[T]} = \frac{\bar{t}}{2} + \frac{\sigma_T^2}{2\bar{t}} \end{aligned} \tag{14}$$

3 Results of the Study on Psychotechnical Parameters for Roundabouts Located in Tokyo and the Tokyo Surroundings

The psychotechnical parameters characterising vehicle drivers, i.e. the gaps rejected and accepted by individual drivers at roundabout entry legs (subsequently used to determine the numerical values for the critical gaps) and the follow-up times, were measured at six single-lane roundabouts:

- Hitachi Taga roundabout,
- Sakuragaocka roundabout,
- Minami Hanyu roundabout,
- Iida Nagano 1 roundabout,
- Iida Nagano 2 roundabout,
- Suzaka Nagano roundabout.

The measurements were conducted using digital cameras in February 2019. The trajectories of the vehicles traversing the main circulatory roadway as well as those at the entry legs were analysed using the Traffic Analyzer image processing system [34]. The position of vehicles was extracted in 0.5 s intervals, and then the position coordinates were converted into a global coordinate system by projective transformation. The vehicle trajectories transformed were smoothened by the Kalman smoothing method.

The values of critical gaps were derived from the cumulative distribution functions of the accepted and rejected gaps as well as using the gap acceptance curve. The gap acceptance curve was also used to calculate the critical gap as the gap for which the probability of acceptance equals 50%. The gaps were only collected for the entry leg vehicles without any other vehicles ahead of the entry leg stop line. An example of how the critical gaps were determined for the entry legs of the Hitachi Taga roundabout using cumulative curves and the acceptance curve has been provided in Fig. 2.

Follow-up times, on the other hand, were calculated as the average value from follow-up times of individual vehicle drivers at the roundabout entry leg. Table 1 provides an example of how the follow-up time values were determined for the entry legs of the Hitachi Taga roundabout. Individual values of follow-up time t_f were analysed for the vehicles queuing at the entry leg, and then the average value of t_f was established for the entry leg in question.

Values of critical gaps for individual entry legs and of average follow-up times between vehicles entering the roundabout from a queue at the entry legs of the analysed single-lane roundabouts in Tokyo and the Tokyo surroundings have been collated in Table 2. Having analysed individual values, one can determine that the critical gap assumed values ranging between 3.10 and 6.60 s, while the follow-up time ranged at 2.70–3.10 s. With reference to the previous studies involving measurements of values of psychotechnical parameters performed at roundabouts in Japan, the following can be established:

- the critical gap parameter assumed values ranging between 3.00 and 3.80 s as per paper [35] and between 3.5 and 4.0 according to paper [36],
- the follow-up time parameter assumed values ranging between 3.26 and 4.90 s as per paper [35] and between 2.6 and 3.8 according to paper [36].

However, it should also be noted that in the studies addressed in both these papers, the relevant measurements were performed at the entry legs of only one single-lane roundabout. The values of the psychotechnical parameters subject to analysis obtained under the author's own studies conducted at entry legs of six single-lane roundabouts coincide with the values provided in papers [35] and [36] as for the critical gaps, and they are similar to the follow-up time values obtained in previous studies. Nevertheless, the results provided in publications [35] and [36] pertained to empirical studies conducted in the years 2002, 2010 and 2011, and hence the conclusion that the decline in the follow-up time values may be due to the fact that drivers had simply become accustomed with roundabouts, and started entering the main circulatory roadway from an entry leg queue with more confidence and at a higher speed.

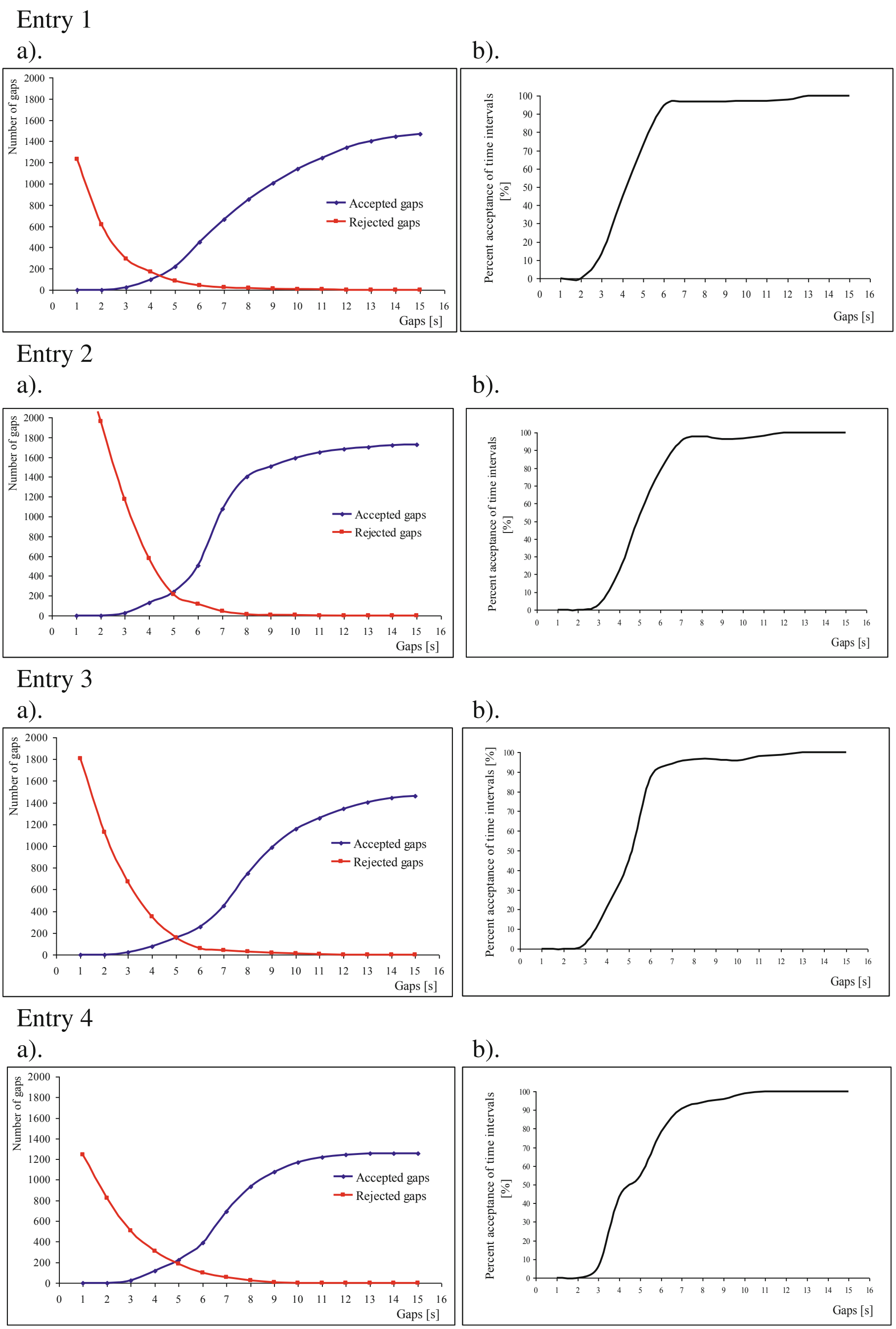


Fig. 2. Critical gap values for the Hitachi Taga roundabout entry legs established using (a) cumulative curves and (b) acceptance curve

Table 1. Follow-up times values for single lane roundabout entry legs at Hitachi Taga roundabout.

Vehicle from the queue	1	2	3	4	5	6	7	8
	t_{f1}	t_{f2}	t_{f3}	t_{f4}	t_{f5}	t_{f6}	t_{f7}	t_{f8}
Entry 1								
Average follow-up time [s]	3.01	2.98	2.98	2.96	2.95	2.93	2.95	2.94
Average follow-up time for entry [s]	2.96							
Entry 2								
Average follow-up time [s]	3.05	2.99	2.98	2.96	2.97	2.93	2.95	2.96
Average follow-up time for entry [s]	2.97							
Entry 3								
Average follow-up time [s]	3.26	3.12	3.00	2.96	2.95	2.93	2.85	2.90
Average follow-up time for entry [s]	3.00							
Entry 4								
Average follow-up time [s]	3.23	2.8	2.95	2.93	2.95	2.93	2.90	2.90
Average follow-up time for entry [s]	2.95							

Table 2. Values of critical gaps and of follow-up times between vehicles entering the roundabout from a queue at the entry legs of the analysed single-lane roundabouts in Tokyo and the Tokyo surroundings.

Single lane roundabout	Entry leg number	t_g [s]	t_f [s]
Hitachi Taga	1	4.40	2.96
	2	4.80	2.97
	3	4.90	3.00
	4	4.90	2.95
Sakuragaocka	1	3.80	2.75
	2	3.20	2.78
	3	3.10	2.73
	4	–	–
	5	–	–
Minami Hanyu	1	5.00	2.95
	2	6.60	2.96
	3	5.20	2.91
Iida Nagano 1	1	4.90	3.00
	2	6.50	3.02
	3	5.10	3.10
	4	5.00	2.98
	5	5.40	2.99
Iida Nagano 2	1	3.50	2.77
	2	3.40	3.00
	3	3.80	2.70
	4	3.60	2.75
	5	3.30	2.80

(*continued*)

Table 2. (*continued*)

Single lane roundabout	Entry leg number	t_g [s]	t_f [s]
Suzaka Nagano	1	5.30	3.04
	2	5.80	3.06
	3	5.60	3.02
	4	5.50	3.07
Average values		4.69	2.93

4 Conclusions

Despite roundabouts are not very popular kind of intersections in Japan, they contribute to an environmentally friendly transport system [37]. The article addresses results of measurements of psychotechnical parameters (i.e. critical gaps and follow-up times) of vehicle drivers at entry legs of single-lane roundabouts located in Tokyo (Japan) and the Tokyo surroundings. The results obtained in the course of the studies have enabled the author to determine that the critical gap assumed values ranging between 3.10 and 6.60 s, while the follow-up time ranged from 2.70 to 3.10 s. These data will provide grounds for further analyses aimed at building models assuming the form of functions making it possible to estimate numerical values for the both parameters analysed in the paper.

Acknowledgements. The present research has been financed from the means of the Polish National Agency for Academic Exchange as a part of the project within the scope of Bekker Programme "Analysis of the applicability of the author's method of roundabouts entry capacity calculation developed for the conditions prevailing in Poland to the conditions prevailing at roundabouts in Tokyo (Japan) and in the Tokyo surroundings".

References

1. Lipscy, P.Y., Schipper, L.: Energy efficiency in the Japanese transport sector. Energy Policy **56**, 248–258 (2013)
2. Lipscy, P.Y.: A casualty of political transformation? The politics of Japanese energy efficiency in the transportation sector. J. East Asian Stud. **12**, 409–440 (2012)
3. Skowrońska, A.: Polityka transportowa Japonii w kontekście stanu i perspektyw rozwoju japońskiego transportu. Logistyka **5**, 7–13 (2014)
4. Basic Plan on Transport Policy. http://www.mlit.go.jp/common/001096409.pdf
5. White Paper on Land, Infrastructure, Transport and Tourism in Japan. http://www.mlit.go.jp/common/001216008.pdf
6. Pilko, H., Saric, Z., Zovak, G.: Turbo roundabouts: a brief safety, efficiency and geometry design review. In: Macioszek, E., Akçelik, R., Sierpiński, G. (eds.) Roundabouts as Safe and Modern Solutions in Transport Networks and Systems. LNNS, vol. 52, pp. 3–12. Springer, Cham (2019)

7. Giuffre, O., Grana, A., Tumminello, M.L., Giuffre, T., Trubia, S.: Surrogate measures of safety at roundabouts in AIMSUN and VISSIM environment. In: Macioszek, E., Akçelik, R., Sierpiński, G. (eds.) Roundabouts as Safe and Modern Solutions in Transport Networks and Systems. LNNS, vol. 52, pp. 53–64. Springer, Cham (2019)
8. Fernandes, P., Coelho, M.: Making compact two-lane roundabouts effective for vulnerable road users: an assessment of transport-related externalities. In: Macioszek, E., Akçelik, R., Sierpiński, G. (eds.) Roundabouts as Safe and Modern Solutions in Transport Networks and Systems. LNNS, vol. 52, pp. 99–111. Springer, Cham (2019)
9. Kang, N., Terebe, S.: Estimating roundabout delay considering pedestrian impact. In: Macioszek, E., Akçelik, R., Sierpiński, G. (eds.) Roundabouts as Safe and Modern Solutions in Transport Networks and Systems. LNNS, vol. 52, pp. 112–123. Springer, Cham (2019)
10. Małecki, K.: The roundabout micro-simulator based on the cellular automata model. In: Sierpiński, G. (ed.) Advanced Solutions of Transport Systems for Growing Mobility. AISC, vol. 631, pp. 40–49 (2018)
11. Macioszek, E.: The application of HCM 2010 in the determination of capacity of traffic lanes at turbo roundabout entries. Transp. Probl. **11**(3), 77–89 (2016)
12. Małecki, K., Wątróbski, J.: Cellular automaton to study the impact of changes in traffic rules in a roundabout: a preliminary approach. Appl. Sci. **7**(7), 742 (2017). Article Number: UNSP
13. Małecki, K.: The use of heterogeneous cellular automata to study the capacity of the roundabout. In: Rutkowski, L., Korytkowski, M., Scherer, R., Tadeusiewicz, R., Zadech, L. A., Zurada, J.M. (eds.) Artificial Intelligence and Soft Computing. LNAI, vol. 10246, pp. 308–317. Springer, Cham (2017)
14. Turoń, K., Czech, P.: Study on roundabouts in Polish conditions - law, safety problems, sanctions. In: Macioszek, E., Akçelik, R., Sierpiński, G. (eds.) Roundabouts as Safe and Modern Solutions in Transport Networks and Systems. LNNS, vol. 52, pp. 137–146. Springer, Cham (2019)
15. Macioszek, E.: The comparison of models for follow-up headway at roundabouts. In: Macioszek, E., Sierpiński, G. (eds.) Recent Advances in Traffic Engineering for Transport Networks and Systems. LNNS, vol. 21, pp. 16–26. Springer, Switzerland (2018)
16. Turoń, K., Czech, P., Juzek, M.: The concept of walkable city as an alternative form of urban mobility. Sci. J. SUT **95**, 223–230 (2017)
17. Turoń, K., Golba, D., Czech, P.: The analysis of progress CSR good practices areas in logistic companies based on reports "Responsible Business in Poland. Good Practices" in 2010–2014. Sci. J. SUT **89**, 163–171 (2015)
18. Macioszek, E.: The comparison of models for critical headways estimation at roundabouts. In: Macioszek, E., Sierpiński, G. (eds.) Contemporary Challenges of Transport Systems and Traffic Engineering. LNNS, vol. 2, pp. 205–219. Springer, Switzerland (2017)
19. Celiński, I., Sierpiński, G.: Method of assessing vehicle motion trajectory at one-lane roundabouts using visual techniques. In: Macioszek, E., Akçelik, R., Sierpiński, G. (eds.) Roundabouts as Safe and Modern Solutions in Transport Networks and Systems. LNNS, vol. 52, pp. 24–39. Springer, Cham (2019)
20. Celiński, I.: Evaluation method of impact between road traffic in a traffic control area and in its surroundings. Ph.D. Dissertation, Warsaw University of Technology Publishing House, Warsaw (2018)
21. Celiński, I.: GT Planner used as a tool for sustainable development of transport infrastructure. In: Suchanek, M. (ed.) New Research Trends in Transport Sustainability and Innovation. SPBE, pp. 15–27. Springer, Cham (2018)
22. Sierpiński, G., Staniek, M., Celiński, I.: Travel behavior profiling using a trip planner. Transp. Res. Procedia **14C**, 1743–1752 (2016)

23. Sierpiński, G.: Distance and frequency of travels made with selected means of transport - a case study for the Upper Silesian conurbation (Poland). In: Sierpiński, G. (ed.) Intelligent Transport Systems and Travel Behaviour. AISC, vol. 505, pp. 75–85. Springer, Cham (2017)
24. Sierpiński, G., Staniek, M.: Education by access to visual information - methodology of moulding behaviour based on international research project experiences. In: Gómez Chova, L., López Martínez, A., Candel Torres I. (eds.) ICERI2016 Proceedings. 9th International Conference of Education, Research and Innovation, IATED Academy, Valencia, pp. 6724–6729 (2016)
25. Sierpiński, G., Staniek, M., Celiński, I.: Shaping environmental friendly behaviour in transport of goods - new tool and education. In: Gómez Chova, L., López Martínez, A., Candel Torres I. (eds.) ICERI2015 Proceedings. 8th International Conference of Education, Research and Innovation, IATED Academy, Valencia, pp. 118–123 (2015)
26. Staniek, M., Czech, P.: Self-correcting neural network in road pavement diagnostics. Autom. Constr. **96**, 75–87 (2018)
27. Chmielewski, J.: Impact of transport zone number in simulation models on cost-benefit analysis results in transport investments. IOP Conf. Ser. Mater. Sci. Eng. **245**, 1–10 (2017)
28. Chmielewski, J.: Transport demand model management system. IOP Conf. Ser. Mater. Sci. Eng. **471**, 1–10 (2019)
29. Chmielewski, J., Olenkowicz-Trempała, P.: Analysis of selected types of transport behaviour of urban and rural population in the light of surveys. In: Macioszek, E., Sierpiński, G. (eds.) Recent Advances in Traffic Engineering for Transport Networks and Systems. LNNS, vol. 21, pp. 27–36. Springer, Cham (2018)
30. Galińska, B.: Intelligent decision making in transport. Evaluation of transportation modes (types of vehicles) based on multiple criteria methodology. In: Sierpiński, G. (ed.) Integration as Solution for Advanced Smart Urban Transport Systems. AISC, vol. 844, pp. 161–172. Springer, Switzerland (2019)
31. Żak, J., Galińska, B.: Design and evaluation of global freight transportation solutions (corridors). Analysis of a real world case study. Transp. Res. Procedia **30**, 350–362 (2018)
32. Galińska, B.: Logistics megatrends and their influence on supply chains. Business logistics in modern management. In: Proceedings of the 18th International Scientific Conference. https://hrcak.srce.hr/ojs/index.php/plusm/issue/view/325
33. Luttinen, T.R.: Capacity and level of service at Finnish unsignalized intersections. Finnish Road Administration, Helsinki (2004)
34. Suzuki, K., Nakamura, H.: Traffic analyzer - the integrated video image processing system for traffic flow analysis. In: Proceedings of the 13th ITS World Congress, London (2006)
35. Manage, S., Nakamura, H., Suzuki, K.: Performance analysis of roundabouts as an alternative for intersection control in Japan. J. East. Asia Soc. Transp. Stud. **5**, 871–883 (2003)
36. Kang, N., Nakamura, H., Asano, M.: An empirical analysis on critical gap and follow-up time at roundabout considering geometry effect. http://library.jsce.or.jp/jsce/open/00039/201211_no46/pdf/129.pdf
37. Jacyna, M., Żak, J., Jacyna-Gołda, I., Merkisz, J., Merkisz-Guranowska, A., Pielucha, J.: Selected aspects of the model of proecological transport system. J. KONES Powertrain Transp. **20**, 193–202 (2013)

Suggested Solutions to Reduce Traffic Congestion During Rush Hours in Al-Jadriya Intersection

Firas Alrawi(✉), Yousif Naji, and Khaleel AlSaffar

Urban and Regional Planning Center, University of Baghdad, Baghdad, Iraq
dr.firas@uobaghdad.edu.iq, {youssef.qassil100b, khaleel.saad1100b}@iurp.uobaghdad.edu.iq

Abstract. The current research aims to suggest some solutions to Aljadriya intersection nearby Baghdad University in order to reduce traffic congestion crisis at this intersection. It is assumed that shifting to more sustainable modes of transport, and the opening of closed traffic routes will significantly improve traffic performance. The traffic movement characteristic has been studied in this intersection depending on some previous research. And as a result, there has been many troubles shown in the level of service for this intersection reached (F level). And by suggesting a group of solutions representing by; first: providing enough space to extend the TOD transmission line from western side (Jadriya bridge) towards the eastern side (Karrada). Second is to open a secondary floating bridge that parallels Aljadriya bridge which works on prepayment, and by applying these solutions we can reduce the traffic congestion from 7–28% depend on strategies which applay.

Keywords: Intersections · Traffic · Traffic congestion · Aljadriya · Sustainable transport

1 Introduction

According to the highway design manual, the traffic intersection is defined as the area where two or more roads intersect or intersect at the same level, including the pathway and sideway of the road for the traffic. Each road leads to an intersection and part of the road is a leg (close by) to the intersection. At a point in which vehicles are likely to interfere and in which pedestrians and cyclists are at risk of crashing accidents.

These are being dealt with the traffic intersections within a comprehensive plan and with the participation of people's views that reflect the public's opinion [1]. As we have mentioned before in class that the main types of traffic intersections are, "T" or the three legs intersection, which is consisted of three approaches and four approaches, and then intersections that include multiple approaches that can be five or more approaches. Therefore, we will examine the quadratic intersection in detail and we will show the rest of the types that are specialized in the Jadriya Intersection and it is in fact a quadrilateral intersection [2]. The Functional and Physical Area of the Traffic Intersection show in Fig. 1.

E. Macioszek et al. (Eds.): TSTP 2019, LNITI, pp. 16–26, 2020.
https://doi.org/10.1007/978-3-030-39109-6_2

The level of service at any intersection on a highway has a significant impact on the overall operational function of the highway. Thus, improving the level of service at each intersection usually results in a general improvement of operational function on the highway. The analysis of determining the capacity or level of service at intersections is an important tool for designers, process personnel, and policy makers. The factors that affect the level of service at intersections include the flow and distribution of traffic, engineering characteristics, and signaling system.

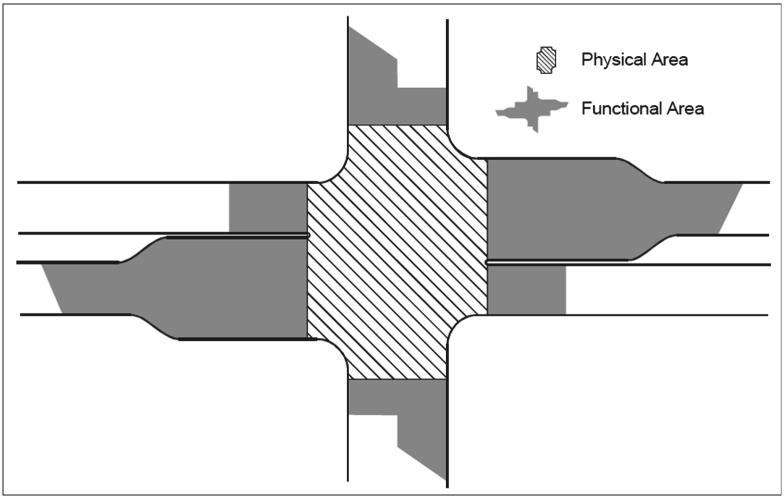


Fig. 1. Functional and physical area of the traffic intersection

Capacity is defined as the maximum number of vehicles that are expected to pass over a specific part of a lane or road over a given period of time under prevailing traffic conditions [3]. As for the level of service which is defined as the qualitative measurement of the impact of a number of factors such as operating speed, duration of travel, traffic errors, freedom of maneuverability, transit, driving safety, comfort, road suitability and operating costs for the service provided by the road to its users [3]. The six levels of service are appointed. For each of one these service levels are identified with the English letters from (A) to (F) [4], better to worse shows in Table 1.

Table 1. The six levels of service (Source: [8, p. 28]).

Property	Occupational ratio	Level of service
Where the flow is free and the movement is high and low in traffic density	Less than 0.4	A
Movement balanced on the street and high speeds	0.4–0.6	B
Stable flow	0.6–0.8	C
Flow is approaching instability and relatively high speeds	0.8–0.9	D
Unstable flow, low speeds and possible traffic jams	0.9–1	E
Low flow with high delays with traffic paralysis	More than 1	F

The delay is usually resulted due to [5]:

- delay severity (second\vehicle), which is related to the perception of the driver of the vehicle that causes delay at the intersection,
- a total accumulated delay (hour\vehicle), which is more related to the economic performance of the intersection.

2 Traffic Congestion Management

Traffic congestion management refers to the activities and strategies we rely on to reduce the traffic volumes on the roads. It refers to all the methods we can use for more efficient traffic movement. Since early in the twentieth Century, transportation planning has focused on providing the necessary supply to support more and more vehicles. This system worked well for some time, while building new transportation infrastructure was inexpensive and houses were still relatively close to employment areas. Nowadays, it appears that the supply theory was not able to propagate a viable transportation system based on the private vehicles; there are two reasons for this:

- the cost of transportation investments has increased due to the high materials' prices and the lack of available inexpensive land to expand over,
- private vehicles are inherently less efficient as a system than transit, bicycling, or walking.

Generally, managing the demand for road use can be done by implementing strategies that works in two different ways [6]. Encouraging public transport, high occupancy vehicles (HOV). And Discouraging private vehicles, single occupancy vehicles (SOV) Fig. 2.

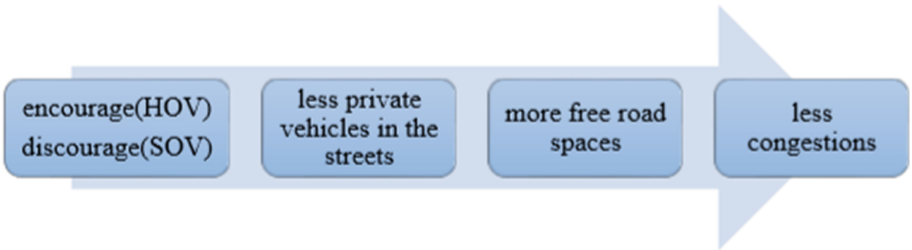


Fig. 2. Show the effect of encouraging (HOV) and discouraging (SOV) on traffic congestion

3 The Effect of Congestion Management

There are many methods and policies through which to manage the traffic congestion, including the pricing of traffic for the purpose of restricting and the other related to the encouraging of the increase vehicles occupancy rate. This section describes some of the policies that we seek to apply in the study area:

- road pricing, congestion pricing imposing some money amount on some roads in a way that can reflect the level of congestion, time of day or type of vehicle, can help in reducing the congestion by limiting unnecessary trips,
- road space management 1 strategies aim to increase the efficiency of roads such as through intelligent transport systems (ITS), freeway management systems, assigning transit only lanes, bus only lanes, or bicycle lanes, and the use of information technology to better manage freeway access and operation [6],
- ridesharing and carpooling a strategy aim to reducing single-occupancy vehicles use through initiatives that encourage the sharing of journeys to common or nearby destinations, for example sharing can be encouraged through assigning special lanes for high occupancy vehicles (HOV lanes), for vehicles with minimum occupancy two passengers or more,
- publicity and public education campaigns This strategy aims at increasing community awareness and up-take of related initiatives, including the use of more sustainable travel patterns and modes. Public education campaigns are necessary to educate people about the importance of reducing private vehicles' use in their daily movements [6].

4 Study Area

The examined intersection is located in the Jadriya district in the southwestern part of Baghdad. This road is characterized by being a major road (Urban Principal Arterial), passing through the areas of Wihda, Karrada and Jadriya to Al Bayaa. This road represents the east-west direction at the intersection. The other direction, the south-north, is a road that is classified as a "Collector Road". And it connects the road of Al Sadda close by the rear gate of the University of Baghdad to Al Zawiya road in the neighborhood of Karrada. The Study Area Show in Fig. 3.

The intersection of Jadriya is substantial because the surrounding area is characterized by various activities. For the following reasons:

- it is located near the Jadriya complex, which includes the Universities of Baghdad and Nahrain, and that increases the momentum of traffic volumes, especially during the academic year,
- it is located near several government buildings such as the Ministry of Science and Technology, the Central Organization for Standardization and Quality Control and the Weather Department,
- it is located near the Jadriya bridge (over the Tigris River), that leads to the accumulation of traffic volumes from different areas of this road to get to Karkh or vice versa,
- this intersection represents the main choice for the first and second exit from and to the residential areas surrounding this intersection.

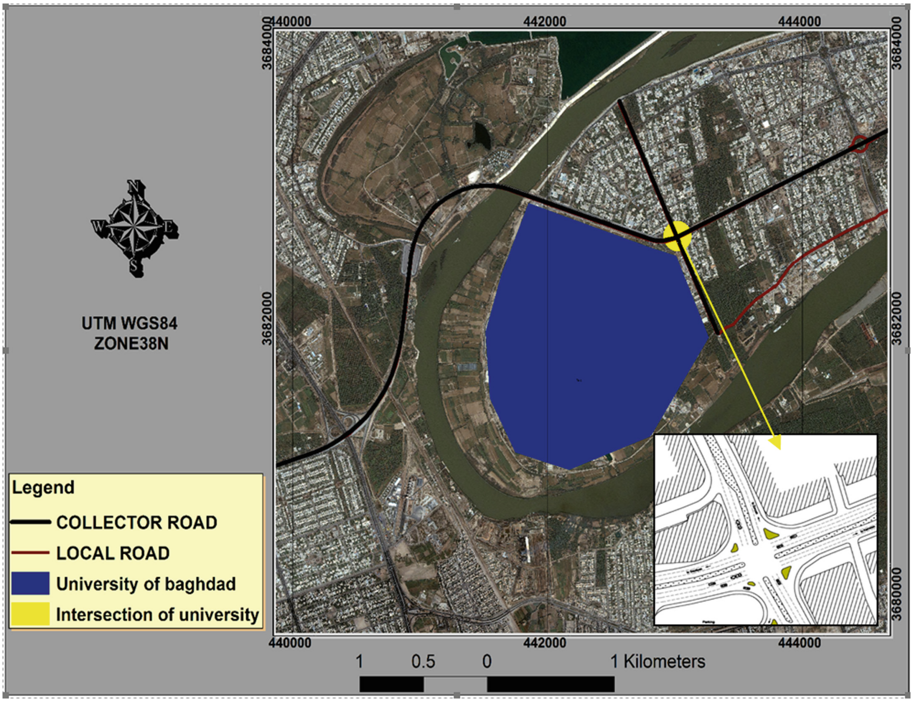


Fig. 3. Study area

5 Data Collection and Traffic Surveys

In order to achieve the requirements of this study, necessary surveys were conducted to collect traffic information for the purpose of calculating the traffic volumes at the Jadriya intersection. A traffic count was carried out twice on Thursday March 7th 2019, Saturday, March 9th 2019. During the week, on each time of the enumeration period was extended from 7:00 am to 5:00 pm to determine the peak or rush hour (the hour at which the highest volume is passing).

5.1 The First Survey on Thursday (3/7/2019)

On this day, a traffic survey was conducted on students' day of the universities of Baghdad and Nahrain and a business day for employees in the government departments close to the intersection. The results of the traffic volume for this day is as shown in the Table 2.

Table 2. Survey on Thursday.

Destination	Vehicles	Traffic volume (Vehicle/hour)	Capacity (Vehicle/hour)	Service level	Evaluation
Passing from Karrada Dakhel (Hurryia Square)	8136	813.6	800	1.01	F
Passing from Jadriya bridge	9503	950.3	800	1.18	F
Passing from Karrada Dakel and Abu Nawas Street	4112	411.2	600	0.68	C
Passing from the rear gate of Baghdad University	2603	260.3	600	0.43	B

5.2 Second Survey on Saturday (3/9/2019)

On this day, the traffic survey was conducted on a holiday for the students of Baghdad and Nahrain Universities as well as for the government departments close to the intersection area. The results of traffic volume for this day were as shown in the Table 3. Tables 4 and 5. Shows a comparison of current surveys with previous years' surveys shows that the same problem has not changed.

Table 3. Survey on Saturday.

Destination	Vehicles	Traffic volume (Vehicle/hour)	Capacity (Vehicle/hour)	Service level	Evaluation
Passing from Karrada Dakhel (Hurryia Square)	5188	518.8	800	0.64	C
Passing from Jadriya bridge	6929	692.6	800	0.86	D
Passing from the rear gate of Baghdad University	459	45.9	600	0.076	A
Passing from Karrada Dakel and Abu Nawas Street	1649	164.9	600	0.27	A

Table 4. Peak hours survey at (7–8 am) (Source: [7]).

Destination	Traffic volume	Capacity (Vehicle/hour)	Level of service	Evaluation
Peak hours survey at (7:00–8:00 am)				
Passing from Karrada Kharij	2913	800	3.6	F
Passing from Jadriya bridge	3391	800	4.2	F
Peak hours survey at (12:45–01:45 pm)				
Passing from Karrada Kharij	1414	800	1.7	F
Passing from Jadriya bridge	2456	800	3.1	B

Table 5. Types of vehicle pass through the intersection at a day (Source: [9]).

Destination	Private cars and taxi	Small trucks, vans and buses carrying up to 24 people	Medium trucks and buses carrying more than 24 passengers
Passing from Karrada Dakhel (Hurryia Square)	10841	2791	1303
Passing from Jadriya bridge	12191	3139	1465
Passing from the rear gate of Baghdad University	6147	1583	738
Passing from Karrada Dakel and Abu Nawas Street	3820	984	460

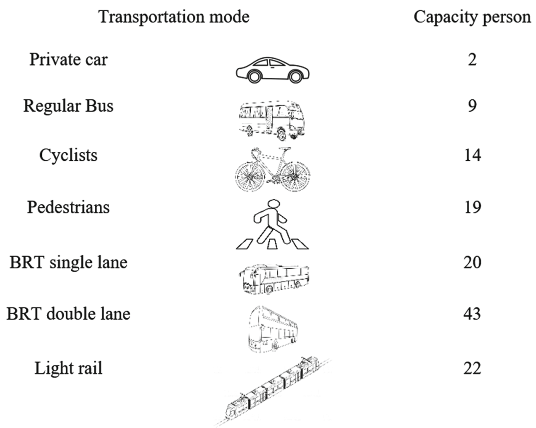


Fig. 4. Shows the absorptive capacity of transport systems (Source: Own study based on [10, p. 6])

6 Analysis and Results

As shown in the previous table, the traffic volume of the vehicles coming from the western side (Jadriya Bridge) has recorded the highest traffic flow during the survey hours in a volume exceeding the capacity of the road. Which affected the operational function of the road, as well as the traffic volume of vehicles coming from the east (Hurriya Square from Karrada), has also exceeded the capacity of the road as shown in the table as the main road with a capacity of (800 vehicles per hour). As for the northern and southern side, coming from Abu Nawas Street, as well as coming from the gate of the University of Baghdad, has recorded the lowest traffic flow compared to the previous two and during the hours of the field survey. And classified as an accumulated road with a capacity of 600 vehicles per hour, specifically during the survey process. To calculate the road service level = Traffic volume (vehicle/hour)/Capacity (vehicle/hour).and Because the traffic volume exceeded the capacity of the road, the service level was low, making unstable flow, low speeds, and possible traffic congestion.

7 Strategies

Due to the previous analysis. and in order to reduce traffic flow because of the field survey. and to ensure upgrading the low service level of the intersection, it is essential to develop sustainable transport strategies to reduce the pressure on the capacity of the road. These strategies are presented below.

7.1 The First Strategy

Providing middle pavements of the road, to provide enough space to extend the TOD transmission line, from the western side coming from the Bayaa area (Jadriya bridge), through the intersection of Baghdad University. And to the east towards Karrada kharij, in the middle part of the street, in accordance with the concept of sustainable transport, and application of public transport policy in this particular region Sown in Fig. 4. In Turkey, the BRT system was used in the east of Istanbul, where the distance was 11 km. The number of BTR operators was 560 personnel per hour and one-way traffic, which had a significant effect on traffic jam flow. It was efficient in reducing congestion, where the efficiency of transport and traffic compared to other networks In order to implement this strategy in the study area, a length of 8 km, starting from Al Bayaa Garage to Hurriya Square, should be constructed. This line consists of one side, that includes two ways. The proposed transmission line will transport 480 people per hour. Using data of the Table 5 and Fig. 4 the formals are as below. Note: The numbers: 2, 12, 30 represent the average number of people in each type of vehicles. Destination Passing from Karrada Dakhel (Fig. 5):

$$10841 \cdot 2 + 2791 \cdot 12 + 1303 \cdot 30 = 94264 \text{ Persons number in all vehicle's type} \tag{1}$$

$$94264/14 = 6733 \text{ Persons per hour} \tag{2}$$

$$480 \cdot 100/6733 = 7.1\% \text{ Congestion reduced} \tag{3}$$

Destination Passing from Jadriya bridge:

$$12191 \cdot 2 + 3139 \cdot 12 + 1465 \cdot 30 = 106000 \text{ Persons number in all vehicle's type} \tag{4}$$

$$106000/14 = 7571 \text{ Persons per hour} \tag{5}$$

$$480 \cdot 100/7571 = 6.33 \text{ Congestion reduced} \tag{6}$$

Hence, this strategy reduces traffic congestion by 14% overall.

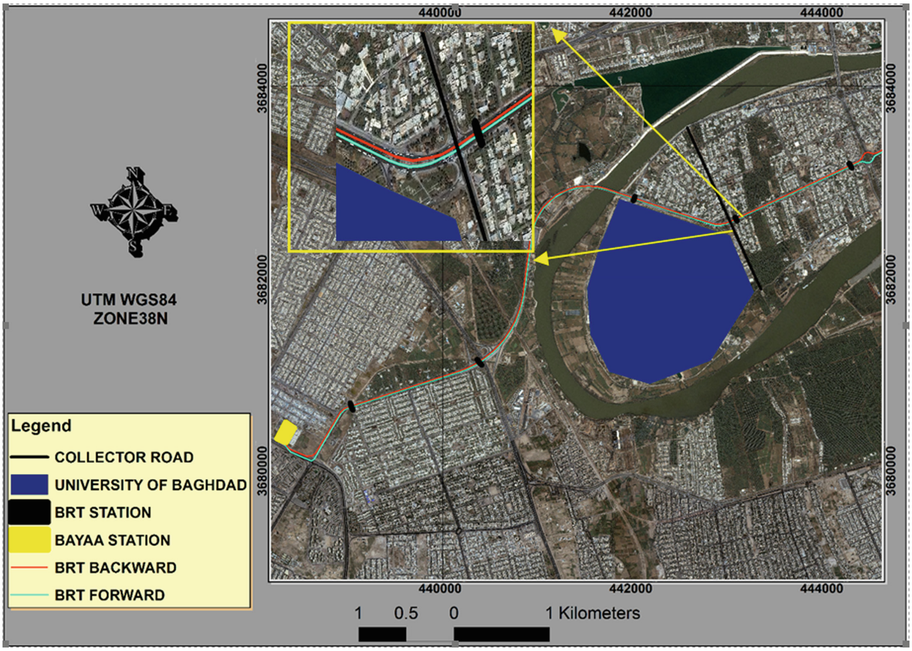


Fig. 5. The first strategy

7.2 The Second Strategy

Is to open a secondary floating bridge that parallels the Jadriya bridge that works on prepayment. It is possible to pass from this road in the morning by filling a prepaid card, which can be crossed for free in the evening. Shown in Fig. 6.

The floating bridge is one of the bridges of the Emirate of Dubai in the United Arab Emirates. It connects Riyadh Road, Dubai Courts and Al Khor Park to Bur Dubai, Baniyas Street, Deira City Center and Dubai Creek Golf and Yacht Club.

The floating bridge is the fifth crossing on the Dubai Creek, with a capacity of about 1600 vehicles per hour. The side of the road has 3 traffic lanes as well as the return side. The bridge is 410 m long and was opened in 2007. The bridge was opened on the bridge with 31% increase compared to the previous one.

Applying this strategy, and by constructing a floating bridge next to the bridge of Jadiriya from the north and with two traffic lanes on each side. The capacity of the one line of bridge would be 800 vehicles per hour and this would reduce traffic congestion on the road bridge Jadiriya. That consists of 320 private vehicles per hour during peak hours. And Using data of the Table 5. the females are as follows:

$$320/2 = 160\,\text{private vehicles in one line} \tag{7}$$

The ratio of private vehicles of other two types is:

$$10800 \cdot 100/(10800 + 2790 + 1300) = 72\% \tag{8}$$

$$10841/14 = 773 \text{ private vehicles per hour} \tag{9}$$

$$160100/774 = 20\% \text{ private vehicles} \tag{10}$$

$$20 \cdot 100/72 = 28\% \text{ congestion reduction} \tag{11}$$

Destination Passing from Jadriya bridge:

$$320/2 = 160 \text{ private vehicles in one line} \tag{12}$$

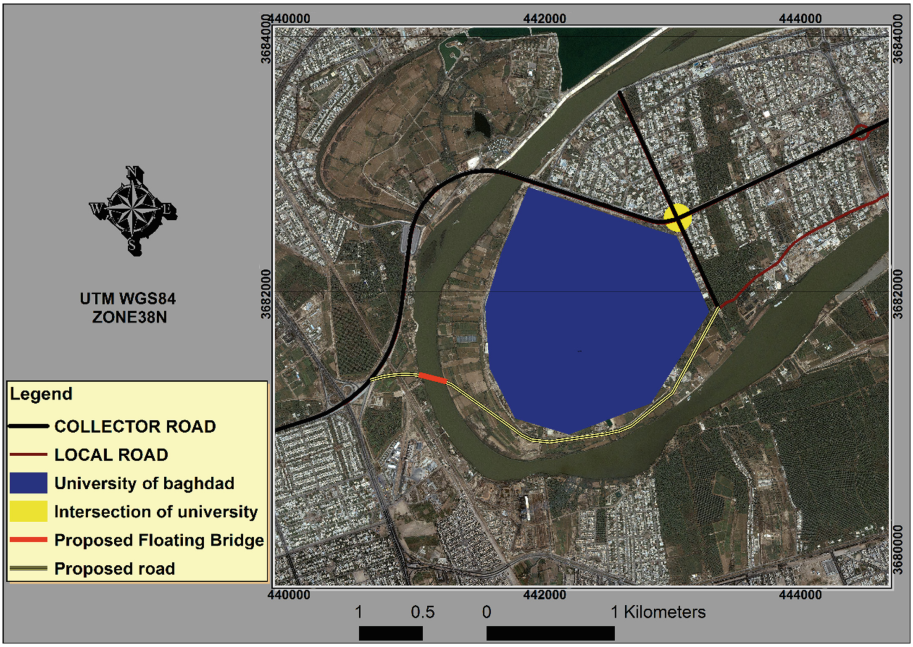


Fig. 6. The second strategy

The ratio of private vehicles of other two types is:

$$12191 \cdot 100/(12191 + 3139 + 1465) = 72\% \tag{13}$$

$$12191/14 = 870 \text{ private vehicle per hour} \tag{14}$$

$$160 \cdot 100/870 = 18\% \, \text{private vehicle} \tag{15}$$

$$18 \cdot 100/72 = 25\% \, \text{congestion reduction} \tag{16}$$

8 Conclusion

The research concluded that by suggesting a group of solutions, representing by first: Providing enough space to extend the BRT transmission line from western side (Jadriya bridge) towards the eastern side (karrada). Also, it's founds that by applying this solution, it will reduce the traffic congestion, by 7% at the western side, and 7% at the eastern side. Second: Which is open a secondary floating bridge that parallels Aljadriya bridge (private cars only). Which works on prepayment, and by applying this solution, we can only reduce the traffic congestion by 28% in road line destination dassing from Karrada Dakhel. and 25% in the road line Passing from Jadriya bridge. The total traffic congestion reduction is (28% + 6.3% = 34.3%) in the road passing from (Jadriya bridge) and (25% + 7% = 32%) in the road passing from (Karrada Dakel). by taking into consideration that the road Passing from the rear gate of Baghdad University and the road Passing from Abu Nawas Street are in a good level of service.

References

1. Kay, F., Mark, D.W., Joseph, D.B.: Urban intersection design guide. Volume 1-Guidelines. Texas Department of Transportation and the Federal Highway Administration, Texas (2005)
2. Garber, N.J., Hoel, L.A.: Traffic & Highway Engineering, 4th edn. West Publishing Company, St. Paul (2009)
3. Ministry of Municipal and Rural Affairs: Road Engineering Design Manual. Ministry of Municipal and Rural Affairs, Baghdad (2016)
4. O'Flaherty, C.A.: Transport Planning and Traffic Engineering. J.W. Arrow Smith Ltd., Bristol (1997)
5. National Research Council: Highway Capacity Manual 2000. Transportation Research Board, Washington (2000)
6. Kutz, M.: Environmentally Conscious Transportation. Wiley, Hoboken (2008)
7. Sarkis, S.M.: Using the Intelligent Systems in Transport Planning for Baghdad City. Master thesis. University of Baghdad, Urban and Regional Planning Center, Baghdad (2016)
8. Gamadi, A.S.: Traffic Jams, Technical Solutions. College of Engineering King Saud University, Riyadh (2003)
9. Khattab, A.: Monitoring the traffic on Al-Jadriah intersection. Professional Higher Diploma Project. University of Baghdad, Urban and Regional Planning Center, Baghdad (2014)
10. Litman, T.: Transportation Cost and Benefit Analysis II - Congestion Costs. Victoria Transport Policy Institute, Victoria (2009)

Improving Capacity and Traffic Operation for Al-Furqan Intersection at Al-Fallujah City (Iraq)

Khalid Hardan Mhana Alwani(✉)

College of Engineering, Al-Anbar University, Al-Anbar, Iraq
khalid.hardan@uoanbar.edu.iq

Abstract. Traffic congestion is one of the main problems in Al-Fallujah city especially in central business district (CBD) area. The main aim of this study is to evaluate the level of service for Al-Furqan intersection and suggested alternative proposals to overcome the delay problem and to present the best proposal to improve the level of service. To achieve this aim, two types of data were collected first, traffic volumes data were collected used video camera, second, geometric data were collected manually. HCS 2010 program is used for the requirements of level of service analysis process. The operational analysis of the existing conditions shows that the intersection work under level of service (F) with an average delay of (105.2) s/veh. Based on the analysis of the suggested proposals it has been indicated that the third proposal (prevent the traffic volume from the west direction) provide the best traffic operation where the level of service is improved to (C) with an average delay of (34.5) s/veh.

Keywords: Traffic delay · Level of service (LOS) · Intersection traffic operation · Peak hour factor (PHF)

1 Introduction

Traffic congestion is considered as one of the main problems especially in large cities in the world. Traffic congestion has a negative impact on the quality of life, global atmospheric conditions and energy resources due to increase the traffic accidents, gas emission and fuel consumption [1].

The intersection is considered as one of the most important and complex location in the road network due to its ability to manage and control the traffic of different types of vehicles and pedestrians especially in peak hours. The main function of the intersection is to provide the change of route directions whose be intersection shared by two or more roads. Intersections vary in complexity from a simple intersection, which has only two roads crossing each other, to a more complex intersection, at which three or more roads cross within the same area [2].

Delay is one of major problems that happened at any part of traffic network especially at intersections. The concept level of service (LOS) is used to evaluate the delay at any intersection. Highway Capacity Manual (HCM) defined the LOS for signalized intersection based on the delay time (the average stopped delay time per

E. Macioszek et al. (Eds.): TSTP 2019, LNITI, pp. 27–38, 2020.
https://doi.org/10.1007/978-3-030-39109-6_3

vehicle for 15-min analysis period), the LOS is varied from LOS A (free-flow conditions) to LOS F (long delays) as shown in Table 1 [3].

Table 1. LOS for signalized intersection based on average delay [3].

LOS	Signalized intersection
A	d $\leq$ 10
B	10 < d $\leq$ 20
C	20 < d $\leq$ 35
D	35 < d $\leq$ 55
E	55 < d $\leq$ 80
F	80 < d

Al-Fallujah city is considered one of the capital cities in Al-Anbar government in Iraq. As part of Al-Fallujah city Al-Furqan intersection is a significant location and have high traffic volumes due to:

- Al-Furqan intersection connected between min directions,
- the existing commercial, educational and residential activities near Al-Furqan intersection (Fig. 1).

Fig. 1. Satellite image for Al-Furqan intersection in Al-Fallujah city (Iraq) (Source: [4])

Therefore, due to these activities Al-Furqan intersection have faced a congestion problem especially at peak hours, this problem leads to increase the delay in this intersection. Al-Furqan intersection is a congested intersection located at the north area in Al-Fallujah city. Al-Furqan intersection is consisted from four major directions:

- north - south direction (Al-Thrthar street to Al-Kamaleat intersection),
- south - north direction (Al-Kamaleat intersection to Al-Thrthar street),
- east - west direction (Al-Hatherha intersection to Al-Julian intersection),
- west - east direction (Al-Julian intersection to Al-Julian intersection).

2 Aims, Objectives and Review of Literature

The main aims of this study are:

- determine the peak hour volume at Al-Furqan intersection,
- calculate the peak hour factor (PHF) for all approaches at Al-Furqan intersection,
- determine the existing LOS for all approaches at Al-Furqan intersection,
- assess all suggested proposals to decrease the delay for Al-Furqan intersection.

To date, several studies have evaluated the LOS at intersections, for instant Al-Ubaidy et al. (2007), used HCS 2000 program to evaluate the LOS for Al-Thawra signalized intersection in Al-Hilla city - Iraq. This intersection was working at LOS F with average delay of 263.7 s/veh. The researchers suggested that bridge overpass to sperate the thought movement for the North-South direction was consider as the best proposals to improve LOS and decrease the delay at all approaches for Al-Thawra intersection. The results showed that the intersection worked with LOS C with average delay of 22.8 s/veh., due to apply the above proposal [5]. Using same program Karim (2011), evaluate the traffic operation for Al-Quds intersection (T- intersection with 3 legs) in Baghdad, Iraq. He found that the existing LOS for the intersection is F with average delay of 328.7 s/veh. The researcher found that the existing LOS was improved to C with average delay of 34.6 s/veh., due to change the geometric layout of the intersection from 3 legs to 4 legs. The research also found that the future LOS will achieve E with average delay of 80.0 s/veh., after 11 years [6]. In another study Awad et al. (2010), evaluated the traffic operation for Al-Zeoat Intersection in Al-Ramadi city, Iraq, using SIDRA traffic program. The researchers found that the Al-Zeoat intersection was worked under LOS F with average delay of 84.7 s/veh. Due to implementing the best proposals to improve the LOS for this intersection. It has been determined that, fly over at the main path of traffic movement at Al-Zeoat intersection (Al-Mohafadha St. - Al-Mahkama St.), it has been found that the Al-Zeoat intersection will be was worked under LOS C with average delay of 34.1 s/veh. [7].

3 Data Collection

A digital camera was used to count the existing traffic volume for all approaches at Al-Furqan from (7:00 am to 7:00 pm) during the workdays of the week from (15 to 20 December 2018). The type of vehicles that are counted are classified into two types:

- passenger cars: All vehicles with four tires only,
- heavy vehicles: All vehicles with more than four tires.

The heavy vehicles were converted to passenger cars by using a passenger car convert factors which is equal to (2.0) (HCM 2010). According the site survey the peak hour was found to be exists at 5:00 to 6:00 pm with 4317 (pcu/h) vehicles for all approaches. The HCS 2010 program is used to calculate the existing saturation flow. Figure 2 shows the existing geometric layout for each approach in Al-Furqan intersection. Table 2 shows the existing saturation flow at the stop line for all approaches in Al-Furqan intersection.

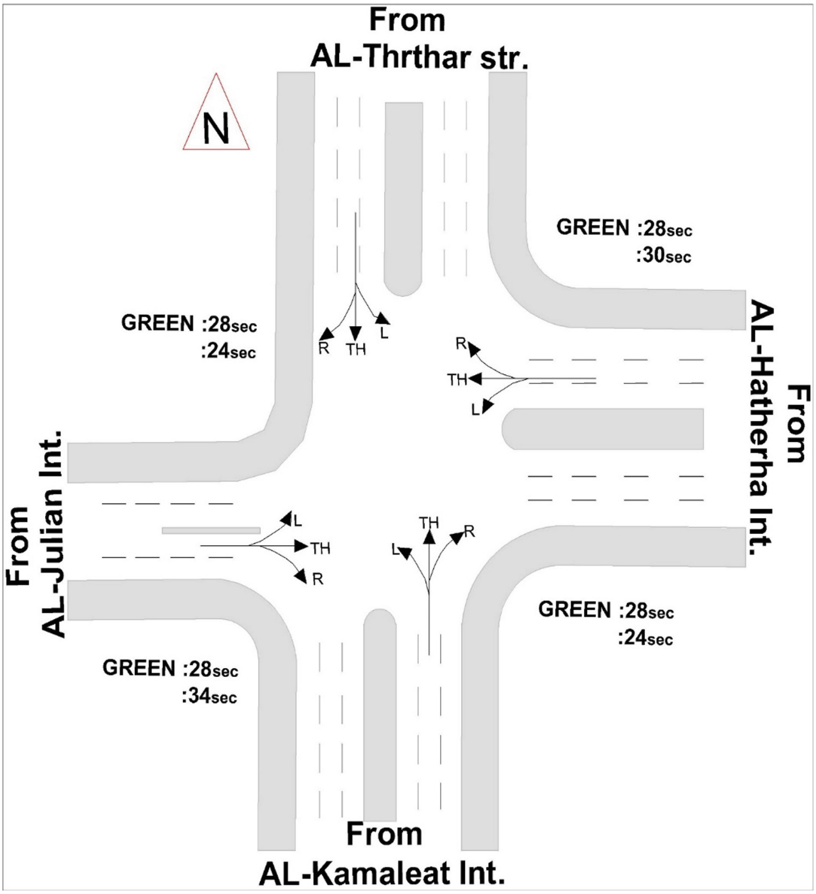


Fig. 2. Existing geometric layout for Al-Furqan intersection

Table 2. Existing saturation flow for Al-Furqan intersection.

Approach	Existing saturation flow	PHF [%]	No. of lanes	Approach directions
From Al-Hatherha intersection	5027	88	3	East
From AL-Julian intersection	3506	93	2	West
From AL-Thrthar street	5059	93	3	North
From Al-Kamaleat intersection	5030	91	3	South

To evaluate the existing LOS for whole intersection it required to know the number of lanes and the direction of movements in each approach at the intersection.

4 Analysis and Results

It was found that the peak hour is limited between 5:00–6:00 pm. The total volume during this hour is (4317) pcu/h (see Fig. 3). The maximum traffic volume (1121 pcu/h) during the peak hour was coming from Al-Hatherha intersection. On the other hand, the lowest volume (1029 pcu/h) which was coming from Al-Julian intersection.

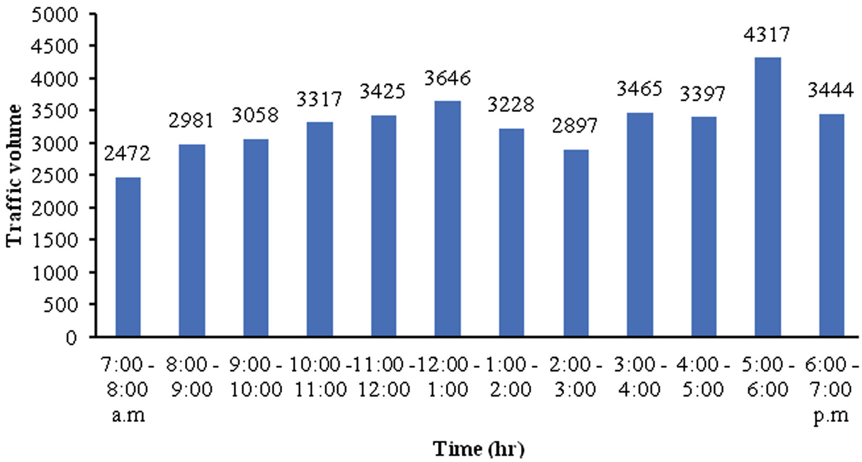


Fig. 3. Variation of traffic volume at 1 h for all approaches at Al-Furqan intersection

The peak hour factor refers to the variation of traffic volume during the peak hour. The peak hour factor can be defined as is the ratio of total hourly volume to the maximum (15 min) rate of flow within the hour. The peak hour factor can be calculated using Eq. (1) (Table 3):

Table 3. PHF values for all approach at Al-Furqan intersection.

Approach	Movement	PHF [%]
From Al-Hatherha intersection	R	78
	TH	95
	L	92
From AL-Julian intersection	R	88
	TH	98
	L	92
From AL-Thrthar street	R	91
	TH	96
	L	92
From Al-Kamaleat intersection	R	84
	TH	96
	L	92

Table 4. Existing phasing time and order for Al-Furqan intersection.

Approach	Movement	Volume	No. of lanes	Phase No.	Cycle length	
					Y	G
From Al-Hatherha intersection	R	94	3	1	2	28
	TH	690				
	L	337				
From Al-Julian intersection	R	81	2	2	2	28
	TH	611				
	L	360				
From Al-Thrthar street	R	95	3	3	2	28
	TH	660				
	L	340				
From Al-Kamaleat intersection	R	88	3	4	2	28
	TH	611				
	L	340				

$$PHF = [(Hourly\ volume)/(4 \cdot Peark\ volume\ in\ 15\,\text{min.})] \tag{1}$$

Table 4 shows the existing traffic volumes, geometrical features and phasing time at each approach that used as input data in HCS 2010 program to determine the existing LOS for Al-Furqan intersection. Table 5 shows the existing LOS for each approach for Al-Furqan intersection. The results indicated that the intersection work under F LOS with average delay of 105.2 s/veh. Therefore, an improvement is required to reduce the intersection delay and improve LOS.

Table 5. Existing level of service for Al-Furqan intersection.

Approach	Average delay [s/veh]	LOS	Approach direction
From Al-Hatherha intersection	84.6	F	East (3 lanes)
From Al-Julian intersection	201.3	F	West (2 lanes)
From Al-Thrthar street	62.2	F	North (3 lanes)
From Al-Kamaleat intersection	61.4	F	South (3 lanes)
Average intersection delay	102.3	F	

5 Suggested Proposals

In order to improve the LOS and decrease the delay for Al-Furqan intersection a number of proposals will be clarified in the following sections. Proposal No. 1 suggested to change the phasing time for all approaches. Table 6 shows the suggested phasing time for each approach by adopting the proposal No. 1. The implementation of this proposal shows that the expected average delay for whole Al-Furqan intersection will be (95.6 s/veh.) which means that the intersection will be operated under F LOS (see Table 7).

Table 6. Properties of traffic operation for Al-Furqan intersection by adopting proposal No. 1.

Approach	Movement	Volume	No. of lanes	Phase No.	Cycle length	
					Y	G
From Al-Hatherha intersection	R	94	3	1	2	30
	TH	690				
	L	337				
From Al-Julian intersection	R	81	2	2	2	34
	TH	611				
	L	360				
From Al-Thrthar street	R	95	3	3	2	24
	TH	660				
	L	340				
From Al-Kamaleat intersection	R	88	3	4	2	24
	TH	611				
	L	340				

In order to improve the LOS for whole intersection, proposal No. 2 suggested to add additional lane in all direction except west direction using the modified cycle time for each approach (see Fig. 4). Table 8 shows the traffic volume, number of lanes and cycle time for each approach by adopting the proposal No. 2. Table 9 shows the results of proposal No. 2, it was found that the implementation of this proposal improves the LOS for whole intersections and become E with average delay of (60.0 s/veh.).

Table 7. Expected LOS for Al-Furqan intersection by adopting proposal No. 1.

Approach	Average delay [s/veh]	LOS	Approach direction
From Al-Hatherha intersection	64.6	E	East (3 lanes)
From Al-Julian intersection	100.3	F	West (2 lanes)
From Al-Thrthar street	111.4	F	North (3 lanes)
From Al-Kamaleat intersection	109.4	F	South (3 lanes)
Average intersection delay	95.6	F	

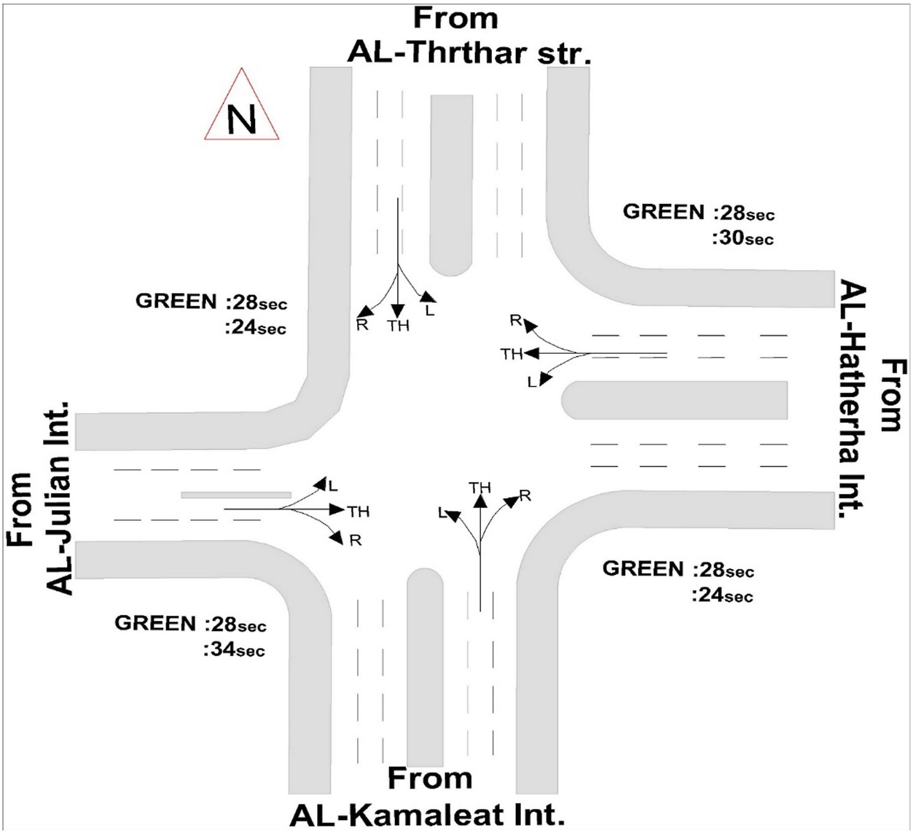


Fig. 4. Proposal No. 2 for Al-Furqan intersection

Table 8. Properties of traffic operation for Al-Furqan intersection by adopting proposal No. 2.

Approach	Movement	Volume	No. of lanes	Phase No.	Cycle length	
					Y	G
From Al-Hatherha intersection	R	94	3	1	2	30
	TH	690				
	L	337				
From Al-Julian intersection	R	81	2	2	2	34
	TH	611				
	L	360				
From Al-Thrthar street	R	95	3	3	2	24
	TH	660				
	L	340				
From Al-Kamaleat intersection	R	88	3	4	2	24
	TH	611				
	L	340				

Table 9. Expected LOS for Al-Furqan intersection by adopting proposal No. 2.

Approach	Average delay [s/veh.]	LOS	Approach direction
From Al-Hatherha intersection	47.1	D	East (3 lanes)
From Al-Julian intersection	41.7	D	West (2 lanes)
From Al-Thrthar street	76.6	E	North (3 lanes)
From Al-Kamaleat intersection	75.4	E	South (3 lanes)
Average intersection delay	60.0	E	

Proposal No. 3 suggested to prevent the traffic volume that coming from the west direction (Al-Julian intersection) to enter Al-Furqan intersection as shown in Fig. 5. Table 10 shows the traffic volume, number of lanes and cycle time for each approach by adopting the proposal No. 3. Table 11 shows the results of proposal No. 3, it was found that the implementation of this proposal improves the LOS for whole intersections and become C with average delay of (34.5 s/veh.).

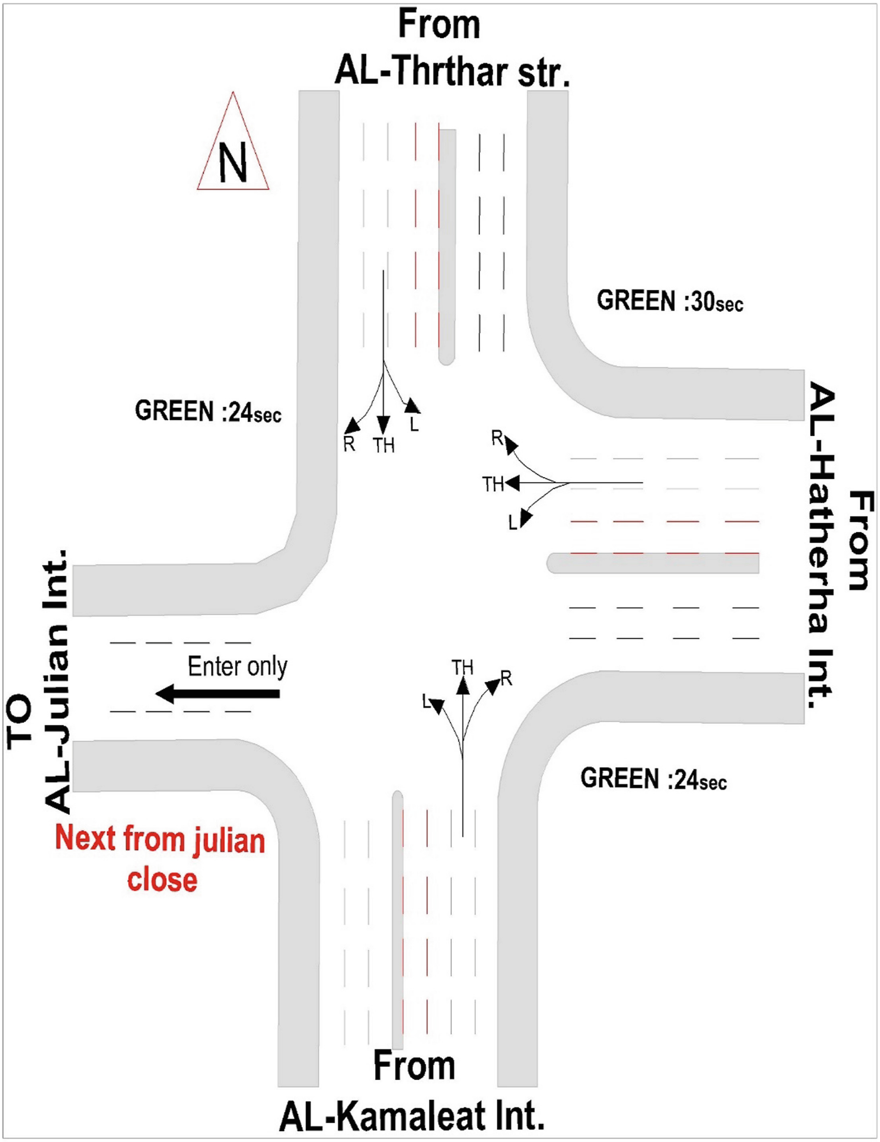


Fig. 5. Proposal No. 3 for Al-Furqan intersection

Table 10. Properties of traffic operation for Al-Furqan intersection by adopting proposal No. 3.

Approach	Movement	Volume	No. of lanes	Phase No.	Cycle length	
					Y	G
From Al-Hatherha intersection	R	94	4	1	2	30
	TH	690				
	L	337				
From Al-Julian intersection	R	81	–	–	–	–
	TH	611				
	L	360				
From Al-Thrthar street	R	95	4	2	2	24
	TH	660				
	L	340				
From Al-Kamaleat intersection	R	88	4	3	2	24
	TH	611				
	L	340				

Table 11. Expected LOS for Al-Furqan intersection by adopting proposal No. 3.

Approach	Average delay (s/veh)	LOS	Approach direction
From Al-Hatherha intersection	35.4	D	East (4 lanes)
From Al-Julian intersection	–	–	West (0 lanes)
From Al-Thrthar street	34.4	C	North (4 lanes)
From Al-Kamaleat intersection	34.4	C	South (4 lanes)
Average intersection delay	34.5	C	

6 Conclusion

The main aim of this study is to evaluate the LOS for Al-Furqan intersection in Al-Fallujah city in Iraq. This study has shown that the operational analysis for the existing conditions of this intersection using HCS 2010 indicated that the intersection work under F- LOS with average delay of 105.2 s/veh. Therefore, an improvement is required to reduce the intersection delay. Three proposals are suggested to improve the LOS for Al-Furqan intersection. It has been concluded that, prevent the traffic volume that coming from the west direction (Al-Julian intersection) to enter Al-Furqan intersection is the best proposal to reduce the delay. It is found that the implementation of this proposal improves the LOS for whole intersections and become C with average delay of 34.5 s/veh.

References

1. Department of Transportation: Federal Highway Administration: Improving Traffic Signal Operations. Federal Highway Administration, Washington (1995)
2. American Association of State Highway and Transportation Officials. http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP25-25(92)_FR-wAppendices.pdf
3. Transportation Research Board: Highway Capacity Manual 2010. Transportation Research Board, Washington (2010)
4. Open Street Map Website. www.openstreetmap.org
5. Al-Ubaidy, A.M., Al-Azzawi, Z.T., Dawood, N.: Evaluation the performance of Al-Thawra at-grade intersection using the HCS2000 computer package. Eng. Tech. J. **28**(15), 5088–5101 (2010)
6. Karim, Q.S.: Evaluation and improving of Al-Quds intersection in Baghdad city. Eng. Dev. J. **15**(2), 19–48 (2011)
7. Awad, H.A., Mohammaed, H.A., Mahmood, W.M.: Evaluation and improvement of traffic operation for Al-Zeoat intersection in Al-Ramadi city. Anbar J. Eng. Sci. **3**(2), 46–57 (2010)

Improving the Capacity of Signalized Intersection Using Smart Traffic Control Systems Supported by Innovative Beam Sensors

Barbara Galińska[1](✉), Jolanta Labuch[2], and Dominik Malinowski[2]

[1] Institute of Social Sciences and Technology Management, Lodz University of Technology, Lodz, Poland
barbara.galinska@p.lodz.pl

[2] SKN Experience, Institute of Social Sciences and Technology Management, Lodz, Poland
jolanta.labuch@gmail.com, dominik.malinowski@ssmizpolska.pl

Abstract. The number of vehicles in the streets has been going up every year, which is the main reason leading to traffic congestions. A way to deal with the problem might be the development of an effective system, that would manage the flow of transport vehicles stream through nodes with traffic lights in congested urban networks. The proposed solution - application of innovative beam sensors - is based on the use of specific light phases periods in traffic light cycles, in a more effective way (effectively reduce the period in which no vehicle is present at the nodes). Its essence is to improve nodes capacity in congested metropolitan areas but also on major roads outside the metropolitan area with high traffic. Any traffic control system supported with the beam sensors would be able to clearly identify if a vehicle has left the node. This way of displaying the green signal for the next phase in a light cycle would be accelerated, while maintaining a very high level of safety. The green period for the phase in which the vehicle was present and the red period for any other traffic lights would be reduced. Thus, the main objective of beam sensors implementation is to reduce the traffic congestions and generally improve the traffic flow, which are certainly main advantages of such solution. They could also contribute to reduction in a vehicle operating costs (related to stop-and-go driving), lower emissions of harmful substances to the atmosphere and finally, to reduced traffic noise.

Keywords: Traffic congestion · Traffic management · Logistics management · Induction loop · High-traffic node · Traffic control · Vehicles stream · Urban network · Pre-selection scales

E. Macioszek et al. (Eds.): TSTP 2019, LNITI, pp. 39–50, 2020.
https://doi.org/10.1007/978-3-030-39109-6_4

1 Introduction

The 21st century has seen dynamic development of many domains, including passenger and cargo transport. People nowadays want to reach their destinations quickly and comfortably, and often prefer to use their own means of transport rather than public ones. The solution is highly convenient outside large metropolitan areas but becomes a problem in cities/towns with a population over 30,000 people. The number of vehicles in the streets has been going up every year and is among major contributors to traffic congestions [1]. Other important factors include a lack of funds to build collision-free nodes, inability to develop the existing road infrastructure (e.g. extending narrow, one-lane roads) and a lack of efficient and effective traffic control systems in nodes with traffic lights. The drivers are those who struggle with the problem of congested streets, not only during peak hours but also in off-peak hours. Despite long time allowed to go over nodes in off-peak hours, covering the same parts of roads during rush hours may increase by 200% [2, 3].

Promoting public transport has become a way to reduce traffic congestions. Unfortunately, in the majority of cities there are no special bus passes. It means of public transport have to queue to go through nodes. Therefore a need arises to develop an effective system to manage the flow of public transport vehicles stream through nodes with traffic lights for congested urban networks [4–6]. A new system and traffic control model have to be designed. This becomes particularly important in the most critical parts of cities. The system could be implemented only at some nodes to support the existing systems or constitute a completely new solution helping to improve efficiency and capacity [7]. One should also remember the need to effectively reduce the period in which no vehicle is present at the nodes (while maintaining the necessary safety of the transport participants).

This paper aims to present a method to use specific light phases periods in traffic light cycles (called traffic signal cycle) in a more effective way. The essence of the proposed solution is to improve nodes capacity in congested metropolitan areas and/or on major roads outside the metropolitan area with high traffic. The studies used directly to fulfil the purpose of the paper were carried out at nodes in selected cities in Poland.

The paper consists of 6 sections. The first section contains a brief introduction and defines the purpose of the paper. The second one presents the rule of induction loops operation, which support traffic light control. The next section describes a sensor that records the parameters of vehicle flows at nodes (called a beam sensor). The beam sensor can help to optimise the number of vehicles driving through nodes during a particular traffic signal phase. Section 4 highlights essential differences between induction loops and beam sensors. The main advantages of the sensors are described. Section 5 presents the results of studies, including their detailed analysis. The last part of the paper contains a summary describing the contribution of the new type of sensors to improvement and significant increase in the capacity of nodes with traffic lights in congested metropolitan networks. The paper is supplemented by a list of references.

2 Induction Loops as a Standard Solution Supporting Traffic Control Systems

Traffic lights are used at high-traffic nodes. They are intended to systematise and coordinate the flows of mechanical vehicles and pedestrians, by improving traffic efficiency and safety [8]. By displaying signals of different colours, frequencies and duration they give clear signals to the traffic participants. The signals inform how the traffic participants should behave in a particular cycle phase [9]. Contemporary traffic lights use a number of sensors and microprocessors. The items are responsible for fully automated changes in the signals displayed, and altogether form integrated traffic control systems [10, 11].

The most popular traffic control and traffic lights coordinating systems in Poland include SCOOT, UTOPIA-SPOT and SCATS [12–15]. The systems use different kinds of detectors which record various traffic parameters at nodes. The detectors adapt the traffic lights setting parameters to current conditions on the road. They operate in a manner opposite to fixed-time traffic signals when the particular light signal duration is set in advance. It means that even if no vehicle is present in a lane, the particular light phase needs to be displayed. The systems can be modified and adapted to nearly any conditions. They can be used at one or more nodes, creating a system which optimises traffic in a larger area. The systems vary for their data processing method [16, 17].

An induction loop is the most popular device used nowadays in all abovementioned traffic control systems (traffic lights) at nodes [18, 19]. A ferromagnetic effect in the loop can detect a vehicle in a lane due to the fact that the vehicle conducts electric current. A vehicle within the loop's reach causes interference in the loop eddy currents. This way the traffic control system is able to read information about the presence of a vehicle and its basic parameters such as e.g. the speed. Traffic lights with induction loops do not activate the green phase in a cycle for a lane with no vehicle. The solution is good for off-peak hours. Then the system allows a vehicle within the induction loop's reach to enter the nodes nearly immediately (unless the same message has been read for the mutual collision direction). Unfortunately during rush hours the solution is completely inefficient because vehicles are always present on the lanes and every loop reads signals about their presence. This way the system is not able to support traffic lights signalling (the duration of the phase periods in a signal cycle is according to the pre-programmed minimum duration of the particular light signal, for the reference traffic light and lane) [20]. Remembering the functional aspects of induction loops one shall not forget their technical disadvantages. Induction loops can be easily damaged by high temperatures. They are usually installed right below or in the asphalt wearing course. On hot days, as a result of asphalt operation, they are broken (interrupted) and no longer fulfil their functions. In order to avoid frequent damage and further time-consuming repairs, the loops are installed in deeper layers of the road. This, however, entails a risk that not all vehicles will be detected. Moreover, in the case of multi-lane roads, two induction loops in adjacent lanes can fall within the impact field of one vehicle. It means that e.g. a big truck, bus or public transport vehicle near the lane edge can interfere with the signals recorded by the neighbouring loop. In such a case a green light phase can be unnecessarily activated for the adjacent lane [21].

3 Innovative Beam Sensor Supporting Traffic Control Systems Operation

Pre-selection scales have become increasingly popular. They are used for detecting and weighing of vehicles. They help to record the approximate axle load, and specify the number or even the speed of vehicles passing. Pre-selection scales often operate based on resistance strain gauge measurements. A vehicle driving onto a horizontal beam in the driveway increases the installed circuit resistance. This way the system gets information that a vehicle axle crossed the device.

Pre-selection scales can also support traffic lights management and control systems at nodes. Once installed before the node's entrance they could provide information about presence or absence of vehicles. It seems a much better solution to use systems with similar characteristics and functions but much simpler and with a lower total cost. A sensor, which needs to record many parameters for pre-selection scales, can be modified in such a way that the sensor reads only one parameter - a presence or absence of a vehicle at the node. The device would come in a form of a horizontal beam (hence the name: beam sensor) consisting of a number of smaller sensors no longer than 2 cm (the shorter the sensor, the more accurate the system). Resistance-based sensors would provide information to the system about vehicle presence in a lane. It would also help to identify if a vehicle has already left the node (if a sensor is also installed at the node exit). Any traffic control system supported with beam sensors (Fig. 1) would be able to clearly identify if a vehicle (with the particular length, axle spacing and vehicles entering the node before and after the vehicle) has left the node. This way displaying

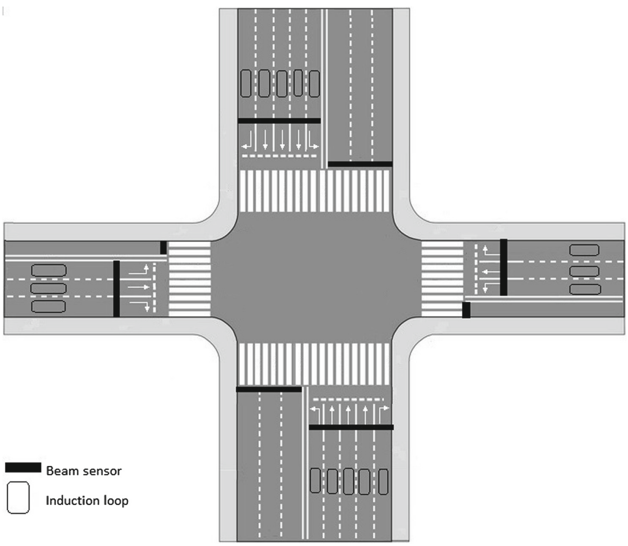


Fig. 1. Diagram of node with the use of an induction loop as a preliminary selection, a beam sensor at the node entry and a beam sensor at the node exit as the appropriate detectors of described solution

the green signal for the next phase in a light cycle would be accelerated while maintaining a very high level of safety. The green period for the phase in which the vehicle was present and the red period for any other traffic lights would be reduced.

The proposed solution addresses the issue of the ever growing vehicle traffic. The solution is innovative and allows the use of the traffic signal cycle time when no vehicle is present at node.

The above mentioned solution involving an innovative beam sensor is patent pending according to a procedure carried out by the Patent Office of the Republic of Poland. The procedure was initiated on request of the authors of the study.

4 Major Differences Between an Induction Loop and a Beam Sensor

A beam sensor as a detector of traffic control systems can be adapted in any kind of nodes. The sensor mounting time and method will be similar to the time and method for the induction loop. The installation cost shall not exceed significantly the induction loop installation cost, either. Other advantages of the solution include its much higher reliability. Geometrical changes in the asphalt surface do not affect the sensor operation (formation of ruts in a lane interrupt the loops and cause the need to make frequent repairs and/or replacements). The sensor has compact dimensions. It can be installed in any place of the node, with any road infrastructure. Induction loops, to the opposite, must not be mounted at the nodes entrance. It is due to presence of e.g. bicycle lanes, traffic separators etc. A beam sensor may come in any length (measured perpendicularly to the roadway axis). This way it can be installed at the entire nodes length, which means that no vehicle can drive through the node without driving onto the sensor (drivers often do not "drive onto" the induction loops in the right way). Contrary to induction loops a beam sensor can be installed in a non-hardened part of a road, for instance in the roadside that drivers use to overtake or pass by other vehicles. There is another advantage to using beam sensors, apart from reducing traffic congestions and improving traffic flow. They could contribute to reduction in vehicle operating costs (related to stop-and-go driving), lower emissions of harmful substances to the atmosphere and reduced traffic noise by reduction of travel time on given sections [22–28].

5 Studying a Flow of Vehicle Stream Through Nodes with Traffic Lights

Traffic measurements were carried out for the needs of the study between 14 December 2018 and 4 February 2019 at selected nodes in Poland. They involved recording the time in which no vehicle was present at the node. The measurements were made during afternoon rush hours, i.e. between 3.30 p.m. and 5.30 p.m. It was non-probability sample study. The main criteria were the accessibility criterion and the degree of differentiation of the advancement of the installed devices supporting the control of traffic lights. The studied nodes were located in the centre of Warsaw - Marszałkowska St. and Świętokrzyska St., and Aleje Jerozolimskie St. and Marszałkowska St., and in

Lodz - Al. Włókniarzy St. and Lutomierska/Wielkopolska St., and Uniwersytecka St. and Jaracza St.. Fixed-time traffic lights were installed at the studied nodes in Warsaw (each phase lasts the same in subsequent cycles). In Lodz the flow of the stream of vehicles was supported by induction loops.

The results of the studies are presented below, in Figs. 2, 3, 4 and 5 and Tables 1, 2, 3 and 4, respectively. The results characterise the light signal phases at the studied nodes. The green period values presented in the tables stand for the green light display time (for the particular phase) when no vehicle was present at the entrance to the node, no vehicle was approaching the node and each vehicle driving through the node has already left it. It means that by shortening the green period for the phase can accelerate and/or extend the green period for another phase. The red periods presented in the tables are the periods between subsequent phases when no vehicle was present at the node.

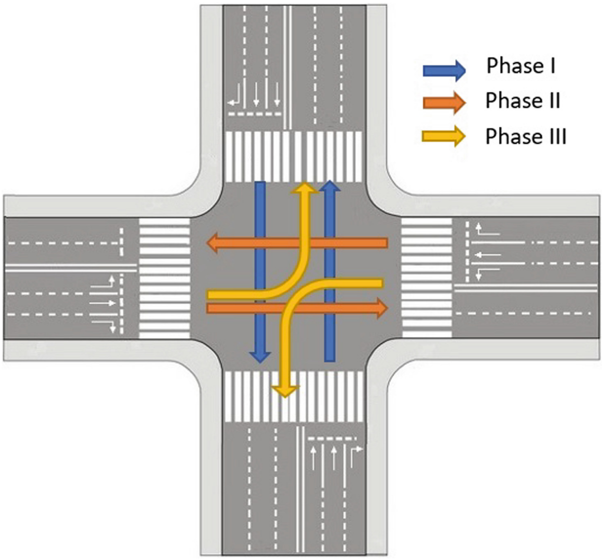


Fig. 2. Marszałkowska St. node with Świętokrzyska St., Warsaw

Table 1. Marszałkowska St. node with Świętokrzyska St., Warsaw-results of measurements.

No.	Phase I		Phase II		Phase III		Cycle duration
	Green	Red	Green	Red	Green	Red	
1.	6.02	7.01	6.03	1.46	0	0	2:01.45
2.	24.02	7.38	0	2.22	0	0	2:02.10
3.	8.43	6.34	0	1.99	0	0	2:00.89
4.	7.77	5.88	3.33	2.73	1.1	0.94	Average:
5.	6.5	4.4	3.95	2.34	1.43	1.36	**2:01.00**
6.	6.2	4.89	1.22	1.94	2.67	1	
7.	8.3	5.2	2.2	3.2	1.7	1.2	Total:
Average	9.61	5.87	2.39	2.27	0.99	0.64	**20.14**

The mean values for each column in Tables 1, 2, 3 and 4 (mean time loss in a reference cycle phase) were calculated and presented in the last lines. The “Total” value is the last line sum, i.e. the time not used in each light signal cycle. The results of the studies do not include (in the total of the reference phase mean times) the time values of less than 2 s (it can be assumed that a driver’s reaction takes 2 s). It means that if it was possible to obtain up to 2 s in each cycle, the validity of replacing fixed-time traffic signals/induction loops with beam sensors should be taken into consideration. The studies clearly suggest that every node has significant time resources which are not used. Even greater reserves can be obtained when the time periods of less than 2 s not taken into account are included.

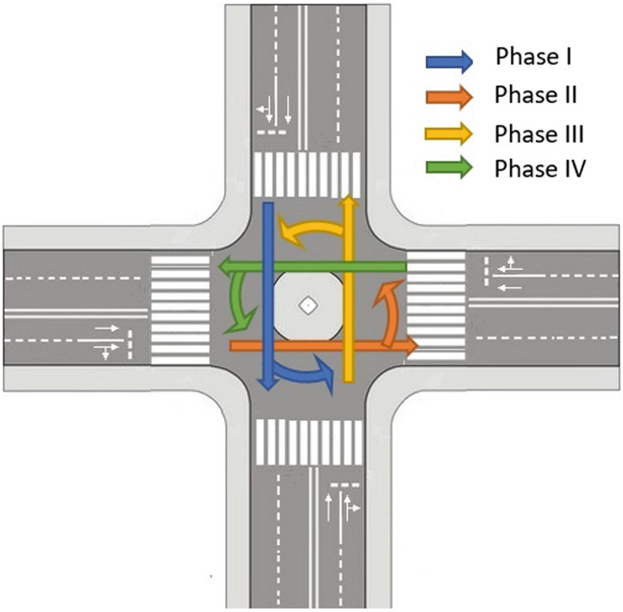


Fig. 3. Al. Jerozolimskie St. node with Marszałkowska St., Warsaw

Table 2. Al. Jerozolimskie St. node with Marszałkowska St., Warsaw - results of measurements.

No.	Phase I		Phase II		Phase III		Phase IV		Cycle duration
	Green	Red	Green	Red	Green	Red	Green	Red	
1.	0	3.05	1.3	2.23	0	5.74	1.2	0	1:51.24
2.	0	0	0	3.53	0	5.25	1.1	14.33	1:50.74
3.	0	1.5	0	3.14	4.02	0	0	9.28	1:51.01
4.	0	0		2.5	14.5	4.5	0	11.65	Average:
5.	1	0	0.8	1.89	2.9	1.22	1.43	10.4	**1:51.00**
6.	0.95	2.1	0	2.6	3.65	3.45	0	6.6	
7.	0	1.9	1.3	4.02	5.8	2.5	1.15	5.67	Total:
Average	0.28	1.22	0.49	2.84	4.41	3.24	0.70	8.28	**18.77**

Nodes in the very heart of Warsaw, the capital of Poland, with high traffic volume, were studied. Fixed-time traffic lights are installed at the nodes. It means that every phase in the light signal cycle lasts the same, regardless of traffic intensity. The displayed light signal duration is not adapted to the current conditions.

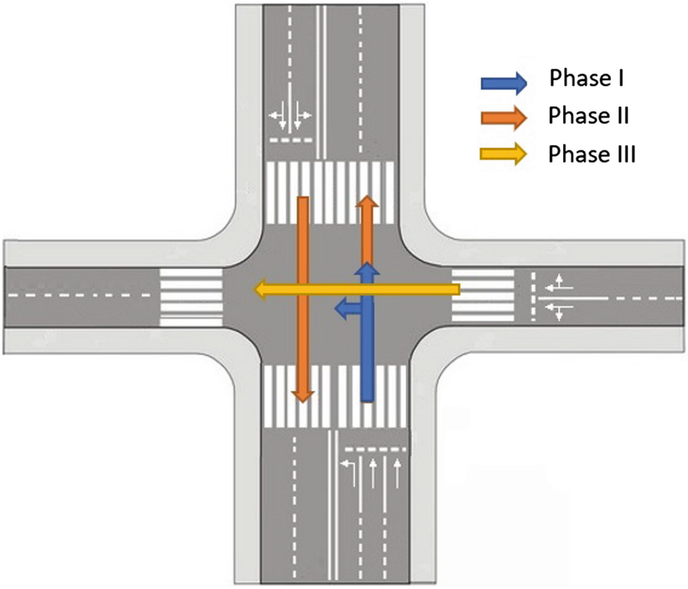


Fig. 4. Uniwersytecka St. node with Jaracza St., Lodz

Table 3. Uniwersytecka St. node with Jaracza St., Lodz-results of measurements.

No.	Phase I		Phase II		Phase III		Cycle duration
	Green	Red	Green	Red	Green	Red	
1.	9.68	0	3.92	3.43	9.31	2.45	1:40.21
2.	4.4	0	5.5	4.11	8.92	3.04	1:41.38
3.	6.54	0	8.11	1.75	7.21	2.2	1:39.25
4.	7.44	0	7.04	2.88	7.11	1.9	Average:
5.	5.5	0.9	4.43	3.1	6.92	3.9	**1:40.00**
6.	4.66	0.5	2.13	3.87	5.94	3.42	
7.	3.3	1	2.2	2.5	4.12	2.6	Total:
Average	5.93	0.34	4.76	3.09	7.08	2.79	**23.65**

According to the data in Table 1 (Marszałkowska St. node with Świętokrzyska St.), the mean traffic light cycle duration is 2:01.00. The mean time with no vehicle at the node accounts for ca. 20% of the whole cycle. A similar situation is true for another node studied in Warsaw (Aleje Jerozolimskie St./Marszałkowska St.). The data in

Table 2 show that the mean cycle duration is 1:51.00. On average there is no vehicle at the node for 16.9% of the time (the light signal cycle duration is 111 s, while the unused time reserves last 18.77, i.e. 16.9% of the whole cycle duration).

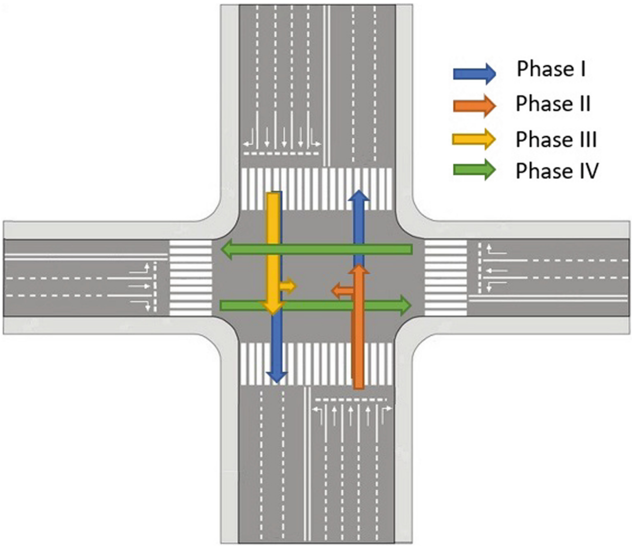


Fig. 5. Al. Włókniarzy St. node with Lutomierska St. and Wielkopolska St., Lodz

Table 4. Al. Włókniarzy St. node with Lutomierska St. and Wielkopolska St., Lodz-results of measurements.

No.	Phase I		Phase II		Phase III		Phase IV		Cycle duration
	Green	Red	Green	Red	Green	Red	Green	Red	
1.	2.7	15.25	4.3	2.41	0	2.69	1.2	1.21	2:20.36
2.	3.9	15.62	3.5	3.54	1.21	3.14	1.1	5.45	2:21.56
3.	0	14.5	3.71	1.26	3.02	2.11	0	3.21	2:21.45
4.	3.4	16.49	1.19	2.36	0	0	0	0	Average:
5.	0	13.05	0.92	1.96	2.65	4.21	1.43	2.12	**2:21.00**
6.	2.8	14.01	3.16	3.21	1.55	3.89	0	2.36	
7.	1.9	17.23	2.32	2.32	1.13	2.14	1.15	4.19	Total:
Average	2.10	15.16	2.73	2.44	1.37	2.60	0.70	2.65	**27.68**

With regard to the above, it seems reasonable to implement a system able to reduce green and red periods in the particular phase and accelerate the green period in subsequent phases by means of horizontal beam sensors. It will help to increase the number of vehicles passing in a column to about 10–20. As compared to the current conditions, it means a significant improvement. It is also possible that once the system is implemented at neighbouring nodes which are connected by a relevant system (e.g. SCATS) the capacity will increase by more than the assumed 10–20 vehicles. At night, at lighter traffic, the system with the proposed beam sensors will adapt the displayed signals to the actual conditions. The adaptation will be aimed to obtain as smooth flow of vehicles as possible, without stop-and-go cycles. Besides shorter times of driving through the nodes, it will be possible to reduce the traffic noise and quantity of exhaust gases released to the environment.

Lodz is the third largest city in Poland (as for the population) and ranked as the fifth most congested city in the world (according to TomTom ranking) [29]. Despite the fact that the city authorities have implemented smart traffic control system in the city, moving around Lodz in peak hours is very difficult. The system is mainly based on induction loop sensors. It does not eliminate traffic phases when no vehicle is present at the node. The same is true for Warsaw, while the per cent share of the phases is definitely much higher. At Aleja Włókniarzy St. node with Lutomierska St./ Wielkopolska St. the period with no traffic at the node accounts for nearly 20% of the whole cycle duration (Table 4), while at Uniwersytecka St. node with Jaracza St. it is nearly 25% (Table 3). If a beam sensor was installed at every node, based on the conducted studies it can be concluded, that each traffic phase could be extended by about 1/4 of the whole cycle duration. The solution could contribute to significant improvement in the capacity and would free the nodes of traffic congestions.

The application of the described system using beam sensors is feasible. It allows the adaptation of current systems and guarantees reasonable green period inter-phase intervals. The solution can be implemented at nodes in congested city centres (like Warsaw), in roads off the very centre (similar to the studied nodes in Lodz) and at junctions of national and regional roads with local roads.

6 Final Conclusions

High traffic intensity and poorly adapted traffic lights are the main causes of traffic congestions worldwide. Advanced traffic control systems based on various kinds of motion detectors - mainly induction loops - have been installed in the largest Polish cities. Despite their application, the majority of systems in the very centres of cities are inefficient during rush hours. It makes moving from one place to another extremely difficult. The situation can be improved owing to better use of inter-phase periods. According to the completed studies, on average about 20% of the whole traffic signal cycle at the most congested nodes is wasted (because there is no vehicle at the node). The use of the proposed horizontal beam sensor solution will help to significantly reduce traffic congestions at nodes. The system will offer accurate information about the vehicles entering and leaving the nodes (including the information about the exit way). Observation of traffic at the nodes leads to a conclusion that if the traffic was by about 10% lower in rush hours, it would be possible to move around smoothly or without any major difficulty. Once the proposed solution has been implemented, extra 10% reserve would still be left. The traffic flow in off-peak or night hours could be fluent or at least more fluent. The solution could not only improve the capacity but also reduce the traffic noise and the quantity of harmful substances emitted to the atmosphere by combustion engines.

References

1. Falcocchio, J., Levinson, H.: Road Traffic Congestion: A Concise Guide. Springer, Cham (2015)
2. Gazis, D.: Traffic Theory. Springer, New York (2002)
3. Mahmood, Z.: Smart Cities. Development and Governance Frameworks. Springer, Cham (2018)
4. Gartner, N., Improta, G.: Urban Traffic Networks. Dynamic Flow Modelling and Control. Springer, Heidelberg (1995)
5. Gordon, R.: Intelligent Transportation Systems. Functional Design for Effective Traffic Management. Springer, Cham (2016)
6. Sierpiński, G., Celiński, I., Staniek, M.: The model of modal split organisation in wide urban areas using contemporary telematic systems. In: 3rd International Conference on Transportation Information and Safety, pp. 277–283. IEEE, Wuhan (2015)
7. Mayinger, F.: Mobility and Traffic in the 21st Century. Springer, Heidelberg (2001)
8. Brilon, W., Huber, F., Schreckenberg, M., Wallentowitz, H.: Traffic and Mobility. Simulation - Economics - Environment. Springer, Heidelberg (1999)
9. Leśko, M., Guzik, J.: Sterowanie ruchem drogowym, sygnalizacja świetlna i detektory ruchu pojazdów. Wydawnictwo Politechniki Śląskiej, Gliwice (2000)
10. Alam, M., Ferreira, J., Fonseca, J.: Intelligent Transportation Systems. Dependable Vehicular Communications for Improved Road Safety. Springer, Cham (2016)
11. Escalera, S., Baró, X., Pujol, O., Vitrià, J., Radeva, P.: Traffic-Sign Recognition Systems. Springer, London (2011)
12. Barceló, J.: Fundamentals of Traffic Simulation. Springer, New York (2010)
13. Kyandoghere, K., Mathis, W., Stoop, R., Chamberlain, C.J., Li, Z.: Recent Advances in Nonlinear Dynamics and Synchronization. Springer, Cham (2018)
14. McDonald, M.: Intelligent Transport Systems in Europe: Opportunities for Future Research. World Scientific Publishing, Singapore (2006)
15. Negenborn, R., Lukszo, Z., Hellendoorn, H.: Intelligent Infrastructures. Springer, Dordrecht (2010)
16. Cichocki, P., Jabkowski, P., Kaczmarek, M.: Inteligentne systemy sterowania ruchem-perspektywa ekspercka a potoczna. Studium zachowań poznańskich kierowców. Wydawnictwo Naukowe UAM, Poznań (2010)
17. Lejda, K., Siedlecka, S.: Charakterystyka systemów telematycznych wykorzystywanych w transporcie drogowym. Systemy i środki transportu samochodowego. Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów (2014)
18. Dainotti, A., Mahanti, A., Uhlig, S.: Traffic monitoring and analysis. In: 6th International Workshop Proceedings. Springer, Heidelberg (2014)
19. Teodorovi, D., Vukadinovic, K.: Traffic Control and Transport Planning. Springer, Cham (1998)
20. Alba, E., Chicano, F., Luque, G.: Smart cities. In: 1st International Conference Smart-CT Proceedings. Springer, Cham (2016)
21. Gaca, S., Suchorzewski, W., Tracz, M.: Inżynieria ruchu drogowego: Teoria i Praktyka. Wydawnictwa Komunikacji i Łączności, Warszawa (2008)

22. Macioszek, E., Lach, D.: Analysis of the results of general traffic measurements in the west pomeranian voivodeship from 2005 to 2015. Sci. J. Silesian Univ. Technol. Ser. Transp. **97**, 93–104 (2017)
23. Macioszek, E., Lach, D.: Analysis of traffic conditions at the Brzezinska and Nowochrzanowska intersection in Myslowice (Silesian Province, Poland). Sci. J. Silesian University of Technology. Seri. Transp. **98**, 81–88 (2018)
24. Macioszek, E., Lach, D.: Comparative analysis of the results of general traffic measurements for the Silesian Voivodeship and Poland. Sci. J. Silesian University Technol. Ser. Transp. **100**, 105–113 (2018)
25. Gruden, D.: Traffic and Environment. Springer, Heidelberg (2003)
26. Holst, H., Nygren, A., Anderson, A.: Transportation, traffic safety and health - human behavior. In: 4th International Conference, Tokyo, Japan. Springer, Heidelberg (1998)
27. Sierpiński, G., Staniek, M., Celiński, I.: New methods for pro-ecological travel behavior learning. In: 8th International Conference of Education, Research and Innovation (ICERI2015), pp. 6926–6933. IATED, Seville (2015)
28. Staniek, M., Sierpiński, G., Celiński, I.: Shaping environmental friendly behaviour in transport of goods: new tool and education. In: 8th International Conference of Education, Research and Innovation (ICERI2015), pp. 118–123. IATED, Seville (2015)
29. TomTom Ranking of crowded cities in the world. https://www.tomtom.com/en_gb/trafficindex/

System Approach for Transport Nodes and Traffic Flows Modelling

Landslides and the Risk of Damage to Road Infrastructure on the Example of a Transport Node

Izabela Skrzypczak[1(✉)], Wanda Kokoszka[1], Tomasz Pytlowany[2], and Wojciech Radwański[2]

[1] Faculty of Civil and Environmental Engineering and Architecture, Rzeszów University of Technology, Rzeszów, Poland
{izas, wandak}@prz.edu.pl
[2] Polytechnic Institute, Krosno State College, Krosno, Poland
tompyt@pwsz.krosno.pl

Abstract. The work presents landslide threats in the context of the planning and spatial planning process. The available sources of information on landslides used for the needs of spatial plating were reviewed and analyzed. Particular attention was paid to the SOPO project - the Anti-slip Shield System. Based on the conducted analyzes, it was found that one of the most important planning problems in the landslide area is the designation of areas for infrastructural investments, including for the development of transport hubs. One of the most effective methods of counteracting and minimizing sludge damage was the properly conducted planning and spatial planning process and risk assessment, among others for road investments.

Keywords: Landslides · Spatial planning · Risk · Road investments · Transport node

1 Introduction

The problem of landslides is touching. a significant part of voivodships located in the area of the so-called Flysch Carpathians, where about 95% of all landslide phenomena occur in our country. The landslide situation in this area is related both to the geological structure of the ground (sandstone - shale flysch rocks) and the high dynamics of relief [1–3]. The most important factor causing the formation of landslides are torrential and rainfall, for example, after heavy rainfall i.e. in May and June 2010 and May 2019. These landslides are usually non-anthropogenic, however, the responsibilities of local government units and individuals are to eliminate environmental hazards through the use of appropriate techniques and technology, as well as through proper implementation of spatial planning tasks [3–8].

The aim of the work is to present the landslide hazard occurring and the associated problems in the field of plating and spatial management as well as risk estimation for the transport node located in the area threatened by landslides.

E. Macioszek et al. (Eds.): TSTP 2019, LNITI, pp. 53–62, 2020.
https://doi.org/10.1007/978-3-030-39109-6_5

2 Landslide and Law Acts

"Landslide is a form created as a result of gravitational movements, resulting in a rapid displacement of rock masses in accordance with the direction of the gravity force, as a result of which material on slopes is moved from higher to lower" [5]. In addition to the geological structure, the main factors affecting the formation of the landslide include the slope and the occurrence of heavy rainfall with a large spatial range. Saturated with water, weather time located between the soil layer and the solid rock absorbs the consistency of the mire and allows the movement of the heavy layers of earth saturated with water on it.

There are many criteria according to which landslides can be classified. From the point of view of planning and spatial planning issues, one of the most important seems to be the criterion based on their activity, understood as the behavior of rock masses defined in time. Due to the above the landslide feature is divided into [3–25]:

- periodically active landslides (landslides) - landslides, in which the symptoms of activity occurred at irregular intervals over the last 50 years,
- continuously active (chronic) landslides - are landslides that are constantly in motion, until the slope is reached,
- inactive landslides (stabilized) - landslides in which no symptoms of activity have been observed and documented for at least 50 years.

Many landslide phenomena cannot be predicted whether to counteract them, and the main factors causing the movement of earth masses belong to the group of non-ergogenic factors. Preventive measures include: creation of an efficient landslide information system, proper development and use of areas exposed to landslides, actions aimed at reducing the negative impact of rainwater and groundwater, or mechanical improvement of rock properties [26, 27].

The most important legal provisions regarding the landslide problem are:

- act of 27 April 2001. Environmental Protection Law (Journal of Laws of 2001, No. 62, item 627) - giving a definition of mass movements of land, and imposing on the county governor the obligation to register areas threatened by mass movements of land and areas where there are these movements,
- act of February 3, 1995 on the protection of agricultural and forest land (Journal of Laws 2004, No. 121, item 1266) - obliging owners of agricultural and forest land to counteract mass movements of land,
- act of 18 April 2002 on the state of natural disaster "(Journal of Laws of 2002 No. 62 item 558) - landslides the nature of a natural disaster, for the prevention or elimination of which the announcement of a state of natural disaster may become deliberate,
- act of 27 March 2003 on spatial planning and development (Journal of Laws 2003, No. 80, item 717) - imposing on the village mayor, the mayor or the president of the city the obligation to consider landslide areas in the records and graphic content of both studies conditions and directions of spatial management of the commune, which is an obligatory document for the whole area of the commune as well as local spatial plans. In addition, the Act obliges the body that performs the study or plan to

request opinions on the solutions of the study or plan to the appropriate body of geological administration,

- the Act of July 17, 1994 Construction law (Journal of Laws 2006, No. 156, item 1118, as amended) and the Act of 11 August 2001 on special rules for the reconstruction, renovation and demolition of buildings destroyed or damaged as a result of the element (Journal of Laws No. 84, item 906, as amended) - regulate the issues of a construction disaster resulting from the slippage of earth masses.

The basic sources of information on landslides used in the spatial planning process currently include studies resulting from the implementation of the SOPO project - Landslide Counteracting System [28]. It is a cartographic project commenced in 2006, implemented by specialists from the Polish Geological Institute, geological enterprises and scientific units. The implementation of the SOPO project was divided into four stages:

- stage I (2006–2008) - Pilot lapping of landslides along with the existence of areas where they occur in Poland,
- stage II (2008–2015) - Mapping and making maps of landslides and theories endangered by mass movements for the area of the Polish Carpathians (75% of the surface) and monitoring of selected landslides in the Carpathians,
- stage III (2016–2018) and STAGE IV (2018–2022) - Mapping and mapping landslides and areas threatened by mass movements for the Polish Carpathians and monitoring of selected landslides in the Carpathians.

The result of the specialists' work are Landslide Registration Cards (KROs) and Registration Cards of Areas at Risk of Mass Movements (KRTZ) developed in accordance with the pattern adopted in the first stage of the project implementation and constituting the basic landslide registration document collected by staters. In addition, within the SOPO, maps of landslides and terrains threatened by mass movements (MOTZ) are created in the scale 1:10000, compiled within communes - in the case of Carpathian areas, and counties - for non-Carpathian Poland.

An extremely important feature of the project is the universal availability of results of its implementation. All developed maps and completed Registration cards are collected in the prepared SOPO database, available to users at the address osuwiska.pgi.gov.pl.

In addition to studies resulting from the implementation of the SOPO project, knowledge about landslides can be derived from ecophysiographic studies, which require a description of individual natural elements and their interrelationships in the area covered by the plan or study. A special role can be played here by problem studies that are next to information about the resources and condition of the region's environment or climate change, they contain characteristics of anthropogenic and natural hazards, including floods or landslides. From the point of view of spatial planning, it is important that in elaborations are designated areas excluded from building due to environmental threats, including landslides.

A detailed description of geological and ground conditions for selected areas of landslides can also be found in the geological engineering documentation and geotechnical documentation.

3 Landslides and Road Investments

The typical impact of landslide movements can include situations when [3]:

- the infrastructure itself does not enter the slopes on which landslides occur, but is located in the "paddling" zone of the mass movement, i.e. in the area into which the tongue may slip or in which the rafting will stop; even if the road lane is not interrupted, it can be at least backfilled with colluvium material,
- the infrastructure is set on the colluvium and is subjected to sudden or slow destruction when the landslide dislocates; a classic example from the Polish Carpathians is the location of a national road on the slopes of the Just mountain (on the Rożnowskie Lake) or a relatively recent landslide on the municipal road in Falkowa, a district of Nowy Sącz,
- the infrastructure was built on a relatively stable slope, but due to the retrogression of the main slope of the landslide (landslide threshold) it will be in the zone of instability. That is why it is very important to recognize the landslips well, to precisely determine the boundaries of individual forms and to take inventory and distinguish the natural impacts of mass movements (landslides) on infrastructure, from those caused by human activities. Slides in embankment slopes and indentation of communication routes may be the cumulative effect of these two factors. The operation of the colluviums can also lead to the launch of a landslide, an example of which is the road from Muszyna to Leluchów. However, where communication routes are not in the area of potential mass movements, the instability of embankment slopes and indentations is rather the result of errors in geotechnical art (design and execution). Therefore, any road settlement, overwhelming or interrupting it should not be considered as caused by mass movements, i.e. landslides in the so-called wider (colloquial) meaning.

4 Risk Analyses

The development of road infrastructure in landslide areas, like any economic activity, is associated with risk and uncertainty. Risk is a measure of threat and is defined as the product of probability and negative consequences of undesired events. Threat means the possibility of an event causing loss of life, health and/or social, material and ecological losses. Identification of hazards and determination of possible scenarios of disasters or structural failures, as well as assessment of the probability of their occurrence and the consequences they may cause, are among the basic tasks related to risk analysis. The risk associated with various stages of the construction process is diversified and depends on the risks associated with each stage. Due to the reasons, two types of threats can be distinguished: natural and anthropogenic. Natural hazards are related to the accidental nature of impacts on building structures, random properties of materials and geometric dimensions of the elements from which they were made. The anthropogenic threat connected with the human factor is directly related to the construction process, resulting from unintentional or deliberate departures from the rules and rules of the building arts (errors and negligence of people). In construction according to [28, 29] risk is a measure of threat defined as a combination of the probability and consequences of an undesirable event occurring. In the event of a random nature of events, they are treated as random events and the risk is a determinate or random value and can be calculated using the formula (1):

$$R = \sum_{i-1}^{n} P_i \cdot S_i \tag{1}$$

where:

P_i - the probability of damaging structures on the area of landslides influence,
S_i - effects related to damaging structures on the area of landslides influence.

Thus, the objective risk in the design of structures in landslides areas is related to the reliability of the structure. The PN-EN 1991-1-7:2008 [30] standard provides for two methods of risk analysis for buildings and structures: A qualitative analysis involving the identification of hazards and their corresponding impact scenarios and the basic use of the structure in order to demonstrate that their safety implications are acceptable. The quantitative analysis is based on risk assessment using the formula recommended inter alias in the ISO 13824:2009 [31] code (2):

$$R = \sum_{i=1}^{n_H} p(Hi) \sum_{j=1}^{n_p} \sum_{k=1}^{n_s} p\left(D_j/H_i\right) p\left(S_k/D_j\right) C(S_k) \tag{2}$$

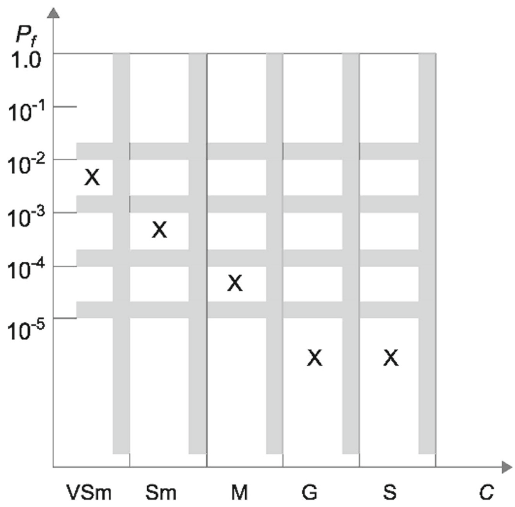
where: it is assumed that the structure is subjected to n_H different threats that can damage it in n_D different ways, where the behavior of the damaged structure can be considered in n_s unfavorable S_k states causing consequences *C(Sk), p(Hi)* is the probability of the occurrence of the *i-th* threat, $p(D_j/H_i)$ is a conditional probability of the *j-th* state of damage causing the *i-th* threat, a $p(S_k/D_j)$ means the conditional probability of the *k-th* negative behavior of the S_k structure causing *j-th* state of damage.

Quantitative risk analysis calculated as the risk value in monetary units according to the formula (1) should be treated as the nominal size, which has no direct reference to financial costs incurred in the event of structural damage. Taking into account the fact that the maximum probability of pfd destruction of a structure, whose cost in the full life cycle of the facility is *C(S),* qualified to the appropriate reliability class *(RCX = {RC3, RC2, RC1}),* for the reference period T_0, was defined in the PN-EN 1990: 2004 [28] the risk index i_R (3) can be accepted as a measure of the risk associated with the analyzed emergency situation in accordance with the publication [29] (3, 4):

$$i_R = \frac{R}{R_{ac}} \tag{3}$$

$$R_{ac} = p_{fd}(RCX; T_0)x(C(S)) \tag{4}$$

The most common quantitative risk analysis includes: estimating the probability of occurrence of possible hazards with a fixed intensity, estimating the probability of occurrence of various damages and their consequences for the threats under consideration, estimation of the probability of unfavorable reactions to local structural damages and related consequences. The most common causes of disasters are factors or circumstances not taken into account in the design phase and the assessment of the technical condition. In such a situation, systematic risk analysis and assessment is recommended as the most appropriate and promising method to ensure a satisfactory level of construction's resistance to exceptional impacts, including hazards related to the impact of mining operations [29]. The basic and controversial issue in the risk assessment is the determination of the risk acceptance criterion. In the literature on the subject, there are numerous proposals for qualitative and mixed criteria, most often not very precise and leading to significantly different results. Most often these are different variants of the ALARP principle, i.e. "as little risk as possible within reason". The PN-EN 1991-1-7: 2008 code [30] presents a mixed criterion (Fig. 1).



Legend: X - means the highest acceptable level of risk
Where: C-Consequence: VSm-Very Small, Sm-Small, M-Moderate, G - Great, S - Serious and P_f- Probability

Fig. 1. Consequences diagram according to PN-EN 1991-1-7:2008 (Source: [30])

5 Example of the Risk Analysis

The subject of the analysis is the transport node qualified for 3 consequence classes made in the landslide area. The exceptional situation of the transport node is caused by the influence of landslides discharged as H_l threat (e.g. threat of landslide effects due to horizontal deformations and sudden depression) that may occur with the probability $p(H_1) = 0.01$ and cause local node damage transport D_1 or complete destruction of node D_2, with conditional probability $p(D_1 \backslash H_1) = 0.01$ and $p(D_2 \backslash H_1) = 0.01$. The probability $p(H_l)$ - concluded taking into account the specificity of the landslide area, a large nuisance of using the node due to the influence of surface deformation, the value of *0.01* was assumed. The effects of local damage to the transport node were defined as the destruction of the node fragment S_1 (up to 15% of the node's surface), or the destruction of larger fragments or the node S_2, and the conditional probabilities of their occurrence are respectively:

$$
\begin{aligned}
p(S_1/D_1) &= 0.1,\\
p(S_2/D_1) &= 0.01,\\
p(S_1/D_2) &= 0.5,\\
p(S_2/D_2) &= 0.05.
\end{aligned}
$$

The consequences of the destruction of the node fragment and the entire node were estimated at:

$$
\begin{aligned}
C(S_1) &= 750.000 \text{ Euro, and}\\
C(S_2) &= 15.000.000 \text{ Euro.}
\end{aligned}
$$

The acceptable risk of destruction of the transport node classified as RC1 reliability class for the reference period $T_0 = 1$ years [28], including the investment costs in the full lifetime of the *C* facility (*S*) = 7.500.000 Euro, is:

$$R_{ac} = p_{fd} \times C(S) = 8.5 \times 10^{-6} \times 7.5 \times 10^{6} = 63.75.$$

The quotient of the risk associated with the destruction of the node as a result of the considered exceptional situation and acceptable risk is: $i_R = R/R_{ac} = 823.25/63.75 = 13.07$ means that the risk of destroying the node exceeds the acceptable level of risk 13 times. Therefore, appropriate measures should be taken to reduce it, for example by applying a more effective procedure related to securing the structure of the node against the effects of landslide by appropriate protection of the structure and its foundation and the associated costs.

6 Discussion

The risk of damage to transport infrastructure in landslide areas is an inseparable element of spatial and financial management. Risk analysis is carried out for the planned project. The most optimal criterion for designing and dimensioning as well as for assessing the condition of facilities on landslides, enabling quantitative and qualitative requirements to be taken into account is the minimum risk criterion. The risk measure is the product of the probability of occurrence of events that may cause the structure to exceed a given state. The estimated risk is characterized not only by the condition of the structure, but also by the various consequences of threats. Recommendations related to quantitative risk analysis and assessment are rather vague and raise many doubts related mainly to the interpretation and quantification of risk factors, i.e. probabilities of occurrence of threats, their local and global effects and consequences.

Risk assessment in the design of road infrastructure is related to the determination of the reliability class of the structure (acceptable probability of destruction), the number of potential victims and financial, social, ecological and other consequences. A particularly difficult issue is the assessment of the effects of the disaster of linear objects.

7 Summary and Conclusions

The landslides hazards are an inseparable element of spatial economy. The landslide aspect is particularly important for the Carpathian region, where, according to estimates, one landslide covers 5 km of a roadway and 10 km of a coil line. The analysis of existing legal sources allows us to conclude that they primarily focus on the obligation to designate threatened areas, but there are too few regulations on how to act in the area of already established landslides. The pressure of spatial development allows us to understand that it is impossible to completely exclude the possibility of development in landslide areas. An example of an investment in a landslide area is, for example, Zakopianka. Economically valuable areas will always be subject to building pressure. It is very important to create such a law (local plan), which will allow you to introduce security and changes in the scope of form, height or construction technology.

The SOPO project is based on the study of landslide phenomena that are already present, that is why there is a lack of permanent monitoring of areas and structures in our country, even those of strategic importance, over regional, not to mention local roads implemented in vulnerable areas and potentially landslide.

References

1. Bober, L.: Landslide areas in Polish Carpathians and their relation to the geology of the region. Bull. Geol. Inst. **340**, 115–158 (1984)
2. Kokoszka, W., Skrzypczak, I., Wilk, K.: Analysis of geotechnical properties of miocene deposits of the Carpathian foredeep. CEER **28**(4), 62–70 (2018)
3. Wójcik, A., Mrozek, T.: Landslides and its elements as threats to the communication infrastructure, i.e. something what we all know. Problems of Landslides at Civil Engineering. Research and Technical Papers of Polish Association for Transportation Engineers. Series Proceedings, vol. 144, issue 88, pp. 421–441 (2008)
4. Cruden, D.M., Varnes, D.J.: Landslides types and processes. In: Turner, A.K., Schuster, R. (eds.) Landslides: Investigations and Mitigation, Transportation Research Board. NRC Special Report 247, pp. 36–75. Transportation Research Board, Washington (1996)
5. Mokritskaya, T.P., Dovganenko, D.A.: Forecast landslide activity in the zones of technogenic geochemical anomalies of urban areas based on remote sensing data. J. Geol. Geogr. Geoecol. **27**(1), 88–94 (2018)
6. Mokritskaya, T.P., Samoylych, K.A.: On some aspects of modeling geodynamic risk in the territory of distribution of subsident soils. Dnipropetrovsk Univ. Bull. Ser. Geol. Geogr. **25** (2), 111–116 (2017)

7. Kablak, N., Reity, O., Stefan, O., Radulescu, A.T.G.M., Radulescu, C.: The remote monitoring of earth's atmosphere based on operative processing GNSS data in the UA-EUPOS/ZAKPOS network of active reference stations. Sustainability **8**(4), 391 (2016)
8. Mokritskaya, T.P., Shestopalov, V.M.: Landslide processes of active Phase of under conditions of technogenesis with the example of Pridneprovsk industrial region of Ukraine. In: Proceedings of 12th International IAEG Congress, vol. 5, 663–665 (2014)
9. Grabowski, D., Marciniec, P., Mrozek, T., Nescieruk, P., Rączkowski, W., Wójcik, A., Zimnal, Z.: Instructions for elaboration of a landslide map and areas threatened by mass movements. PIG, Warszawa (2008)
10. Brabb, E.E.: Innovative approaches to landslide hazard and risk mapping. In: Proceedings of IVth International Conference and Field Workshop Landslides, vol. 1, pp. 17–22. Japan Landslide Society, Japan (1984)
11. Carrara, A., Guzzetti, F., Cardinali, M., Reichenbach, P.: Landslide hazard evaluation: a review of current techniques and their application in a multi-scaled, Central Italy. Geomorphology **31**(1–4), 181–216 (1999)
12. Bazan-Krzywoszańska, A., Mrówczyńska, M., Tront, S.: GIS technology, 3D models and mathematical models as a tool for assessing development capabilities of flood risk land to make arrangements of municipal planning documents. JEE **20**(1), 25–33 (2019)
13. Senneset, K.: Assessment of shallow landslide susceptibility by means of statistical techniques. In: Proceedings of the 7th International Symposium on Landslide, Trondheim, pp. 147–152. Balkema, Rotterdam (1996)
14. Steenbergen, R.D., Vrouvenvelder, A.: Safety philosophy for existing structures and partial factors for traffic loads on bridges. Heron **55**(2), 112–120 (2010)
15. Cruden, D.M., Varnes, D.J.: Landslide Types and processes. Special Report 247. Transportation Research Board, National Academy of Sciences, Washington (1996)
16. Skrzypczak, I., Kogut, J., Kokoszka, W., Zientek, Z.: Monitoring of landslide areas with the use of contemporary methods of measuring and mapping. CEER **1**(24), 69–82 (2017)
17. Mrowczynska, M., Sztubecki, J.: Group method of data handling as a tool to determine vertical displacements. In: IOP Conference Series: Materials Science and Engineering, vol. 471, pp. 1–7 (2019)
18. Gontaszewska-Piekarz, A., Mrówczyńska, M.: The application of Airborne Laser Scaning for identifying old lignite workings - case study: the mine "Borussia" near Ośno Lubuskie (Western Poland). In: E3S Web of Conferences, vol. 36, pp. 1–8 (2018)
19. Macioszek, E., Lach, D.: Analysis of the results of general traffic measurements in the west pomeranian voivodeship from 2005 to 2015. Sci. J. Silesian Univ. Technol. Ser. Transp. **97**, 93–104 (2017)
20. Guettouche, M.S.: Modeling and risk assessment of landslides using fuzzy logic. application on slopes of the Algerian Tell (Algeria). Arab. J. Geosci. **6**, 3163–3172 (2013)
21. Macioszek, E., Lach, D.: Analysis of traffic conditions at the Brzezinska and Nowochrzanowska Intersection in Myslowice (Silesian Province, Poland). Sci. J. Silesian Univ. Technol. Ser. Transp. **98**, 81–88 (2018)
22. Cornforth, D.H.: Landslides in Practice: Investigation, Analysis and Remedial Preventive Options in Soils. Wiley, Hoboken (2005)
23. Macioszek, E., Lach, D.: Comparative analysis of the results of general traffic measurements for the Silesian voivodeship and Poland. Sci. J. Silesian Univ. Technol. Ser. Transp. **100**, 105–113 (2018)
24. Furtak, K., Sala, A.: Stabilization of landslides communication methods of construction. Geoeng. Roads Bridges Tunnels **3**(6), 12–22 (2005)

25. Macioszek, E.: Analysis of significance of differences between psychotechnical parameters for drivers at the entries to one-lane and turbo roundabouts in Poland. In: Sierpiński, G. (ed.) Intelligent Transport Systems and Travel Behaviour. AISC, vol. 505, pp. 149–161. Springer, Switzerland (2017)
26. Bielski, S.: Stability of slopes. http://www.mikropal.pl/statecznosc-zboczy.html
27. SOPO project - Landslide Counteracting System. http://geoportal.pgi.gov.pl/SOPO/aplikacja
28. JCSS Probabilistic Model Code Part 3: Resistance Models. https://www.jcss.byg.dtu.dk/-/…/jcss/…/probabilistic_model_code/
29. Woliński, S.: Risk reliability-based design. In: Proceedings of the XIth International Conference on Metal Structures, pp. 887–895. Taylor & Francis Group, Milton Park (2006)
30. The European Union: EN 1991-1-7: 2006. Eurocode 1: Actions on structures - Part 1-7: General actions - Accidental actions. European Committee for Standardization, Brussels (2006)
31. International Organization for Standardization: ISO 13824:2009 - Bases for design of structures - Part 1-7 General actions. Accidental actions. International Organization for Standardization, Geneva (2009)

Nodes in the Railway Network as Potential Places of Integration of Public Transport

Piotr Soczówka(✉), Renata Żochowska, and Adrian Barchański

Silesian University of Technology, Faculty of Transport, Katowice, Poland
{piotr.soczowka, renata.zochowska, adrian.barchanski}@polsl.pl

Abstract. One of the most important aspects of operation of transport system in urban areas is the integration of public transport. It is a complex task, that requires multiple actions, i.e. the choice of potential places of integration. The article presents therefore the methodology of assessment of possibility of integration of railway transport with other sub-systems of public transport. Different aspects of functioning of public transport stops have been chosen in order to compare them in wide range. Proposed method has been presented for two cities in Metropolis GZM.

Keywords: Spatial integration · Public transport · Railway network

1 Introduction

Integration of public transport is one of the most important aspects of operation of transport systems in modern metropolitan areas and urban agglomerations. Not only does it enhance the attractiveness of public transport but also the perceived quality of a whole transport system in the area. Proper integration of public transport may also lead to better exploitation of available resources and reduction of costs [1–7].

However, integration of public transport is a complex and difficult issue. Each subsystem of public transport plays a different role in it and is required to fulfill different tasks. It is especially visible when taking into consideration subsystems of railway, bus and tram transport. Railway should be the backbone of public transport in metropolitan areas, allowing to travel greater distances in shorter time. Buses and trams should play a supplementary role, i.e. operating in areas with no railway service and enabling passengers to travel from their homes or workplaces to stations or railway stops where they can change the mean of transport and continue they journey i.e. by train.

That approach, however, brings up the issue of selection of nodes in the railway network that should be places of integration of railway transport with different sub-systems of public transport. The article presents the methodology of assessment of public transport stops in terms of possibility of integration with railway transport.

E. Macioszek et al. (Eds.): TSTP 2019, LNITI, pp. 63–81, 2020.
https://doi.org/10.1007/978-3-030-39109-6_6

2 Selected Aspects of Integration of Public Transport

Among the biggest tasks currently faced by public transport, one should mention the assurance of multidimensional integration [1–3], which level shows the system's maturity and the degree of its development as well as determines fulfilling the transport needs of residents ensuring proper accessibility and reliability of service. The set of activities implemented as part of ensuring integration is aimed at increasing the attractiveness of the transport system of the region as a whole, through better, consistent use of all modes of transport based on their complementarity and substitutability. It allows to take advantage of positive features of the particular subsystems and minimize their disadvantages, by appropriately allocating specific transport tasks to particular branches, in accordance with their specificity. This results in a synergy effect that causes the growth of the volume of transport in all subsystems and the increase of the satisfaction of travelers as well as reduction of the inconvenience of their trips. This is achieved through the conscious and thoughtful and, above all, consistent shaping of all elements of the system, i.e. spatial planning of linear and point infrastructure elements, management, organization, technology implementation, land use considerations, and, above all, the tariff system. From the passenger's point of view, it is important that one comprehensive, coherent and multi-branch public transport functions. Such centralized activities will ensure a total improvement of quality that would not be possible if there was real competition between individual systems, i.e. in the absence of integration.

The integration motivation is the benefit that market participants and transport policy entities can get as a result of this process [8]. The main premise of transport integration is considered to be shortening the time of transport (travel) [9]. Other transport postulates are a precondition for integration as it affects:

- increased spatial and temporal accessibility of services,
- convenience and security of travel by limiting operations related to the organization of transport by various means of transport.

In market economy conditions, integration becomes an important tool for increasing competitiveness - both in the subjective (e.g. individual market entities) and systemic (e.g. public transport subsystem) way. Problems related to restrictions of integration in the European Union concern in particular on railway transport infrastructure and passenger transport in cities (especially in agglomerations) [5].

When it comes to public transport, the functioning of such a complex conglomerate of various forms of transport and carriers requires the existence of points enabling their change. Public transport infrastructure includes stations and stops, which are, by definition, places of change in the form of transport, and they play a special role in the places of intersection of several transport routes or public transport lines. Then they form the so-called integration nodes giving the possibility to choose the form and means of transport, depending on the destination of the trip, sometimes requiring several transfers between different types of transport [10]. The most efficient change in the type of transport is based on the minimization of spatial and temporal barriers, i.e.

on the optimization of transfers between modes of transport. Usually three main objectives of multimodal transport stand out:

- minimization of transport costs,
- minimization of transport time,
- improvement of the transport process.

There are many areas of transport integration, which should be approached in a systematic way. The most important aspects of system integration included:

- functional integration,
- spatial integration,
- intermodal integration,
- tariff integration,
- social integration,
- technological integration,
- management integration.

They remain closely related to each other in a variety of ways. The strength of interaction and relation is different. The areas of intermodal and functional integration are the closest to spatial integration. All three aspects are mutually interpenetrated. Therefore, they will be discussed in the next part of the chapter.

Spatial integration includes two areas of activity. On the one hand, one should strive to ensure the minimization of the distance traveled during interchanges, consistency of stops through their readability and ease of navigation, on the other hand it is important to increase the served area and access to public transport for people traveling in diverse relationships and distances. This is achieved through the cooperation of independent branches and types of transport operating at different levels of spatial coverage and accessibility of destinations for individual travelers.

In the first case, spatial integration primarily includes the proper organization and location of interchange points. It is important to shape them in a way that ensures service through as many branches of transport as possible (metropolitan, interurban, metro, bus, tram and intermodal transport like Park and Ride and Bike and Ride). The interchange node should take the form of a consistent, spatially and functionally functional station accessible for various modes of transport, those serving the urban area as well as the farther, extra-urban and regional range. The integration of public transport significantly increases the role of interchange points, which become a natural place to connect individual elements of the transport system. An appropriate interchange infrastructure (train stations with waiting rooms and commercial facilities, information points, etc.) makes it possible to alleviate the inconvenience of interchanges, which favors the integration of the public transport system. Along with the growing role of transfers in traveling by public transport, attention should also be paid to the systems responsible for providing information on possible delays or changing routes. The use of telematics, including ITS solutions, which should support transport through its optimization and high quality standard, constitute a great potential. Increasing the quality and achieving specific savings related to the rationalization of tasks and transport activities - these are the main opportunities in the use of ITS in passenger transport [11]. Moreover, these systems are important tools for shaping urban mobility [12–15].

The organization of transfers is strongly related to the availability of a specific means of public transport. In a well-designed integration node, at least the following factors should be considered [16, 17]:

- ensuring transfer reliability,
- minimizing transfer time,
- number of public transport lines and their frequency at different times of the day,
- ensuring visibility for drivers of vehicles between which the transfer takes place,
- the ability to compensate for delays.

These factors affect, among others, the number and location of public transport stop stations for vehicles serving various lines.

An important task is also to increase the territorial scope of direct links with public transport with the suburban area, i.e. spatial break through the barrier of administrative boundaries of the city and start servicing the relations in accordance with the real needs and functioning of the inhabitants. It also opens up completely new possibilities and demand for travel.

Intermodal integration concerns enabling passengers to make multi-branch trips using different types of transport on their route. In practice, this means, among others, basing public transport on the metropolitan railway and its complementation with other subsystems, enabling the transport of bicycles, building transfer nodes in form of Park and Ride and Bike and Ride systems, and including taxis in the urban transport system. These activities greatly increase the transport accessibility of the entire area, facilitate the implementation of multi-purpose trips in the door-to-door system and adapt the system to the individual needs of individual residents, their habits and opportunities. In turn, through the integration of public and individual transport (e.g. P&R or B&R hubs), the demand for transport and the accessibility of public transport (including urban) increases through indirect support of areas not covered by the public transport network.

Functional integration includes centralizing the organizational activities of the public transport system, such as coordination and defining the course and route of the line, scheduling synchronized timetable, allowing planning of complex journeys using many means of transport without excessive inconvenience and minimizing delays for the passenger. Thus, the accessibility of public transport and the possibility of efficient travel are increased regardless of the relation, direction and range. In addition, the centralized timetable of many transport branches connected by a common transport organizer offers the possibility of using one, universal information platform of a travel planner with information on all transport systems in the city. This allows for earlier efficient planning of complex trips fitted to the individual needs of public transport users.

3 Methodology for Assessing the Possibilities of Integration of Public Transport

The study area is a specific territorial unit with boundaries defined in an administrative manner (e.g. city, municipality, district, voivodship), or individually depending on the needs of research (e.g. area of impact of particular railway line). The proposed methodology for assessing the possibilities of integrating public transport is aimed at determining public transport stops (e.g. bus, trolleybus, tram) whose close proximity to the node of railway network that supports passenger transport (i.e. station or railway stop) makes the integration of these subsystems possible. In addition, it is assumed that the greatest benefits will be achieved by integrating stations or railway stops and public transport stops with the highest functionality. The general scheme of the proposed methodology has been presented in Fig. 1.

The proposed approach includes three main stages:

- stage 1 - analysis of the equidistance for stations and railway stops,
- stage 2 - analysis of walking access from stations and railway stops to public transport stops,
- stage 3 - ranking of public transport stops with respect to their functionalities.

Stage 1 begins with identification of all nodes of railway network serving passenger transport in the analyzed area. As a result, the identified elements are numbered and presented in the form of a set:

$$SPK = \left\{1, \ldots, spk, \ldots \overline{SPK}\right\} \tag{1}$$

where:
spk - the number of the individual station or railway stop,
$\overline{SPK}$ - number of all stations and railway stops in the study area.

Next, for each of the elements of SPK - the set of stations and railway stops, an equidistance[1] with a specific radius is determined. This radius can be selected individually depending on the assumptions and local conditions. Its length may also result from studies on the preferences of public transport passengers. A detailed analysis of the area covered by the range of the designated equidistance allows to identify the public transport stops that are located in this area. The set of numbers of all public transport stops identified at the stage of the equidistance analysis (stage 1) was formulated as:

$$PTZ = \left\{1, \ldots, ptz, \ldots \overline{PTZ}\right\} \tag{2}$$

[1] A circle is the set of all points in a plane that are equidistant from a given point, in this case node of railway network.

where:

ptz - the number of the individual public transport stop,

$\overline{PTZ}$ - number of all public transport stops identified at stage 1 in the study area.

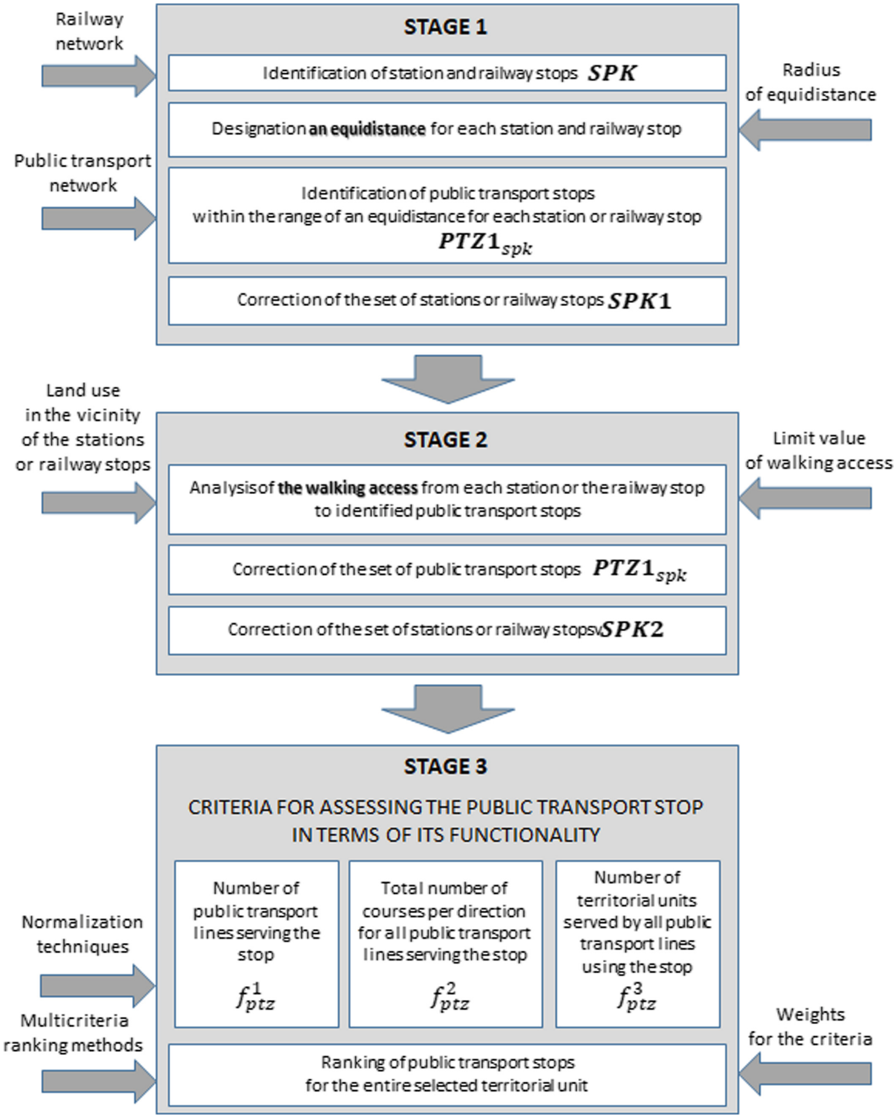


Fig. 1. Scheme of methodology for assessing the possibilities of integration of public transport

Each public transport stop refers to a specific station or railway stop. Therefore, the mapping *x1* has been introduced, which assigns elements from the set {0,1} to each element of the Cartesian product *PTZ* × *SPK*, i.e.:

$$x1 : PTZ \times SPK - \rightarrow \{0, 1\}$$

wherein:

$x1_{ptz,spk} = 0$ when the *ptz*-th stop is not in the range of the designated equidistance of *spk*-th station or railway stop,

$x1_{ptz,spk} = 1$ when the *ptz*-th stop is in the range of the designated equidistance of *spk*-th station and railway stop.

Therefore, for each $spk \in SPK$ the set $PTZ1_{spk}$ containing the public transport stops in the range of its equidistance was determined as:

$$PTZ1_{spk} = \left\{ptz : x1_{ptz,spk} = 1, ptz \in PTZ\right\}, \; spk \in SPK \tag{3}$$

Only those stations and railway stops are subject to further analysis, for which at least one public transport stop has been identified in the range of their equidistance. This means reducing the set *SPK* by removing items that do not meet this condition. The set after the appropriate reduction was formulated as:

$$SPK1 = SPK \backslash \left\{spk : PTZ1_{spk} = \emptyset, spk \in SPK\right\} \tag{4}$$

Stage 2 covers the analysis of the walking access from the *spk*-th station or the railway stop ($spk \in SPK1$) to the public transport stops identified at stage 1. If the length of the route to reach the public transport stop exceeds the assumed limit value (set individually by the analyst), this stop is removed from the set $PTZ1_{spk}$.

For modeling purposes, the mapping *x2* was introduced, which assigns elements from the set {0,1} to each element of the Cartesian product $PTZ1_{spk}$ *x* *SPK1*, i.e.:

$$x2 : PTZ1_{spk} \times SPK1 \rightarrow \{0, 1\}, \; spk \in SPK1$$

wherein:

$x2_{ptz,spk} = 0$ when the length of the walking access from the *spk*-th station or railway stop ($spk \in SPK1$) to the *ptz-th* stop ($ptz \in PTZ1_{spk}$) is longer than the assumed limit value,

$x2_{ptz,spk} = 1$ when the length of the walking access from the *spk*-th station or railway stop ($spk \in SPK1$) to the *ptz*-th stop ($ptz \in PTZ1_{spk}$) is not longer than the assumed limit value.

Therefore, the set $PTZ2_{spk}$ containing public transport stops within the range of the equidistance of *spk*-th station or railway stop with the length of the walking access to this node of railway network not longer than the assumed limit value, was determined as:

$$PTZ2_{spk} = \left\{ptz : x2_{ptz,spk} = 1, ptz \in PTZ1_{spk}\right\}, \; spk \in SPK1 \tag{5}$$

Only those stations and railway stops are subject to further analysis, for which at least one public transport stop has been identified with the length of the walking access not longer than the assumed limit value. This means reducing the set *SPK1* by removing items that do not meet this condition. The set after the appropriate reduction was determined as:

$$SPK2 = SPK1 \backslash \{spk : PTZ2_{spk} = \emptyset, spk \in SPK1\} \tag{6}$$

In stage 3, all public transport stops from the sets $PTZ2_{spk}$ are considered for further analysis. For each *spk*-th station and railway stop ($spk \in SPK2$) the ranking of public transport stops ($ptz \in PTZ2_{spk}$) is determined in terms of:

- number of public transport lines serving the stop $\left(f_{ptz}^{1}\right)$,
- the total number of courses per direction for all public transport lines serving the stop $\left(f_{ptz}^{2}\right)$,
- number of territorial units served by all public transport lines using the stop $\left(f_{ptz}^{3}\right)$.

These values are the criteria for assessing the public transport stop in terms of its functionality. The proposed methodology assumes that first of all spatial integration should be carried out for the stops with the most functionality.

At each public transport stop, there may be a certain number of stations from which vehicles of the same (but in various directions) or different public transport lines depart. An example of location of railway station, public transport stop and station within the stop has been presented in Fig. 2.

A set of numbers of stop stations within each public transport stop has been defined as:

$$ST_{ptz} = \left\{1, \ldots, st, \ldots \overline{ST_{ptz}}\right\},\ ptz \in PTZ2_{spk}, spk \in SPK2 \tag{7}$$

where:

st - the number of the individual stop station within public transport stop,
$\overline{ST_{ptz}}$ - number of all stop stations within the *ptz-th* public transport stop.

It has been assumed that if at least one stop station within the public transport stop ($ptz \in PTZ2_{spk}$) is located in the range of the equidistance and accepted lengths of walking access to the *spk-th* station or railway stop, all stop stations within this public transport stop are taken into consideration.

The public transport lines serving each stop station $st \in ST_{ptz}$ may be marked in various ways (e.g. in the form of numbers, digits, combinations of numbers and digits, others). For simplicity, each line was given an individual order number. When numbering the lines, all the lines serving all the stops identified at stage 2 were taken into account. Therefore, the set of public transport lines was determined as:

$$LK = \{1, \ldots, lk, \ldots, \overline{LK}\} \tag{8}$$

where:

lk - the number of the individual public transport line,
$\overline{LK}$ - number of all public transport lines serving all the stops identified at stage 2.

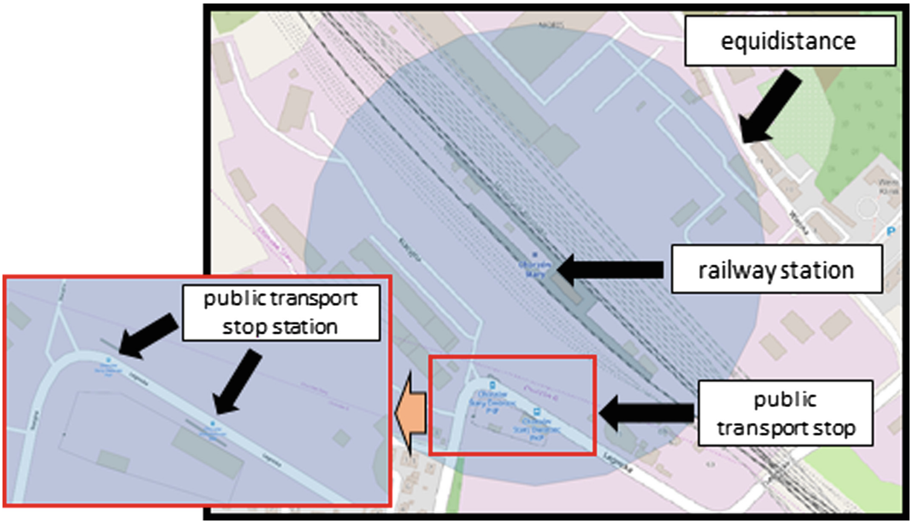


Fig. 2. An example of location of public transport stop stations (Source: Own research based on [18])

To determine the set of public transport lines serving each stop station $st \in ST_{ptz}$ the mapping *x3* has been introduced. It assigns elements from the set {0,1} to each element of the Cartesian product $ST_{ptz} \times LK$, i.e.:

$$x3 : ST_{ptz} \times LK \rightarrow \{0, 1\},\ ptz \in PTZ2_{spk}, spk \in SPK2$$

wherein:

$x3_{st,lk} = 0$ when the *lk-th* public transport line ($lk \in LK$) does not serve the *st-th* stop station ($st \in ST_{ptz}$),

$x3_{st,lk} = 1$ when the *lk-th* public transport line ($lk \in LK$) serves the *st-th* stop station ($st \in ST_{ptz}$).

The set of public transport lines serving the *st-th* stop station ($st \in ST_{ptz}$) was formulated as:

$$LK_{st} = \{lk : x3_{st,lk} = 1, lk \in LK\},\ st \in ST_{ptz}, ptz \in PTZ2_{spk}, spk \in SPK2 \tag{9}$$

Whereas the set of public transport lines serving all stop stations at one stop is described as:

$$LK_{ptz} = \bigcup_{st \in ST_{ptz}} LK_{st},\ ptz \in PTZ2_{spk}, spk \in SPK2 \tag{10}$$

The number of public transport lines serving the *ptz-th* stop is therefore the size of the set LK_{ptz} determined as:

$$f^1_{ptz} = \overline{\overline{LK_{ptz}}},\ ptz \in PTZ2_{spk}, spk \in SPK2 \tag{11}$$

The number of courses for a given public transport line from each stop station at a given stop may be different. Therefore, the mapping *kr* was introduced, which assigns elements from the set of natural numbers *N* to each element of the Cartesian product $LK_{st} \times ST_{ptz}$, i.e.:

$$kr : LK_{st} \times ST_{ptz} \rightarrow N,\ st \in ST_{ptz}, ptz \in PTZ2_{spk}, spk \in SPK2$$

where *kr*(*lk*, *st*) should be interpreted as the number of courses for the *lk-th* public transport line from the *st-th* stop station.

In the case where the public transport line serves more than one stop station within the same stop, a set of such stop stations and its size should be determined. Thus, the set of stop stations served by the *lk-th* public transport line within the *ptz-th* stop is defined as:

$$ST_{lk,ptz} = \left\{ st : x3_{st,lk} = 1, st \in ST_{ptz} \right\},$$

$$lk \in LK_{ptz},\ ptz \in PTZ2_{spk},\ spk \in SPK2 \tag{12}$$

The average number of courses for the *lk-th* public transport line at the *ptz-th* stop was determined as:

$$kr^{śr}_{ptz}(lk) = \frac{\sum_{st \in ST_{lk,ptz}} kr(lk, st)}{\overline{\overline{ST_{lk,ptz}}}},\ lk \in LK_{ptz},\ ptz \in PTZ2_{spk},\ spk \in SPK2 \tag{13}$$

where:

$\overline{\overline{ST_{lk,ptz}}}$ - the size of the set $ST_{\text{lk,ptz}}$.

Therefore, the total number of courses per direction for the *ptz-th* stop was determined as:

$$f^2_{ptz} = \sum_{lk \in LK_{ptz}} kr^{śr}_{ptz}(lk) \tag{14}$$

The study area was divided into smaller territorial units. Depending on the scope and level of detail of analyzes, these may be individual municipalities, districts, traffic analysis zones (TAZs) or other areas separated on the basis of predefined criteria [19].

All territorial units served by public transport lines departing from all stops identified at stage 2 were appropriately numbered and organized in the form of a set:

$$JT = \left\{1, \ldots, jt, \ldots, \overline{JT}\right\} \tag{15}$$

where:

jt - the number of the individual territorial unit,

$\overline{JT}$ - number of all territorial units served by all public transport lines departing from all stops identified at stage 2.

To determine the set of territorial units achieved from each public transport stop station $st \in ST_{ptz}$, the mapping $x4$ has been introduced, which assigns elements from the set $\{0,1\}$ to each element of the Cartesian product $ST_{ptz} \times JT$, i.e.:

$$x4 : STptz \times JT \rightarrow \{0, 1\},\ ptz \in PTZ2_{spk}, spk \in SPK2$$

wherein:

$x4_{st,jt} = 0$ when the *jt-th* territorial unit ($jt \in JT$) is not achieved from the *st-th* public transport stop station ($st \in ST_{ptz}$),

$x4_{st,jt} = 1$ when the *jt-th* territorial unit ($jt \in JT$) is achieved from the *st-th* public transport stop station ($st \in ST_{ptz}$).

The set of territorial units achieved from the *st-th* public transport stop station ($st \in ST_{ptz}$) was determined as:

$$JT_{st} = \left\{jt : x4_{st,jt} = 1,\ jt \in JT\right\},\ st \in ST_{ptz},\ ptz \in PTZ2_{spk},\ spk \in SPK2 \tag{16}$$

Whereas the set of territorial units achieved from all public transport stop stations within one stop is described as:

$$JT_{ptz} = \bigcup_{st \in ST_{ptz}} JT_{st},\ ptz \in PTZ2_{spk},\ spk \in SPK2 \tag{17}$$

Therefore, the number of territorial units served by all public transport lines using the *ptz-th* stop is the size of the set JT_{ptz} described as:

$$f^3_{ptz} = \overline{JT_{ptz}}, ptz \in PTZ2_{spk},\ spk \in SPK2 \tag{18}$$

Next, for each of the criteria f^1_{ptz}, f^2_{ptz} and f^3_{ptz} the weights w_1, w_2 and w_3 were assigned respectively, wherein:

$$\sum_i w_i = 1,\ i = 1, \ldots, 3 \tag{19}$$

The assessment of each stop in terms of its functionality is based on the formula:

$$F_{ptz} = \sum_i w_i \cdot f'^{i}_{ptz},\ i = 1, \ldots, 3,\ ptz \in PTZ2_{spk},\ spk \in SPK2 \tag{20}$$

where:

w_{i} - weight for the *i-th* criterion of the assessment,

f'^{1}_{ptz} - the normalized value of the *i-th* criterion of the assessment for the *ptz-th* public transport stop (normalization techniques have been described, among others in [20–23]).

Based on the F_{ptz} value the ranking of public transport stops for the entire selected territorial unit (e.g. city, municipality, district, voivodship) is determined in terms of their functionality. This means that the stops are organized in a non-increasing order in terms of the value of the F_{ptz} function.

4 Case Study

Two cities: Będzin and Chorzów, located in Metropolis GZM have been chosen for further analysis. First stage of proposed method requires identification of all railway stations and stops in the area of analysis. Table 1 presents railway stations and stops identified in both analyzed cities.

Table 1. Stations and railway stops identified in analyzed cities.

City	Railway station or railway stop
Będzin	Będzin Ksawera
	Będzin Miasto
	Będzin
Chorzów	Chorzów Batory
	Chorzów Miasto
	Chorzów Stary

Basing on data from Table 1 two sets *SPK* has been established, one for each city.

Next step of proposed method was an imposition of an equidistance with a radius of 250 m and with a center located in the middle of a analyzed railway station or railway stop. Figures 3 and 4 present equidistance for each station and railway stop respectively in Będzin and in Chorzów.

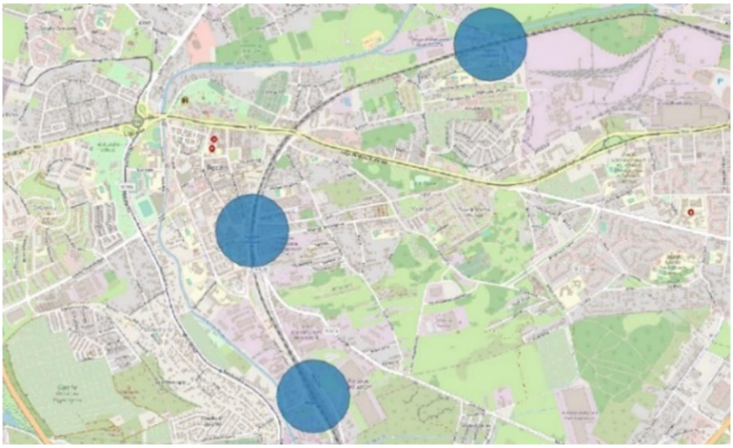


Fig. 3. Equidistance for each station and railway stop in Będzin (Source: Own research based on [18])

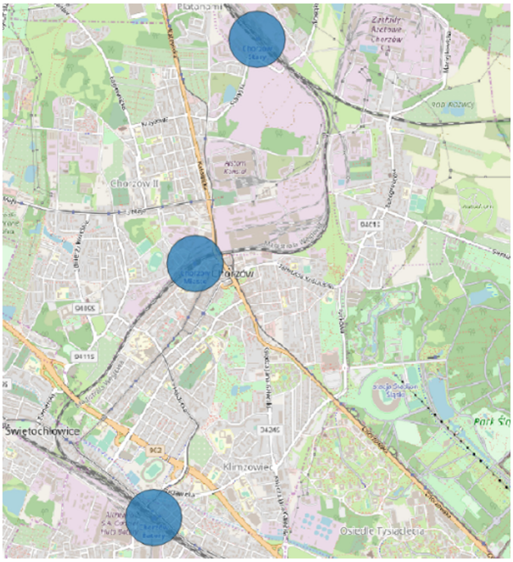


Fig. 4. Equidistance for each station and railway stop in Chorzów (Source: Own research based on [18])

In order to establish set *PTZ*, for each equidistance public transport stops located within its range have been identified. Results of such identification have been presented in Table 2.

Table 2. Identified public transport stops.

City	Public transport stop
Będzin	Będzin Poczta
	Będzin Dworzec PKP
	Będzin Brata Alberta
	Będzin Sienkiewicza
	Nowy Będzin Dworzec PKP
	Będzin Huta
Chorzów	Chorzów Batory Dworzec PKP
	Chorzów Miasto Dworzec PKP
	Chorzów Dworcowa
	Chorzów Stary Dworzec PKP

According to an assumption that each public transport stop refers to a particular station or railway stop each public transport stop from Table 2 was assigned to a particular railway station or railway stop from Table 1. Results of that assignment have been presented in Table 3. A public transport stop is assigned to station or railway stop if it is located in the range of equidistance of particular railway station or railway stop. In this way a set $PTZ1_{spk}$ for each station or railway stop has been created.

Table 3. Public transport stops assigned to each identified station or railway stop.

Station or railway stop	Public transport stop
Będzin Ksawera	–
Będzin Miasto	Będzin Poczta
	Będzin Dworzec PKP
	Będzin Brata Alberta
	Będzin Sienkiewicza
Będzin	Nowy Będzin Dworzec PKP
	Będzin Huta
Chorzów Batory	Chorzów Batory Dworzec PKP
Chorzów Miasto	Chorzów Miasto Dworzec PKP
	Chorzów Dworcowa
Chorzów Stary	Chorzów Stary Dworzec PKP

If there is no public transport stop assigned to a particular railway station or railway stop such station or stop is excluded from further analysis. In this manner the set *SPK1* has been established. Basing on Table 3 it turns out that only one railway stop has to be removed from further analysis. Hence, two sets *SPK1* (each for one city of analysis) contain following railway stations or railway stop: Będzin Miasto, Będzin, Chorzów Batory, Chorzów Miasto, Chorzów Stary.

In stage 2 an analysis of walking distanced between a particular station or railway stop and public transport stops located in the range of its equidistance has been performed. An assumption has been made that the limit value of the length of the route to reach public transport stop was 250 m.

After analyzing public transport stops from Table 3 it turned out that only one walking distance exceeded the limit value. Although public transport stop 'Będzin Huta' is located in the range of the equidistance of railway station 'Będzin' the system of platforms and railway tracks impedes the access to the public transport stop from the railway station. Hence, public transport stop 'Będzin Huta' has been removed from further analysis. Nevertheless, there is still one more public transport stop on the range of the equidistance of the railway station 'Będzin' which means that this station is not removed from the analysis. Therefore, the set *SPK2* equals the set *SPK1*, despite the fact that one public transport stop has been excluded and the set $PTZ2_{spk}$ does not equal the set $PTZ1_{spk}$.

After performing first two stages of proposed method sets *SPK2* and $PTZ2_{spk}$ have been established. Set *SPK2* contains stations and railway stops that have been chosen for stage 3 and set $PTZ2_{spk}$ contains public transport stops that meet all criteria and are assigned to stations and stops from set *SPK2*.

List of elements of these sets has been presented in Table 4.

Table 4. Stations, railway stops and public transport stops chosen for the analysis in stage 3.

Elements of set *SPK2*	Elements of set $PTZ2_{spk}$ assigned to each station or railway stop from set *SPK2*
Będzin Miasto	Będzin Poczta
	Będzin Dworzec PKP
	Będzin Brata Alberta
	Będzin Sienkiewicza
Będzin	Nowy Będzin Dworzec PKP
Chorzów Batory	Chorzów Batory Dworzec PKP
Chorzów Miasto	Chorzów Miasto Dworzec PKP
	Chorzów Dworcowa
Chorzów Stary	Chorzów Stary Dworzec PKP

In stage 3 of proposed method a ranking of public transport stops has been determined. Following criteria of functioning of a public transport stop have been included:

- number of public transport lines serving the stop $\left(f_{ptz}^{1}\right)$,
- the total number of courses per direction for all public transport lines serving the stop $\left(f_{ptz}^{2}\right)$,
- number of territorial units served by all public transport lines using the stop $\left(f_{ptz}^{3}\right)$.

An analysis has been carried out in order to determine values of f_{ptz}^{1}, f_{ptz}^{2} and f_{ptz}^{3}. Results have been presented in Table 5.

Table 5. Aspects of functioning of public transport stops.

City	Public transport stop	f_{ptz}^{1} [−]	f_{ptz}^{2} [−]	f_{ptz}^{3} [−]
Będzin	Będzin Poczta	30	443.5	13
	Będzin Dworzec PKP	32	492.5	13
	Będzin Brata Alberta	2	33.0	3
	Będzin Sienkiewicza	2	36.0	3
	Nowy Będzin Dworzec PKP	3	27.0	3
Chorzów	Chorzów Batory Dworzec PKP	18	486.0	7
	Chorzów Miasto Dworzec PKP	5	98.0	2
	Chorzów Dworcowa	4	216.0	4
	Chorzów Stary Dworzec PKP	5	87.5	3

Basing on zero-unitarization method each value from Table 5 has been converted to a number from a range <0,1>. The following formula has been used.

$$f'^{i}_{ptz} = \frac{f_{ptz}^{i} - \min\limits_{ptz} f_{ptz}^{i}}{\max\limits_{ptz} f_{ptz}^{i} - \min\limits_{ptz} f_{ptz}^{i}}, \quad i = 1, 2, 3, \; ptz \in PTZ2_{spk}, \; spk \in SPK2 \tag{21}$$

wherein:

f'^{1}_{ptz} - normalized value of *i-th* criterion $\left(f_{ptz}^{1}, f_{ptz}^{2} \,\text{or}\, f_{ptz}^{3}\right)$ for *ptz-th* object (elements of $PTZ2_{spk}$ sets separately for Będzin and Chorzów),

f_{ptz}^{1} - value of *i-th* criterion $\left(f_{ptz}^{1}, f_{ptz}^{2} \,\text{or}\, f_{ptz}^{3}\right)$ for *ptz-th* object (elements of $PTZ2_{spk}$ sets separately for Będzin and Chorzów).

The values of particular criteria for Będzin have been presented in Table 6 and for Chorzów in Table 7. For each of the criteria f_{ptz}^{1}, f_{ptz}^{2} and f_{ptz}^{3} a weight has been assigned. For criteria f_{ptz}^{2} and f_{ptz}^{3} a weight of 0.4 has been chosen whereas for criterion f_{ptz}^{1} a weight 0.2. Basing on formula (20) the value of a final measure of functionality of a public transport stop (F_{ptz}) has been calculated. Results have been presented in Tables 8 and 9.

Table 6. The values of particular criteria for public transport stops in Będzin.

Public transport stop	f_{ptz}^{1} [−]	f_{ptz}^{2} [−]	f_{ptz}^{3} [−]
Będzin Poczta	0.89	0.93	1.00
Będzin Dworzec PKP	1.00	1.00	1.00
Będzin Brata Alberta	0.00	0.01	0.00
Będzin Sienkiewicza	0.00	0.02	0.00
Nowy Będzin Dworzec PKP	0.03	0.03	0.00

Table 7. The values of particular criteria for public transport stops in Chorzów.

Public transport stop	f_{ptz}^{1} [−]	f_{ptz}^{2} [−]	f_{ptz}^{3} [−]
Chorzów Batory Dworzec PKP	1.00	1.00	1.00
Chorzów Miasto Dworzec PKP	0.07	0.03	0.00
Chorzów Dworcowa	0.00	0.32	0.40
Chorzów Stary Dworzec PKP	0.07	0.00	0.20

Table 8. Ranking of public transport stops in Będzin.

No.	Public transport stop	F_{ptz} [−]
1.	Będzin Dworzec PKP	1.00
2.	Będzin Poczta	0.94
3.	Będzin Brata Alberta	0.01
4.	Będzin Sienkiewicza	0.01
5.	Nowy Będzin Dworzec PKP	0.01

Table 9. Ranking of public transport stops in Chorzów.

No.	Public transport stop	F_{ptz} [−]
1.	Chorzów Batory Dworzec PKP	1.00
2.	Chorzów Miasto Dworzec PKP	0.02
3.	Chorzów Dworcowa	0.29
4.	Chorzów Stary Dworzec PKP	0.09

5 Conclusions

Integration of railway transport with other sub-systems of public transport in urban areas is a complex issue. One of a very important aspects of such integration is a location of nodes in the railway network that could be integrated with public transport stops. It is significant not to choose too many railway stations and stops because of possibility of unnecessary elongation of journey by train but on the other hand few places of integration may reduce the level of accessibility to railway transport. Therefore it is important to develop a method of assessment of public transport stops in terms of possibility of integration with railway.

The article focuses on spatial integration of public transport as it is the first stage of integrating different sub-systems. Integration of i.e. timetables should be performed in specific places that should be identified during the analysis of the possibility of spatial integration. Selected aspects of operation of public transport have been chosen as a measures that allow to compare existing public transport stops and identify those which should be integrated with railway transport in the first place.

A case study has been performed for two cities in Metropolis GZM. Railway stations and stops as well as public transport stops have been analyzed. For each city a ranking of public stops in terms of adaptation for integration with railway transport has been prepared using zero-unitarization method.

Further research may involve different aspects of integration, such as integration of timetables or fares.

References

1. Nosal, K., Solecka, K.: Application of AHP method for multicriteria evaluation of variants of the integration of urban public transport. Transp. Res. Procedia **3**, 269–278 (2014)
2. Solecka, K.: Integration of public transport in polish and EU documents and examples of solutions for integration of public transport in Poland and in the world. Transp. Probl. **6**(4), 23–34 (2011)
3. Fierek, S., Żak, J.: Planning of an integrated urban transportation system based on macro - simulation and MCDM/A methods. Procedia – Soc. Behav. Sci. **54**, 567–579 (2012)
4. Starowicz, W., Janecki, R.: Integracja regionalnego transportu zbiorowego. Transp. Miejski i Regionalny **3**, 4–10 (2004)
5. Saliara, K.: Public transport integration: the case study of Thessaloniki, Greece. Transp. Res. Procedia **4**, 535–552 (2014)
6. May, A., Kelly, C., Shepherd, S.: The principles of integration in urban transport strategies. Transp. Policy **13**, 319–327 (2006)
7. Janic, M., Reggiani, A.: Integrated transport systems in european union: an overview of some recent developments. Transp. Rev. **21**(4), 469–497 (2001)
8. Nosal Hoy, K., Solecka, K., Szarata, A.: The application of the multiple criteria decision aid to assess transport policy measures focusing on innovation. Sustainability **11**, 1–23 (2019)
9. Piskozub, A.: Gospodarowanie w transporcie. WKiŁ, Warszawa (1982)
10. Wachowiak, W.: Integracja podsystemów transportowych w węzłach przesiadkowych komunikacji publicznej Poznania w oparciu o kolejowe dworce miejskie. Biuletyn KPZK PAN **270**, 82–106 (2018)
11. Goldman, T., Gorham, R.: Sustainable urban transport: four innovative directions. Technol. Soc. **28**, 261–273 (2006)
12. Kos, B., Krawczyk, G., Tomanek, R.: Modelowanie mobilności w miastach. Wydawnictwo Uniwersytetu Ekonomicznego w Katowicach, Katowice (2018)

13. Karoń, G., Janecki, R.: Development of various scenarios of ITS systems for urban area. In: Sierpiński, G. (ed.) Intelligent Transport Systems and Travel Behaviour. AISC, vol. 505, pp. 3–12. Springer, Cham (2017)
14. Lubieniecka-Kocoń, K., Kos, B., Kosobucki, Ł., Urbanek, A.: Modern tools of passenger public transport integration. In: Mikulski, J. (ed.) Activities of Transport Telematics. CCIS, vol. 395, pp. 81–88. Springer, Heidelberg (2013)
15. Karoń, G., Żochowska, R.: Problems of quality of public transportation systems in smart cities-smoothness and disruptions in urban traffic. In: Sładkowski, A. (ed.) Modelling of the Interaction of the Different Vehicles and Various Transport Modes. LNITI, pp. 382–414. Springer, Switzerland (2020)
16. Wyszomirski, O.: Transport miejski. Ekonomika i organizacja. Wydawnictwo Uniwersytetu Gdańskiego, Gdańsk (2008)
17. Polat, C.: The demand determinants for urban public transport services: a review of the literature. J. Appl. Sci. **12**, 1211–1231 (2012)
18. Google maps. https://www.google.com/maps
19. Karoń, G., Żochowska, R., Sobota, A., Janecki, R.: Selected aspects of the methodology for delimitation of the area of urban agglomeration in transportation models for the evaluation of ITS projects. In: Sierpiński, G. (ed.) Advanced Solutions of Transport Systems for Growing Mobility. AISC, vol. 631, pp. 243–254. Springer, Cham (2018)
20. Vafaei, N., Ribeiro, R.A., Camarinha-Matos, L.M.: Normalization techniques for multi-criteria decision making: analytical hierarchy process case study. In: Camarinha-Matos, L. M., Falcao, A.J., Vafaei, N., Najdi, S. (eds.) Technological Innovation for Cyber-Physical Systems. IFIP AICT, vol. 470, pp. 261–269. Springer, Cham (2016)
21. Podviezko, A., Podvezko, V.: Influence of data transformation on multicriteria evaluation result. Procedia Eng. **122**, 151–157 (2015)
22. Ginevičius, R.: Normalization of quantities of various dimensions. J. Bus. Econ. Manage. **9**(1), 79–86 (2008)
23. Lakshmi, T.M., Venkatesan, P.: A comparison of various normalization in techniques for order performance by similarity to ideal solution (TOPSIS). Int. J. Comput. Algorithm **3**(3), 255–259 (2014)

Synchronisation of Road Traffic Streams

Ireneusz Celiński(✉)

Faculty of Transport, Silesian University of Technology, Katowice, Poland
ireneusz.celinski@polsl.pl

Abstract. The article addresses the overall body of problems related to synchronisation of traffic streams. With such a perspective in mind, the author discusses the problem of studying characteristics of traffic streams using a research tool of his own design. Characteristics of traffic streams affect the relations between one another (including internal impacts within individual streams). Consequences of non-synchronised traffic streams include excessive effects such as vehicle queues and delay in the network. Further outcomes of non-synchronised streams may be road traffic incidents and accidents. The article provides a discussion on the general concept of traffic stream synchronisation analysed from the perspective of both internal and external aspects. It establishes the context against which the problem of traffic self-regulation at non-signal-controlled intersections is discussed. Synchronisation of traffic streams appears to be possible, given the prospects of further development of technologies such as V2V (vehicle to vehicle) and V2I (vehicle to infrastructure).

Keywords: Traffic stream · Synchronising · Synchronisation · V2V · V2I · Traffic regulation

1 Introduction

Road traffic streams are described using a number of basic characteristics, such as traffic volume, density, average speed, average headway between vehicles, average buffer etc. [1–4]. These characteristics fail in accurately reflecting the irregularity and inhomogeneity of traffic as it can be observed in reality. What they also fail to reflect is the relations between different traffic streams. One can observe variability of parameters in nearly every traffic stream of vehicles.

One may speak of regularity of the vehicular traffic stream when vehicles appear at the same point at constant time intervals. Homogeneity is the capacity to maintain traffic volume of a constant level. One may digress on the homogeneity of traffic stream characteristics in a macroscopic scale, once the effect of the type structure has been taken into account. Homogeneity of the traffic stream describing characteristics (e.g. traffic volume) typically pertains to street sections of small length, where it is observed (in a single cross-section) with regard to small observation intervals. A regular stream is not necessarily homogeneous, especially for small traffic variations.

Whether or not a traffic stream is regular/homogeneous affects the emergence of both internal impacts, observed within a single stream, and external impacts between different streams. A regular traffic stream characterised by considerable variability of

E. Macioszek et al. (Eds.): TSTP 2019, LNITI, pp. 82–99, 2020.
https://doi.org/10.1007/978-3-030-39109-6_7

type structure may be inhomogeneous. High variability of traffic parameters within a single stream forces individual vehicle drivers to frequently change their driving speed (traffic self-regulation). All these changes consequently translate into individual vehicles' impacts and delay, increasing the probability of road traffic collision. Such problems have been addressed in the literature of the subject from traffic measurement to the angle of what is referred to as the traffic smoothness theory [5–11]. Irregularity and inhomogeneity are also deleterious in major vehicular traffic streams in the vicinity of road intersections. In certain periods, this situation may hinder merging with the traffic for vehicles incoming from minor approach, effectively reducing the capacity of selected intersection elements. This is the case when the acceptable critical gap interval is increased [1, 2]. A lot depends on the selection of route in the transport network [12–14].

This article discusses results of studies of streams based on measurements of their positioning in the network [8–10]. These study results have been provided with reference to pairs of traffic streams combined in a major/minor approach. Based on these studies, the author has discussed the problem of traffic stream regulation at non-signal-controlled intersections and the possibility to synchronise streams, claiming that such an approach is only realistic when using (in the future) contemporary means of communication between automotive vehicles, i.e. V2V (vehicle to vehicle) and V2I (vehicle to infrastructure).

2 V2O, Vehicle to Object (V2V and V2I)

The vehicle to vehicle (V2V) type communication has enabled vehicles driven by different persons to communicate directly between one another over the road network. The prerequisite of successful communication is the appropriate infrastructure on-board the vehicle. Using the means of wireless information exchange between vehicles, drivers can warn each other about the manoeuvres they are about to perform somewhat in advance. It should also be stressed that such communication often precedes reactions of the drivers involved, which result directly from their perceptive and psychophysical capabilities. This increases the information capacity of the road transport system, and consequently, an opportunity emerges to optimise transport and to improve it safety. V2V is essentially a subject-to-subject type of communication, and it steps far beyond the scope of warning messages.

An extension to the V2V technology is V2I (vehicle to infrastructure), designed to enable communication between vehicles and the network infrastructure, control systems and - more broadly - the ITS. According to this communication concept (subject-to-object type), the transport infrastructure functioning within a traffic lane and in its vicinity can collect information about the traffic characteristics, traffic incidents, etc. Consequently, based on the information thus acquired, feedback for vehicles (actually, in practical terms, for drivers, at least until traffic is optimised) can be generated to meet specific goals depending on the traffic or weather conditions, traffic organisation or other temporary needs (adaptation to traffic).

The V2V and V2I infrastructures use diverse technical equipment, mainly devices which operate on the basis of the wireless technology and the RFID readers. Both the transmission between vehicles and that which involves the transport infrastructure are based on dedicated short range communication (DSRC) frequencies.

This article presents a concept of synchronisation of road traffic stream characteristics which may be implemented using the features offered by the V2V and V2I technologies (V2*).

3 Traffic Stream Studying Technique

The studies addressed in this article were conducted using a microprocessor-based device of the author's own design intended for detection of the vehicle presence. It was built on the basis of the RCWL-0516 short range microwave motion sensor. Making the most of the microwave technology, this device detects vehicles in a distance of up to ca. 5 m away from the sensor's front antenna. The detector is coupled with the ATmega328 2560 microprocessor system. Additionally, the device features the Neo-6M GPS module enabling it to store vehicle detection data using the GPS system time. The data are stored on an SD memory card. The motion sensor is capable of monitoring vehicular traffic in one or two lanes for more than 24 h. Figure 1a is a photograph showing the device in a dedicated enclosure. Figure 1b presents the device in operation. In its miniature version, the detector can be mounted to road shoulder posts, barriers, cat's eye type devices, etc.

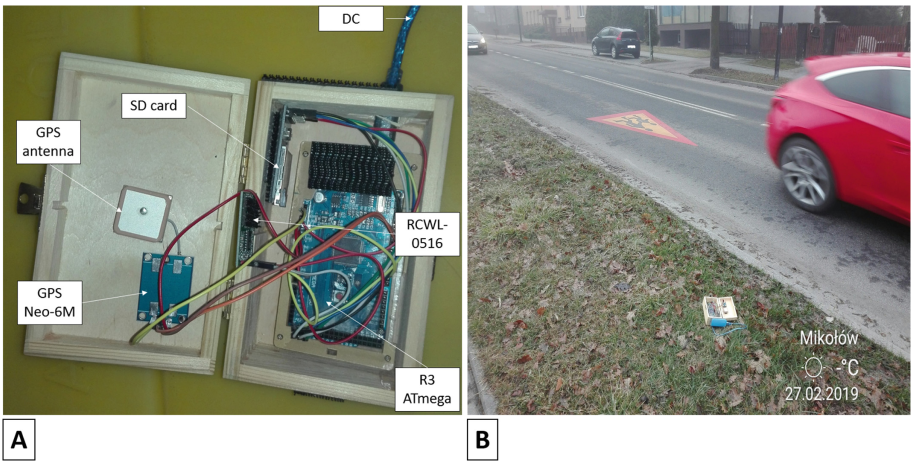


Fig. 1. Measuring device: (a) overview photograph, (b) device in operation

During measurements, the device is placed outside the roadway so that the range of detection is limited to one traffic lane, which affects both the process itself and the accuracy of detection (its position is calibrated by model detector with counter). As vehicles move within a lane, which the device covers while performing its detection function, the passing of individual vehicles is recorded with the accuracy corresponding to that of the GPS time (at 1 s interval).

4 Selected Measurement Results

Different pairs of streams were parameterised during the studies, namely major and minor approach at selected intersections (including one roundabout and circular intersection). The following characteristics have been discussed in this paper with regard to individual road intersections:

- structure no. 1 - two colliding traffic streams, 4 approach,
- structure no. 2 - two colliding traffic streams, 3 approach,
- structure no. 3 - two colliding traffic streams at a roundabout,
- structure no. 4 - two colliding traffic streams at a traffic circle intersection.

Figure 2 contains graphs showing instants of detection of vehicles moving in the major traffic streams at the structures subject to the study in measurement cross-sections shown in Fig. 6. The X-axis is divided into consecutive seconds of the measurement (clocked by a GPS signal), while on the Y-axis, the value of 1 signifies the fact that a vehicle was detected. The value of zero signifies the fact that a vehicle wasn't detected. Several such values in a row means that a single vehicle was detected in consecutive measurement intervals. The detection time duration depends on the parameters of the vehicle's motion, i.e. the lower the speed, the higher the number of detection points. This is also the case of the heavy vehicles (their length being determinant) - the larger the type structure, the higher the number of detection points. Therefore, the vehicle detection depended on the running speed and the traffic structure by type.

Figure 2 demonstrates the considerable irregularity of the traffic streams subject to the study. One could observe particularly notable intervals separating individual detection entries at structures no. 2, 3 and 4. The structures were characterised by diversified intensity of detection entries. Traffic homogeneity was not recorded (non-surveyed structure by type), however, no atypical distributions of the traffic structure by type were observed during the measurements.

Figure 3 contains graphs showing instants of detection of the vehicles moving in the minor stream at the structures in question. Individual axes correspond to the same quantities as in Fig. 2. One can clearly notice the irregularity of detection entries, and the intervals separating them are large. There were queues forming at approach, hence the frequently observed continuous detection signal.

Figure 4 shows headway observed between vehicles moving in the major traffic streams at the structures examined. Short headway ranging up to several seconds are predominant. At the first structure, they are from 0 to 3 s long, from 4 to 7 s at the second one (in fact, in range 0–3; they represent values from 2 to 3 s, since the buffer time between vehicles was not recorded), and from 8 to 11 s at the fourth one. Very atypical characteristics were recorded at the third structure, where higher volumes were observed at a minor approach.

Figure 5 illustrates headway observed between vehicles moving in the minor traffic streams at the structures examined. As in the case of the major streams, short headway of ca. several seconds are predominant. They come to 0–3 s at the first and the second structure. They range from 4 to 7 s at fourth structures. One can also notice that longer headway, exceeding 28 s, started being recorded. And again, the characteristics of structure no. 3 were atypical compared to others.

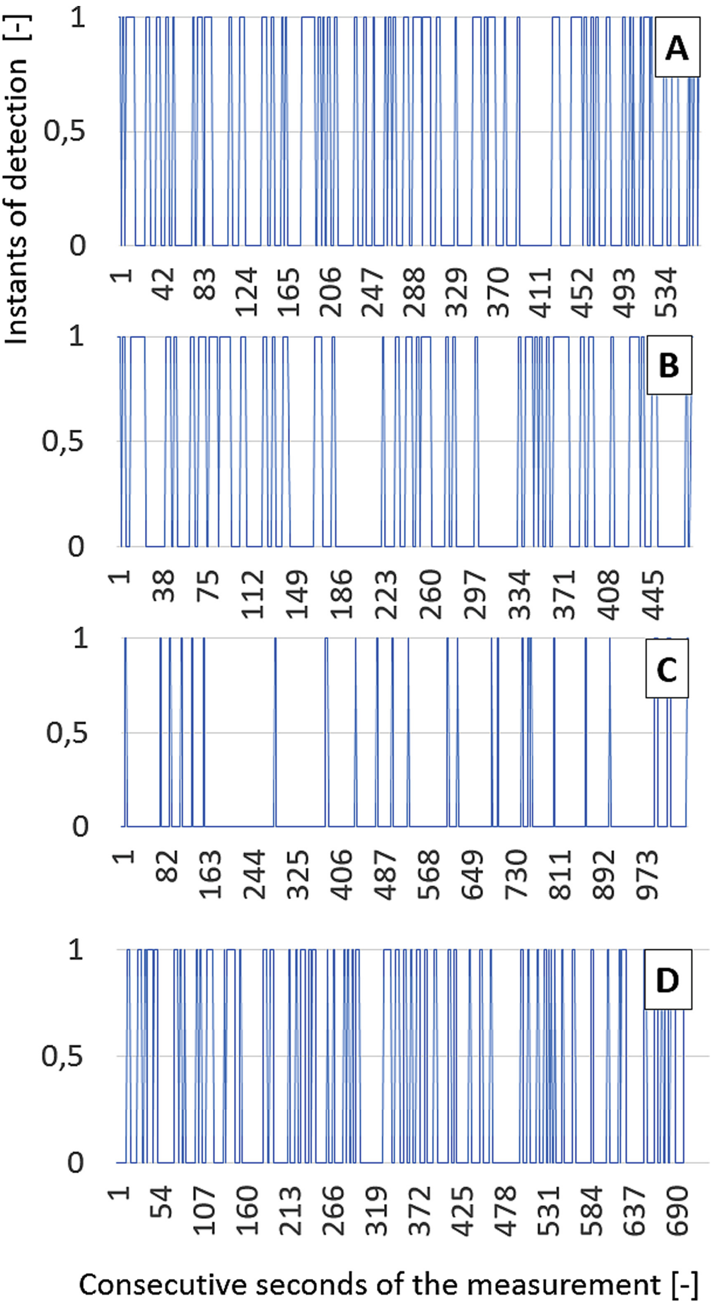


Fig. 2. Vehicle detection characteristics, major streams: (a) structure no. 1, (b) structure no. 2, (c) structure no. 3, (d) structure no. 4

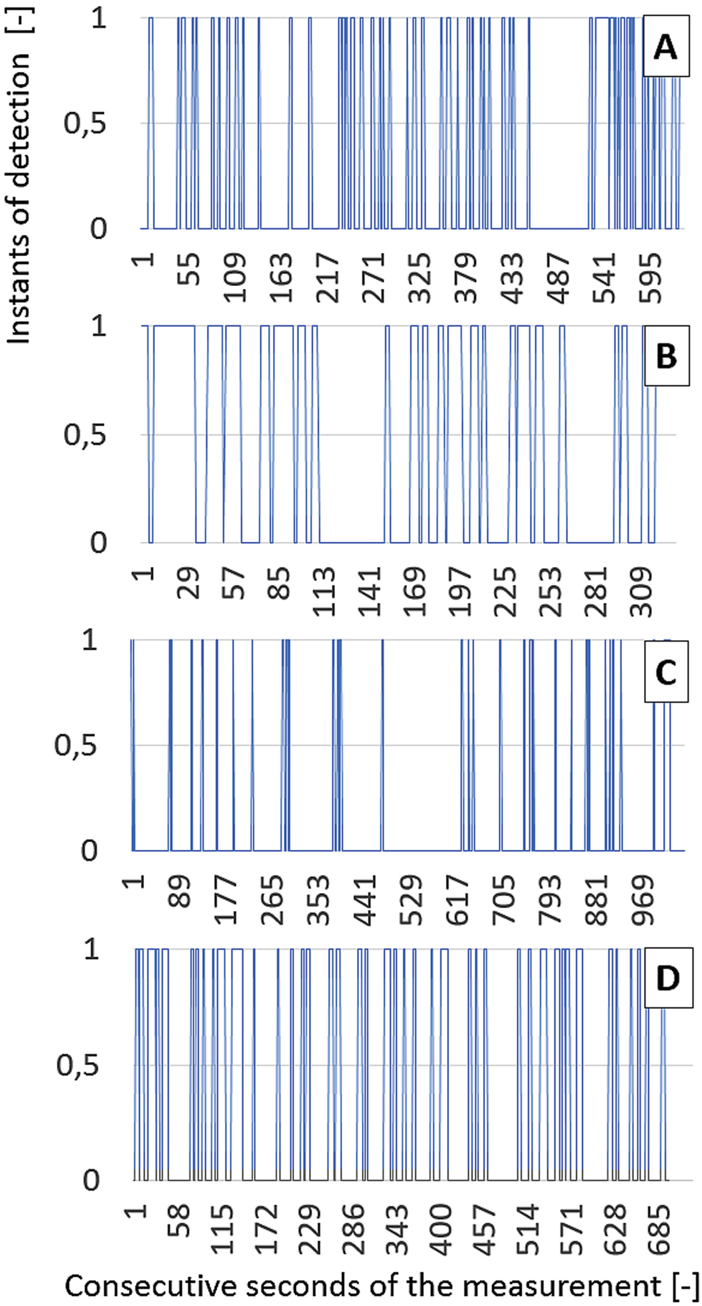


Fig. 3. Vehicle detection characteristics, minor streams: (a) structure no. 1, (b) structure no. 2, (c) structure no. 3, (d) structure no. 4

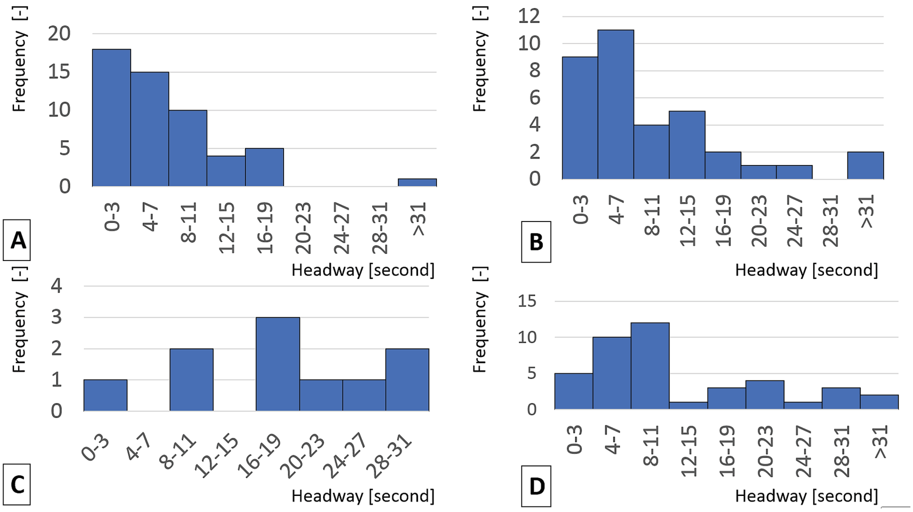


Fig. 4. Vehicle headway time characteristics, major streams: (a) structure no. 1, (b) structure no. 2, (c) structure no. 3, (d) structure no. 4

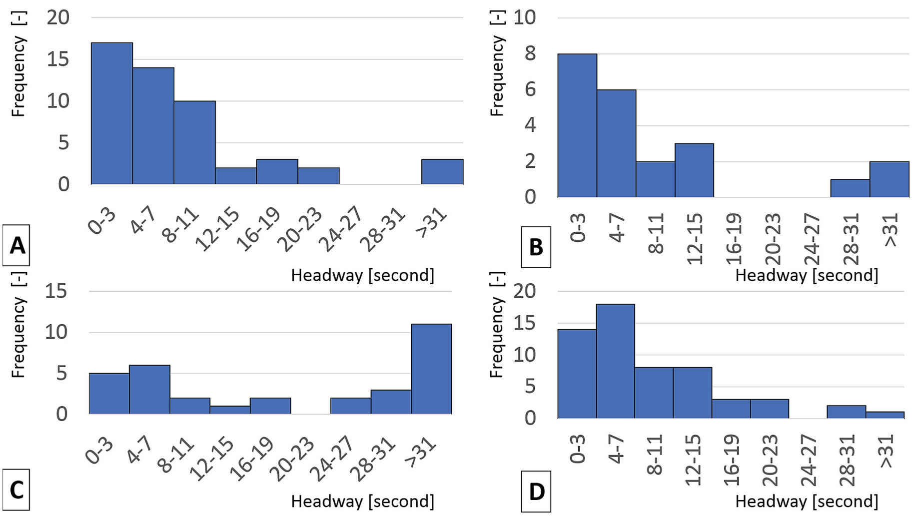


Fig. 5. Vehicle frequency characteristics, minor streams: (a) structure no. 1, (b) structure no. 2, (c) structure no. 3, (d) structure no. 4

Figure 6 provides schematic diagrams representing the intersections where characteristics of traffic streams were studied. On the diagrams, the examined traffic streams have been indicated and the cross-section designated with cubes. An green arrow marks the plane of symmetry of the motion detection area.

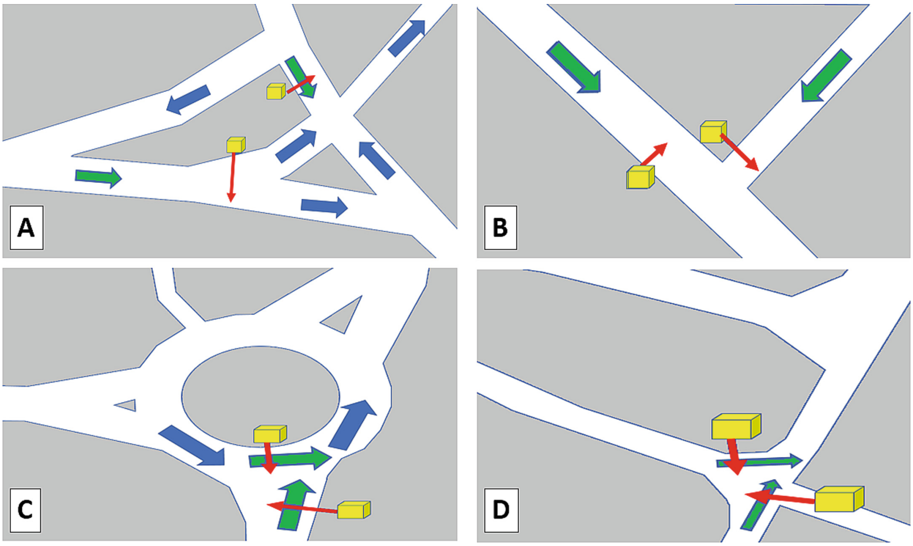


Fig. 6. Traffic streams studied at the respective intersections: (a) structure no. 1, (b) structure no. 2, (c) structure no. 3, (d) structure no. 4

Variability of daily, weekly, monthly and long-term traffic causes that traffic research should be carried out constantly [8–10]. Such research should be carried out for various types of objects. Comprehensive research in all network areas is conducive to the presented method.

5 Traffic Stream Synchronisation Method

Traffic in the transport network may either be regulated or self-regulating. Railway traffic is regulated, since every section of the network which may be occupied by a one rail vehicle is controlled by control systems or by a traffic management system (save for individual special traffic management cases). Unlike railway traffic, road traffic regulates itself. A special form of traffic self-regulation can be observed at non-signal-controlled intersections. Drivers entering these road structures from minor approach regulate their respective driving parameters in order to adapt to the applicable traffic regulations and the traffic conditions observed. This is how the traffic stream self-regulation is achieved. When another vehicle positions itself in a field of collision (with the major stream) at a non-signal-controlled intersection, such regulation is obligatory, and it is individually performed by the vehicle using the minor street, without any intervention of traffic control systems. In this process, there are certain differences between traffic signs A7 and B20.

In terms of traffic self-regulation, one should distinguish between the probability of traffic regulation on a global and local scale. Both global and local traffic regulation involves the prohibition to merge with traffic at an intersection imposed upon a vehicle approaching from a minor street on account of other vehicles using major streams (taking places in a field of collision). The difference between global and local regulation is that of the reference level (stream vs. vehicle), and the global probability of traffic regulation is calculated over the entire period of observation of the minor stream (e.g. measurement intervals: 10, 15, 20, 30 and 60 min). This probability is not always linked with a single vehicle, but also with an entire traffic stream in the chosen observation period. Hence the term *global (macroscopic)*. It is given by a quotient of the out-of-traffic time for the minor stream and the analysis period (Relation 1). The collision area is blocked by vehicles moving in major streams. For the major stream, the estimated probability of the collision area being occupied (otherwise referred to as forced regulation, exclusion from traffic) is calculated as (PSRN):

$$P_{rn}^{s} = \frac{\sum_{i-1}^{n} t_{i*} * k}{t_a} \tag{1}$$

where:

P_{rn}^{s} - estimated probability of the collision area occupation (forced potential regulation) calculated for the major traffic stream (rn) by taking the total collision area occupancy (exclusion) time into account [-]. Pertains to the chosen minor stream,

t_i - i^{th} measurement interval where occupancy of a major road by vehicles using the major stream (i) is identified directly in front of the collision area [minutes],

t_a - selected global analysis period [minutes],

n - number of intervals occupied by vehicles using major streams which collide with the analysed minor stream [-],

k - correction coefficient resulting from the time required to arrive at the point of collision with the minor stream [-].

Relation (1) is an estimation, since the calculation of the probability at which the collision area is excluded from use for the minor streams results from the occupancy of the major approach directly before the major streams enter the intersection's (which is how the detector counts it). This time may differ from the actual occupancy of the intersection's conflict zone. In a longer time horizon, this would require further development of an occupancy validation method. An alternative solution is to directly examine the conflict zone occupancy, e.g. using visual techniques which are more expensive in both design and operation, but also more accurate in this specific case. This problem will be addressed by the author in further publications.

And analogically, for the minor stream, one can calculate the probability at which an attempt is made to enter the conflict zone, which may be referred to as the probability of direct access to the conflict zone (PxRP):

$$P_{rp}^{x} = \frac{\sum_{j=1}^{u} t_j * \rho}{t_a} \tag{2}$$

where:

P^{x}_{rp} - probability of direct access to the conflict zone for the minor traffic stream, involving a vehicle standing first in a queue at a minor approach with a (potential) possibility to merge with traffic [-],

t_{j} - j^{th} measurement interval where occupancy of a minor approach by the minor stream's vehicle (queued first) is identified [seconds, minutes],

u - number of intervals occupied by the minor stream's vehicles [-],

ρ - correction coefficient resulting from the time required to arrive at the point of conflict with the major stream [-].

Relation (2) is also an estimation to a certain extent, as it disregards the queue length, while it only takes into account the fact of a vehicle being present and queued first at the minor approach. In practice, vehicles using major traffic streams often occupy the conflict zones at non-signal-controlled intersections at the same time, which does not largely increase the global time for which the minor approach vehicles cannot merge with traffic, and consequently:

$$P^{s}_{rn} = \frac{\sum_{i=1}^{n} t_i * k - \sum_{w=1}^{m-1} t_w}{t_a} \tag{3}$$

where:

t_{w} - time for which the conflict zones are occupied by the major stream's vehicles which merged with traffic at the intersection in time $i \pm \Delta t$ [seconds],

m - number of vehicles simultaneously having access to the intersection's conflict zones [-].

This is how the probability of forced regulation was defined at a non-signal-controlled intersection using the occupancy of the conflict zones and the probability of direct access to the conflict zones at a minor approach.

For a single vehicle using the minor stream, the probability of global regulation is merely an indicator of the quality of traffic at the minor approach. Such datum can be used in control algorithms. In practice, on account of the irregularity of traffic, one should determine what is referred to as probability of local regulation for each vehicle separately (in a very short time interval when the vehicle is waiting for an opportunity to perform a manoeuvre, taking into account temporary traffic conditions and primarily the conditions that are relevant to this vehicle):

$$P^{A}_{rln} = \frac{\sum_{i=1}^{n} t_i}{t_{al}} * \frac{t_{min}}{\bar{t}} \tag{4}$$

where:

P^{A}_{rl} - probability of forced local regulation for a single vehicle A [-],

t_{i} - i^{th} measurement interval where occupancy of a major approach by a vehicle has been identified [seconds],

t_{al} - local analysis period [seconds]; $t_a \gg t_{al}$,

n - number of intervals occupied by the major stream's vehicles [-],
$\frac{t_{min}}{\bar{t}}$ - traffic irregularity coefficient chosen in such a way as to match the analysis period, being the quotient of minimum headway between vehicles and the average one [-].

An event of a vehicle emerging at the minor approach is established with a certain probability, determining the possibility to directly access the conflict zones:

$$P^A_{rlp} = \frac{\sum_{k=1}^{o} t_k}{t_a} * \frac{t_{min}}{\bar{t}} * \frac{l_{min}}{\bar{l}} \tag{5}$$

where:
P^A_{rlp} - probability of a vehicle emerging/waiting at the minor approach [-],
t_k - k^{th} measurement interval where occupancy of a minor approach by a vehicle has been identified [seconds],
o - number of intervals occupied at a minor approach [-],
$\frac{l_{min}}{\bar{l}}$ - coefficient of irregularity of a queue at a minor approach, being the minimum queue length in observation period to average queue length ratio.

Calculation of traffic regulation parameters is only useful in practice in cases when a vehicle is present at the major and the minor approach at the same time, regardless of the configuration of conflicting streams (mutual self-regulation of vehicles at major approach has not been taken into consideration). Otherwise, traffic regulation is typically absent, or it is highly specific. For minor approach, and with no vehicles in the major stream, it is the traffic case regulated by the B20 sign. Whether or not a vehicle emerges at a minor approach simultaneously with another vehicle emerging at a major approach is not interdependent (save for certain cases), which is why local traffic regulation (RRL) occurs when:

$$RRL = P^A_{rln} * P^A_{rlp} \tag{6}$$

And analogically, the probability of global regulation equals:

$$RRG = P^s_{rn} * P^x_{rp} \tag{7}$$

Comparing respective probabilities using the research technique discussed in this article (i.e. presence detector) is intuitive and quick. It is the very fundamental advantage of the method in question. It suffices to sum up the relevant intervals connected with the fact that a vehicle has been detected in the relevant measurement cross-sections of major and minor approach, and to multiply them by the correction coefficients pre-established with reference to the intersection geometry measurement. Assuming that vehicle presence detectors dedicated to individual traffic streams have been installed at the intersection, one may collate tables of traffic regulation probability for all conflicting streams on a real-time basis. Table 1 summarises the global regulation probabilities calculated for the four structures analysed. It is easy to notice that none of the examined objects during the observation was excessively burdened with traffic. What can not be said about individual approach.

Table 1. Probability of global regulation.

Structure no.	Probability PSRN	Probability PxRP	Probability RRG	% of observation time
1	0.418	0.282	0.118	12
2	0.369	0.474	0.175	17
3	0.075	0.086	0.006	1
4	0.312	0.312	0.097	10

Note: structure no. 4 is characterised by identical probabilities for both traffic streams analysed, i.e. the major and the minor one.

In practice, it is the period of local analysis, understood as the time for which traffic regulation is measured for individual vehicles using a minor approach, that proves crucial from the perspective of synchronisation of traffic streams. The foregoing stems from the dynamics of changes in traffic characteristics observed in practice.

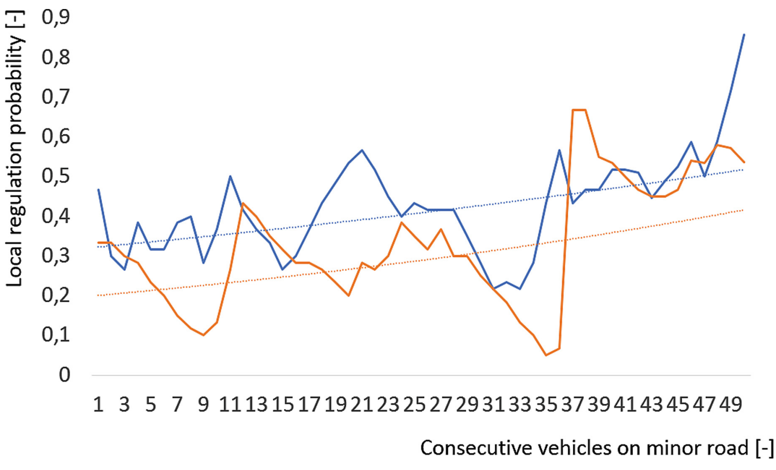


Fig. 7. Graphs of local regulation probability for the time of 60 s

During this period of time, one also determines the probability of the conflict zone being occupied by vehicles moving in major streams. Unlike the global traffic regulation analysis, local analyses should be conducted for very short time intervals. In accordance with the research results provided in the literature of the subject, most drivers representing typical populations make use of nearly all critical gap times within up to 20 s [1, 2]. A typical driver merges with traffic within a period of time ranging between 3 and 20 s (with a dominant less than 10 s). Therefore, according to the author, one should study the probability of local regulation in intervals of 10, 20, 30, 40 and 60 s. In the local regulation calculations, structure no. 1 was used as an example, and the regulation probability analysis interval was assumed to equal 60, 20 and 10 s. Figure 7 provides a graph of local regulation probability for all vehicles at structure no. 1, assuming an interval of 60 s (blue - probability of occupancy, orange - probability of direct access).

Interpretation of Fig. 7 may be such that the longer time of local analysis implies higher probability of occupancy of the intersection's collision zones versus the probability of having a direct opportunity to perform a manoeuvre (which results from the traffic structure). For the exponential model, the curves are almost parallel. This statement requires further research in order to generalize.

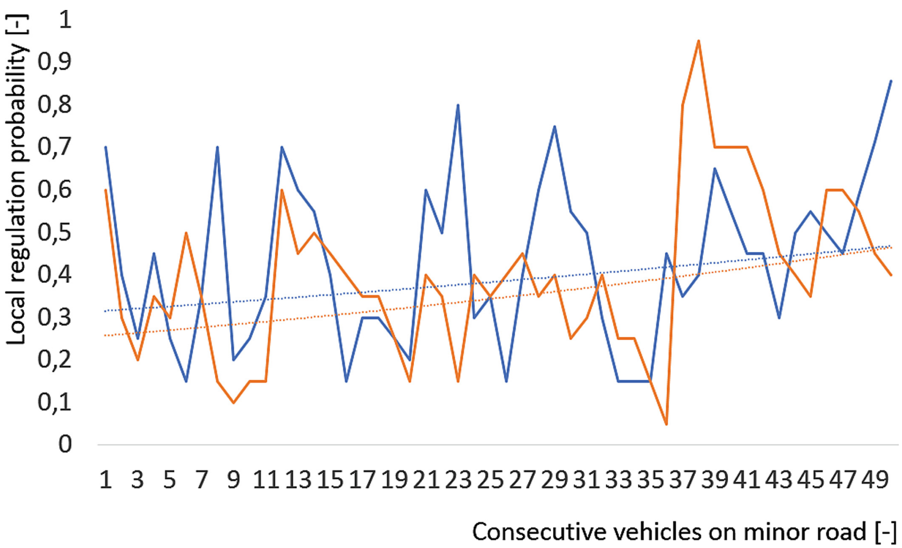


Fig. 8. Graphs of local regulation probability for the time of 20 s

For shorter periods of local analysis, the probabilities in question are becoming even on average, however, one can observe their considerable inhomogeneity in time. Both probabilities increase compared to Fig. 7 (exponential time intervals).

Figures 6, 7, 8 and 9 illustrate the fact that, for the traffic streams subject to analysis, one finds disadvantageous synchronisation in time to occur for all observation intervals (10, 20 and 60 s). What one can also observe is a nearly constant probability of blocking (blue polyline, Fig. 10). These cases (only 4 object) may obviously be specific. However, if the blue straight line (intervals: 20–60 s) in Fig. 10 descended more rapidly (negative slope), it would be possible that the probability of regulation should be reduced by changing the time intervals between vehicles in a horizon of up to 60 consecutive seconds (remark: very similar period to average signalisation cycle in Poland). The foregoing means that, on average, a delay is introduced for every vehicle running in the traffic stream at the minor approach before reaching the intersection (detection entries are spread over a period of 60 s), but it will consequently cause a quicker entry into the conflict zone. One can also analyse forced acceleration, but the legitimacy of such an approach is dubious at road junctions. The difference between a delay in the minor stream and the benefit resulting from passing the conflict zones more effectively requires further statistical research.

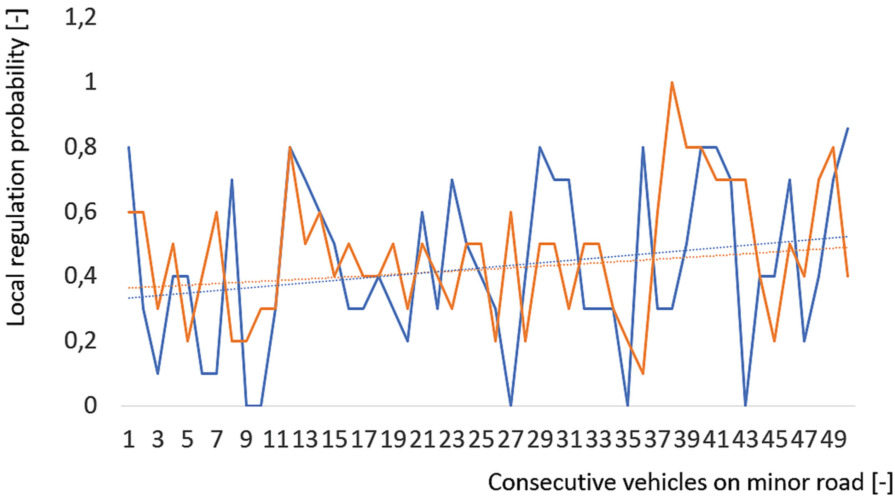


Fig. 9. Graphs of local regulation probability for the time of 10 s

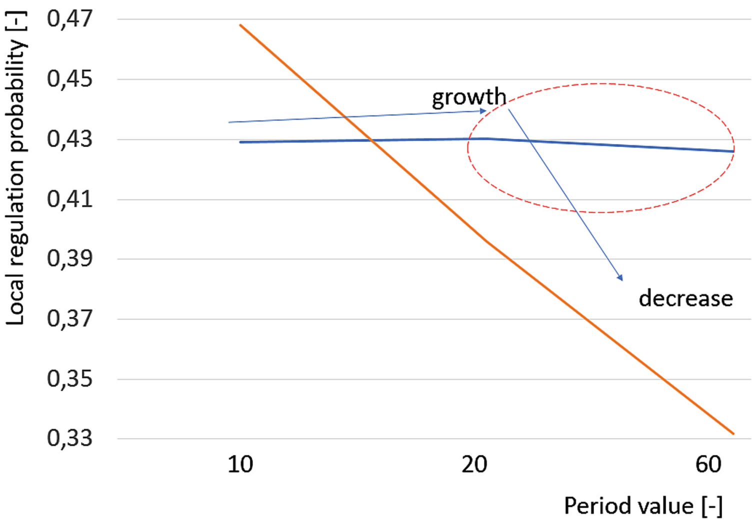


Fig. 10. Graphs of local regulation probability for a mean value of this parameter

Figure 10 clearly shows that the probability of forced regulation at the structure subject to analysis is nearly constant and independent of the analysis time (the differences are so small that they have been intentionally exposed by appropriate words), while the probability of direct access declines as the analysis time increases.

Hence the question about the conditions which the major and minor traffic streams must meet to increase the capacity. First and foremost, the probability of forced traffic regulation must be low. It is not appropriate to achieve this by reducing the major traffic stream, since traffic issues will merely be shifted to another intersection. It may, however, be accomplished by deliberately changing time intervals between vehicles, so that the headway suffice to enable the minor stream vehicles to merge with traffic. Another question is whether delaying the major stream vehicles makes any sense. It may prove reasonable provided that the analysis covers the entire network area instead of being limited to individual intersections. Therefore, from such a perspective, the distribution of headway in the major stream is optimised depending on the characteristics of detection entries at the minor approach, as given below:

$$minimum\, P^{A}_{rln} \leftarrow optimum\left\{t_f\left(q_p\right)\right\} \tag{8}$$

where:

t_{f} - set of headway in the major stream [seconds],

q_{p} - intensity of detection entries in the minor stream [-].

Relation (8) implies that minimisation of the probability of forced traffic regulation is attained for a known distribution of headway in the major stream, the latter being modified depending on the temporary intensity of detection entries at the minor approach. A converse procedure entails regulation of intensity of detection entries at the minor approach.

The V2V and V2I technologies provide adequate tools to regulate headway in the major and/or the intensity of detection entries in the minor stream. These technologies make it possible to communicate the need to adapt the traffic speed to enable merging with traffic at the subsequent road junction (desirable speed). In the case of automated traffic, such procedures may be used to directly regulate vehicle driving speed in both streams. Synchronisation of traffic streams may also pertain to their internal structure, without taking the parameters of collision streams into consideration. From such a perspective, the V2V and V2I technologies allow for the average traffic stream speed to be regulated by regulating the speed of individual vehicles. It should be noted that, irrespective of the conditions required to adapt vehicles to the V2V communication, the traffic regulation capability will also depend on other technical factors, including the road infrastructure condition. The road pavement condition, route path and type of product (type of vehicle) may prevent regulation of the traffic stream speed in broad ranges of values [15–20]. On the one hand, the poor condition of roads and so slow down the flow of traffic. On the other hand, it makes it impossible to make wider changes to its parameters. Nevertheless, examining the condition of the road surface is helpful to implement this method. Changes in the parameters of the traffic flows must take into account the condition of the road surface.

6 Conclusions

The article describes the method of studying and parameterisation of road traffic streams using a tool of the author's own design which enables simple and quick estimation of approximate values of probability of traffic regulation at non-signal-controlled intersections. The traffic regulation probability is estimated by totting binary values describing the chosen pairs of major and minor traffic streams or their sets. Based on the estimated values of the probabilities in question, they can be minimised by optimising the distribution of headway in the major stream and the intensity of detection entries in the minor stream.

The traffic synchronisation technique proposed by the author requires validation, for instance by visual means, in order to determine the relationship between the estimated regulation probability and the actual time of occupancy of the conflict zones. Such studies should also comprise atypical geometric parameters of minor approach. This, as stated, requires further research in a larger statistical material (not only 4 object). Both the major and the minor traffic stream can be synchronised by means of adequate communication messages transferred via the V2V and V2I channels. In the case of traditional traffic (without autonomous vehicles), one will observe delay difficult to estimate, emerging on account of the manual process of speed regulation in the major and minor streams. Synchronisation of traffic streams will become feasible, and with increasing efficiency, as the share of autonomous vehicles in traffic grows (in the perspective of 2050).

With regard to the foregoing research, a dedicated method has been developed and presented in this paper, one which enables analysis of the possibility introduction of synchronisation process in traffic stream in vast areas of the road network by means of predefined measures (presence detectors operating on binary values). The traditionally applied reductionistic description of road traffic processes (measurement with classical counters e.g. loops) has been replaced in this method with a near quasi continuous examinations (cheap and small detectors). The devices used in the field tests can be minimised. Even to the size of the cat's eye (row size in relation to the loop). It is more suitable for contemporary road networks where the dynamics of traffic has been growing systematically. The vehicle queues observed in contemporary road networks often cross administrative borders of municipalities within which traffic is organised. Hence the legitimacy of the author holistic approach [11].

Another interesting issue is to take into account the homogeneity of the travel behaviour in traffic network space. Tools such as travel planners make it possible to predict the load on the cross-sections of the road network. They allow, to a certain extent, the parameterization of the corresponding probabilities [12, 14, 16].

Of course there are cases in which this method can not be used. This applies, for example, to the passage of columns of emergency vehicles, governments column, transportation of unexploded ordnance, explosives and hazardous substances [18]. In these cases, synchronization is debatable. Nevertheless, the network occupancy of such vehicles is negligible with some exclusions (capital city area).

References

1. Daganzo, C.F.: Fundamentals of Transportation and Traffic Operations. Emerald Group Publishing Limited, Bingley (1997)
2. Chodur, J.: Funkcjonowanie skrzyżowań drogowych w warunkach zmienności ruchu. Monografia 347. Wydawnictwo Politechniki Krakowskiej, Kraków (2007)
3. Drew, D.R.: Traffic Flow Theory and Control. McGraw Hill, New York (1968)
4. Haight, F.A.: Mathematical Theories of Traffic Flow. Academic Press, Cambridge (1969)
5. Molugaram, K., Rao, G.S.: Statistical Techniques for Transportation Engineering. Elsevier, Rio de Janeiro (2017)
6. Karoń, G., Żochowska, R.: Modelling of expected traffic smoothness in urban transportation systems for ITS solutions. Arch. Transp. **33**(1), 33–45 (2015)
7. Jacyna, M.: Multicriteria evaluation of traffic flow distribution in a multimodal transport corridor, taking into account logistics base service. Arch. Transp. **11**(3–4), 43–66 (1999)
8. Macioszek, E., Lach, D.: Analysis of the results of general traffic measurements in the West Pomeranian Voivodeship from 2005 to 2015. Sci. J. Sil. Univ. Technol. Ser. Transp. **97**, 93–104 (2017)
9. Macioszek, E., Lach, D.: Analysis of traffic conditions at the Brzezinska and Nowochrzanowska intersection in Myslowice (Silesian Province, Poland). Sci. J. Sil. Univ. Technol. Ser. Transp. **98**, 81–88 (2018)
10. Macioszek, E., Lach, D.: Comparative analysis of the results of general traffic measurements for the Silesian Voivodeship and Poland. Sci. J. Sil. Univ. Technol. Ser. Transp. **100**, 105–113 (2018)
11. Celiński, I.: Evaluation method of impact between road traffic in a traffic control area and in its surroundings. Ph.D. dissertation, Oficyna Wydawnicza Politechniki Warszawskiej, Warsaw (2018)
12. Sierpiński, G.: Distance and frequency of travels made with selected means of transport - a case study for the Upper Silesian conurbation (Poland). In: Sierpiński, G. (ed.) Intelligent Transport Systems and Travel Behaviour. AISC, vol. 505, pp. 75–85. Springer, Cham (2017)
13. Celiński, I., Sierpiński, G.: Availability of data regarding traffic safety and existing infrastructure as a support for optimization of the emergency system. Traffic Eng. **1**, 36–40 (2018)
14. Sierpiński, G.: Technologically advanced and responsible travel planning assisted by GT Planner. In: Macioszek, E., Sierpiński, G. (eds.) Contemporary Challenges of Transport Systems and Traffic Engineering. LNNS, vol. 2, pp. 65–77. Springer, Cham (2017)
15. Staniek, M., Czech, P.: Self-correcting neural network in road pavement diagnostics. Autom. Constr. **96**, 75–87 (2018)
16. Sierpiński, G., Staniek, M.: Education by access to visual information - methodology of moulding behaviour based on international research project experiences. In: 9th International Conference of Education Research and Innovation (ICERI 2016). IATED, Seville, pp. 6724–6729 (2016)
17. Staniek, M.: Detection of cracks in asphalt pavement during road inspection processes. Sci. J. Sil. Univ. Technol. Ser. Transp. **96**, 175–184 (2017)
18. Burdzik, R., Celiński, I., Czech, P.: Optimization of transportation of unexploded ordnance, explosives and hazardous substances - vibration issues. Vibroengineering Procedia **10**, 382–386 (2016)

19. Macioszek, E.: The Influence of Motorcycling and Cycling on Small One-Lane Roundabouts Capacity. In: Mikulski, J. (ed.) Transport Systems Telematics. CCIS, vol. 239, pp. 291–298. Springer-Verlag, Heidelberg (2011)
20. Staniek, M.: Moulding of Travelling Behaviour Patterns Entailing the Condition of Road Infrastructure. In: Macioszek, E., Sierpiński, G. (eds.) Contemporary Challenges of Transport Systems and Traffic Engineering. LNNS, vol. 2, pp. 181–191. Springer, Cham (2017)

Modern Types of Intersections to Improve Traffic Safety

Driver Behavior Analysis at Roundabout Considering Geometry Impact by Applying Driving Simulation

Nan Kang[1(✉)], Yahiro Fujii[1], Tadashi Kawaguchi[2], Kentaro Kirito[2], Susumu Okuda[2], and Shintaro Terabe[1]

[1] Faculty of Science and Technology, Tokyo University of Science, Noda, Japan
kangnan@rs.tus.ac.jp, terabe@rs.noda.tus.ac.jp
[2] TOKEN C.E.E. Consultants Co. Ltd., Nagoya, Japan
{kawaguchi-t, kirito-k, okuda-s}@tokencon.co.jp

Abstract. In recent years, the installation of roundabout (RAB) has been promoted in Japan since roundabouts can be operated safely and at the time of disaster. However, due to the limited cases, the impacts of geometry under Japanese situation have not been totally understood and certificated. Thus, in this analysis, five roundabouts which have different geometric structures were created for examining the impacts through conducting experiments using a driving simulator (DS). It was confirmed that the influence of the entry radius was strong, and the larger the entry radius, the faster the entry speed and the farther the driving position from the RAB center. Moreover, from this study, it is possible to confirm the effectiveness of using DS for examining the geometric impacts. The application of DS experiments under more conditions is expected in future.

Keywords: Roundabout · Geometry · Driver behavior · Driving simulation

1 Introduction

With the revision of the Road Traffic Law in 2014, roundabout has been officially identified in Japan and the installation has been promoted. Vehicle behavior at roundabout is largely dependent on geometry. However, in Japan, due to some unique circumstances such as left-handed traffic and limited space, it is impossible to totally follow and apply overseas experience. The following matters are shown in the Roundabout Manual [1] as the relationship between the geometric structure and the vehicle behavior at roundabout:

- the speed may increase under the geometry structure of the entry and exit radius, and outer diameter which steering wheel is only by one operation from enter to exit,
- as the relation between the outer diameter and the central island diameter, when the central island is small, the speed of straight vehicles becomes high,
- the impact of outer diameter, entry/exit radius, circulating road width and central island diameter are closely related and they cannot be designed separately.

E. Macioszek et al. (Eds.): TSTP 2019, LNITI, pp. 103–114, 2020.
https://doi.org/10.1007/978-3-030-39109-6_8

Moreover, in the report of International Association of Traffic and Safety Sciences (Studies on social implementation and promotion of roundabouts) [2], the central island diameter was verified by social experiments to show that the traveling speed tended to increase with inappropriate central island diameter.

However, due to the various road and experiment conditions, it is difficult to summarize the impact of each geometry element separately. Therefore, in this research, a relatively inexpensive and easy way-driving simulator (hereafter DS) for conducting experiment is applied to identify the impact of geometry independently. Through drawing several roundabouts with different geometry structures in DS, the impact of entry radius and center island diameter are expected to be elucidated.

2 Literature Review

Impact of Geometry at Roundabouts

Roundabout Manual of Japan [1] has been published in 2016. The manual describes the basic concepts of planning, design, and operation that are necessary for actively installing roundabout in Japan, and summarizes the technical basic matters related to design. The manual covers the definitions and types of roundabouts, application conditions, geometric design, traffic operations using road signs, etc. In this study, these indicators are used as a reference. However, due to few installation experiences, there are some geometric structures such as entry radius and central island diameter that are not clearly described. Therefore, in this research, experiments were conducted focusing on the entry radius and central island diameter.

The reports of International Association of Traffic and Safety Sciences (Research on practical development of safe and eco-roundabout I–IV, Studies on social implementation and promotion of roundabouts I–III) [2–8] recorded social experiments of Japan from 2009 to 2014. In each case, the history of achieving roundabout, points taken into consideration when converting to roundabout in social experiments, achievements, considerations, and points improved by implementation are summarized. However, in the social experiment, since the roadside environment in the surrounding area also affects the vehicle behavior, it is difficult to obtain the pure influence of the geometrical structure. For this reason, in this study, driving simulator is used to conduct an experiment with a constant roadside environment.

Kobayashi et al. [9] compared and summarized design concepts based on technical standards in foreign countries with the aim of accumulating roundabout knowledge. In addition, trial design based on the design vehicle and driving method of Japan and driving experiment using the actual vehicle were performed. Through these experiments, standard values of outer diameter, central island diameter and circulating road width which are the most basic elements of the geometric structure were discussed. However, in large-scale driving experiments using actual vehicles, due to the high cost and long time, types of geometric structures which can be examined are limited. Thus, other geometric structures which have not been examined should also be considered.

Yoshioka et al. [10] tested the traveling speed at regular roundabout. The speed in the circulating road was approximately 20 km/h, and after passing by the central island, the speed was increased until exiting roundabout. Moreover, the entry speed showed large variation in the analysis. In addition, there was a correlation between the travelling position passing through central island and the radius of curvature of the traveling path, and as a result, impact on the speed in circulating road was confirmed. Based on this analysis, the necessity of focusing on entry speed is defined.

Driving Simulator (DS)

Oshima et al. [11] summarized the application needs and issues of DS through interviews with relevant organizations and literature survey. In particular, since DS has the utility value "scenarios that can only be evaluated in DS", the reproducibility, weather, etc. that are difficult to set in actual experiment or repeat under the same conditions can be easily controlled in DS. In addition, it is also useful in technical evaluation for dangerous events that can not be tested on actual vehicles. There are three problems that DS have, "standardization of evaluation method", "real environment reproducibility of simulator and simulator sickness", and "load on scenario creation and customization". The study will be conducted under paying attention to these issues.

The Relationship Between Travelling Speed and Safety Performance

As recorded in WHO [12] speed management: A road safety manual for decision-makers and practitioners, cars and pedestrian fatality rates is significantly influenced by speed. According to the results, the fatality rate becomes 80% or more when the car collides with the pedestrian at the speed of 50 km/h or more. On the other hand, the fatality rate is reduced to 10% or less than this value when the vehicle speed is lower than 30 km/h. By this, speed is considered as the safety index in this study.

3 Methodology

Hypothesized Geometric Layout

The basic geometry layout which is hypothesized in this study is shown in Fig. 1.

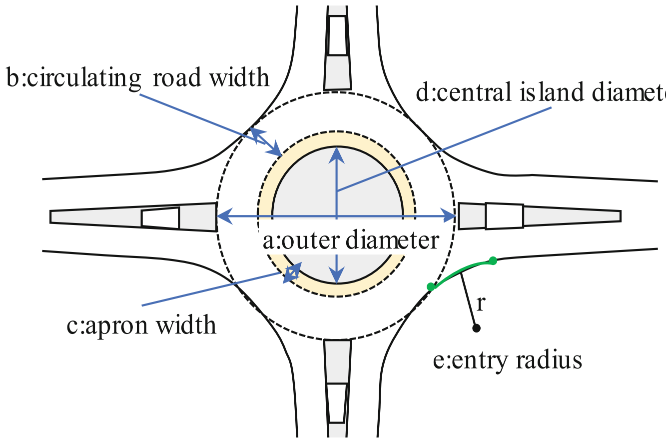


Fig. 1. Roundabout geometry

It is a regular four-leg roundabout with physical separate island and apron around central island. The value of geometry elements such outer diameter are shown in Table 1.

Table 1. The value of geometry [m].

RAB geometry	a	b	c	d	e
Standard	27.00	5.00	1.50	12.00	8.75
Large entry radius (L-ER)			1.50	12.00	15.00
Small entry radius (S-ER)			1.50	12.00	4.00
Large central island diameter (L-CID)			2.50	10.00	8.75
Small central island diameter (L-CID)			0.50	14.00	8.75

For all examined cases, the outer diameter values are assumed to be 27 m based on discription of Roundabout Manual of Japan [1]. The circulatory road width is fixed to be 5 m. Based on previous analysis [2, 3], it is roungly known that entry radius and central island diameter have significant impact on driving behavior at roundabout, but it is not clearly recorded in Roundabout Manul of Japan [1]. Thus, these two geometry elements are selected as examined factros.

Driving Simulator (DS)

Figure 2 shows the DS used in this experiment. It is operated based on FORUM 8 "Compact Research Simulator" system and supported by "TOKEN C.E.E. Consultants Co. Ltd". The DS is characterized by no motion (inclination of the vehicle is not reproduced, etc.), three LCD monitors, and the seat and steering wheel are made similar to those of actual vehicle. The application sof winkers, accelerator pedals, brake pedals, side brakes, shifts lever are reproduced. The operation system of this driving simulator is "UC-win/Road Drive Simulator" which manufactured by FORUM 8.

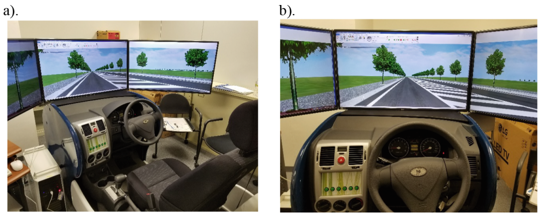


Fig. 2. Applied DS in this experiment

Subject of Experiment

20 subjects who are staff of TOKEN C.E.E. Consultants Co. Ltd participate in this experimet. Figure 3 shows the age, gender ratio and driving frequency of 20 subjects.

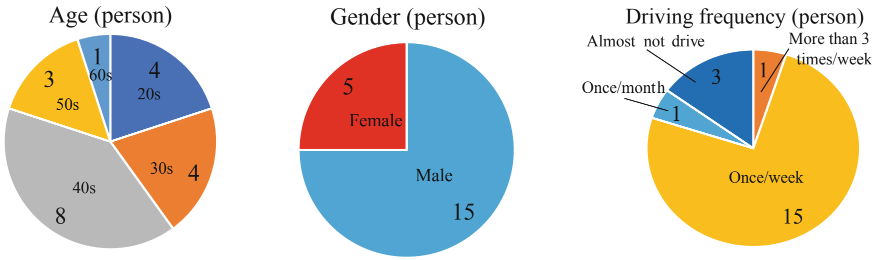


Fig. 3. Information of subjects

According to the graph, the majority is around 40 s, and the male/female ratio was 15:5. About driving frequency, many people were driving about once a week. Also, according to the questionnaire, out of the 20 subjects, 10 had experience of driving at roundabout.

Driving Course

Figure 4 shows one example of driving courses in formal experiment. Five hypothesized roundabouts are located at flat space as a straight line and the space between adjacent two roundabouts is equally set to be 200 m. Instruction "going straight" is given before subject entering roundabout. Five roundabout connection patterns are prepared, and they are randomly assigned to subjects. In order to purely examine the impact of geometry, subject vehicle is assumed to passenger car and set to be free-flow vehicle during driving. Trees are planted at regular intervals to give a sense of speed. Experiment screen is shown in Fig. 5.

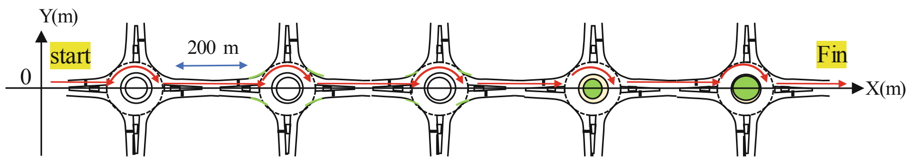


Fig. 4. Experiment course

Sequence of Experiment

The sequence of experiment are explained to subjects before formal experiment, but the intention of experiment and difference of roundabouts are not explained to subjects. At the beginning of formal experiment, there is 5-min test driving. Then, formal driving experiment are conducted as "first driving-rest-second driving".

In the end after all driving, all subjects are requested to answer questionnaire about this experiment. In the questionnaire, in addition to basic information such as age, driving frequency, roundabout driving experience, in this experiment, subjects are also requested to answer the question "Did you feel any difference in the structure of roundabout during driving?".

Fig. 5. Screen shot of experiment

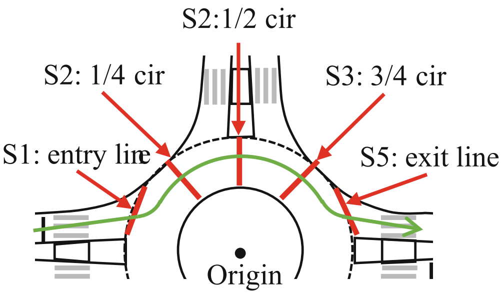


Fig. 6. Definition of section (cir: circulating road)

4 Results and Discussion

4.1 Reliability of Driving Simulator

In order to classify the difference of driving behavior between in DS and in real world, travelling speed at standard geometry is compared at first. In DS, the layout of standard geometry is shown in Table 1, and in real world, roundabout located in Yaizu City, Shizuoka Profecture (outer diameter: 27 m, circulating road width: 5 m, apron width: 2 m, central island diameter: 11 m) is selected. Five sectors from entry to exit which are shown in Fig. 6 are identified for comparing travelling speed. The result is shown in Fig. 7. Subjects of DS and real roundabout are from two different groups. T-test is conducted at each sector and it is found that 5% significant difference obtained expect central sector S3. The difference is considered that the results of Yaizu roundabout were observed by citizens who are familiar with travelling roundabout that would pass by higher speed, especially at the moment entering and exiting roundabout. The biggest difference of speed is 5 km/h at entry line and exit line which is reasonable and acceptable, thus, it is certified that DS can reasonably reproduce driver behavior.

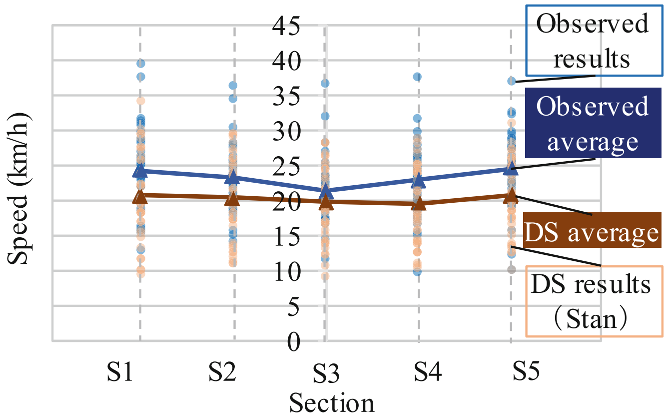


Fig. 7. Speed comparison of standard roundabout and field site

4.2 Impact of Geometry on Speed and Trajectory

Speed Comparison

Figure 8 shows the results of sector travelling speed of five hypothesized roundabouts. With regard to the entry radius, traveling speed shows higher value under the geometry of large entry radius comparing to other cases from entering to exiting. In addition, T-tests are performed on “large entry radiuss” and “small entry radius” at each sector. At the sector S1 (entry line), the results show 5% significant difference. It is because the larger the corner radius, the easier it is to bend and the higher the speed tends to be.

On the other hand, a large difference is not obtained for the central island diameter. A T test is performed on the “large central island diameters” and the “small central island diameter”, and a 5% significant difference is not obtained for all cross sections. This may be caused by fixing the circulating road width in this experiment. Although the central island diameter is changed, apron width is also changed depending on the central island diameter for fixing circulating road width. Due to this, it is supposed that circulating road width has greater impact on travelling speed that central island diameter. On the other hand, the step of apron could not be made in DS, thus, although apron width shows significant difference in screen, it could not influence driver behavior as real world.

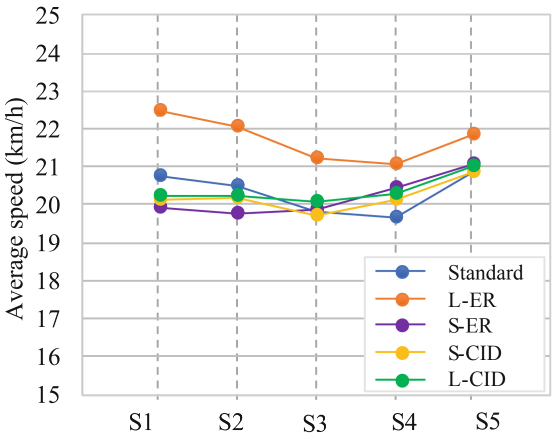


Fig. 8. Speed comparison of five roundabouts

Comparison of Trajectory

In order to compare vehicle trajectory, Y coordinates in each section are collected and the results of five roundabouts are shown in Fig. 9. The origin 0 of the Y coordinate is defined at the center of roundabout's central island, as shown in Fig. 6.

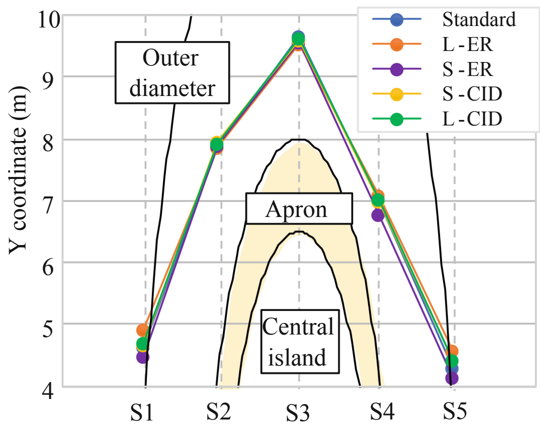


Fig. 9. Comparison of trajectory of five roundabouts

As a result of the entry radius, based on the result of T test on "large entry radius" and "small entry radius", a 5% significant difference of two conditions was obtained on entry section S1 and the exit section S5. It is a reasonable result since entry radius have impact on entry speed, further influencing trajectory at entry corner. Thus, the impact of entry radius on travel trajectory is identified. Moreover, since difference of driving behavior by DS under three patterns of entry radius have been performed, DS can be applied as an effect way in understanding influence of roundabout geometry.

On the other hand, the difference of Y coordinates on "central island diameter" cannot be found at any section. Like the reason of speed, although central island diameter has been changed, circulating road width is fixed through adjusting apron width. And under the suppose that circulating road width has greater impact than central island diameter, trajectory may not significantly change when fixing circulating road width.

4.3 Entry Radius and Entry Design

Based on the results shown above, it is suggested that the entry radius have strong impact at entry. Thus, several analyses are conducted to show more details.

The steering wheel operation data between the section 12 m in front of entry line and the section 2 m after exit line is collected and the results are shown in Fig. 10. The "large entry radius" case starts to operate the steering wheel relatively early. The reason is considered that the larger the entry radius, the wider the cornering range. based on the T-test result, it is found that at the position 1.5 m in front of entry line, T-test shows 5% significant difference. Moreover, it is suggested that in the case of "large entry radius", the overall amount of steering wheel operation is smaller, and it tends to entry more easily and smoothly than the case of "small entry radius". This result can response to the questionnaire opinions like "there was roundabout easy to drive and roundabout hard to drive" and "there was difference in the easiness of driving though it was not visually understood". Thus, the impact of entry radius is also confirmed by drivers' feeling. However, as it was confirmed in the speed comparison, the speed tends to increase as the entry radius increases, and it should be pay attention that if the ease of driving increases, further increasing the entry speed and this kind of design will lose safety performance of roundabout. Therefore, the entry radius considering the ease of driving and safety performance is required in future discussion.

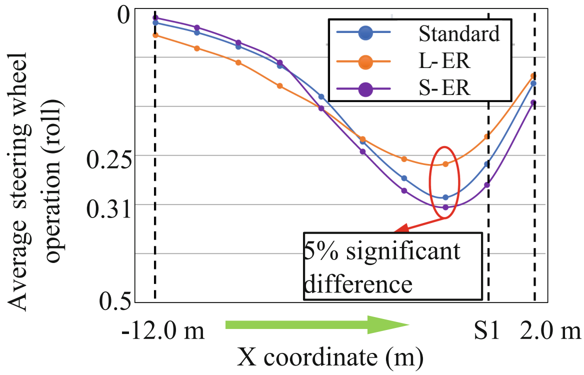


Fig. 10. The result of steering wheel operation at entry

The relationship between the entry radius and the entry speed and entry position (distance between center of roundabout and the position of left-front wheel of vehicle when passing the entry line) is shown in Fig. 11a and b, respectively. As the entry radius increases, the entry speed increases, and the entry position is farther from the roundabout center. Moreover, a correlation tendency is suggested due to the results. However, since there are only three patterns which were examined in this experiment, further DS experiments are required.

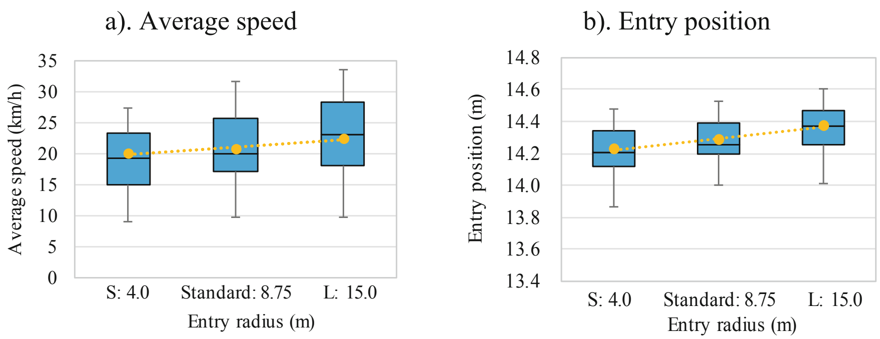


Fig. 11. The correlation tendency of entry radius and speed/entry position

5 Conclusions and Future Work

In the world, roundabouts are very popular type of intersections [13–16]. In this study, a driving experiment for examining impact of roundabout geometry was performed though applying driving simulator. Entry radius and central island diameter were selected as the examined factors. The impacts of these two factors were examined through analyzing speed, trajectory and steering wheel operation. Also, from this experiment, the applicability and reliability of DS was also examined. From this study, it can be concluded that:

- DS showed lower speed performance (2–3 km/h) than real observation. While, since considering the slight difference of geometry and characteristics of subjects, it is recognized that DS can provide quite reasonable performance for examining driver behavior. The application of DS in future is expected,
- the influence of the entry radius was confirmed at entry and exit. Especially around entry line, the larger the entry radius, the higher the entry speed and farther passing position from roundabout center. In addition, the amount of steering wheel operation decreases as the entry radius increasing, further causing driving at entry easier and much more smooth. On the other hand, since this easy driving may decrease the safety performance of roundabout, engineers should pay more attention on entry area design at roundabouts,
- the influence of the central island diameter could not be confirmed from this experiment. It was supposed that circulating road width provide greater impact on driving behavior than center island diameter, especially when vehicle driving in circulating road.

For future work, experiments under more roundabout geometry structures are desired. In particular, the correlation tendency of entry radius and speed or trajectory is expected to be clarified by increasing patterns of entry radius.

Acknowledgements. This work was supported by JSPS KAKENHI Grant-in-Aid for Young Scientists (B), Grant Number 17K14743.

We really appreciated the support of TOKEN C.E.E. Consultants Co. Ltd., Nagoya Branch for providing the driving simulator and we also would like to sent our full thanks to Tadashi Kawaguchi, Kentaro Kirito and Susumu Okuda who gave great help to this experiment, and all subjects who participated this experiment.

References

1. Japan Society of Traffic Engineers: Roundabout Manual of Japan. Japan Society of Traffic Engineers, Tokyo (2016)
2. International Association of Traffic and Safety Sciences: Research on practical development of safe and eco-roundabout I. International Association of Traffic and Safety Sciences, Tokyo (2009)
3. International Association of Traffic and Safety Sciences: Research on practical development of safe and eco-roundabout II. International Association of Traffic and Safety Sciences, Tokyo (2010)
4. International Association of Traffic and Safety Sciences: Research on practical development of safe and eco-roundabout III. International Association of Traffic and Safety Sciences, Tokyo (2011)
5. International Association of Traffic and Safety Sciences: Research on practical development of safe and eco-roundabout IV. International Association of Traffic and Safety Sciences, Tokyo (2012)
6. International Association of Traffic and Safety Sciences: Studies on social implementation and promotion of roundabouts I. International Association of Traffic and Safety Sciences, Tokyo (2012)
7. International Association of Traffic and Safety Sciences: Studies on social implementation and promotion of roundabouts II. International Association of Traffic and Safety Sciences, Tokyo (2013)
8. International Association of Traffic and Safety Sciences: Studies on social implementation and promotion of roundabouts III. International Association of Traffic and Safety Sciences, Tokyo (2014)
9. Kobayashi, H., Takamiya, S., Yoshioka, K., Yoneyama, Y.: Fundamental research toward the formulation of geometric design standards for roundabouts. Int. Assoc. Traffic Saf. Sci. Rev. **39**(1), 37–46 (2014)
10. Yoshioka, K., Nakamura, H., Shimokawa, S., Morita, H.: An analysis on impact of roundabout geometric elements on driving behavior. JSTE J. Traffic Eng. **4**(1), 47–54 (2018)
11. Oshima, D., Yamada, K., Takenouchi, A., Yamashita, H., Nakamo, K., Suzuki, T., Ono, S., Hirasawa, T., Hong, S., Sugimachi, T., Zheng, R., Suda, Y., Oguchi, T., Horiguchi, R., Shiraishi, T.: A study on needs and advanced technologies for a driving simulator. J. Seisankenkyu **67**(2), 87–92 (2015)
12. World Health Organization: Speed management: a road safety manual for decision-makers and practitioners. World Health Organization, Geneva (2008)

13. Macioszek, E.: Analysis of significance of differences between psychotechnical parameters for drivers at the entries to one-lane and turbo roundabouts in Poland. In: Sierpiński, G. (ed.) Intelligent Transport Systems and Travel Behaviour. AISC, vol. 505, pp. 149–161. Springer, Cham (2017)
14. Macioszek, E.: The comparison of models for critical headways estimation at roundabouts. In: Macioszek, E., Sierpiński, G. (eds.) Contemporary Challenges of Transport Systems and Traffic Engineering. LNNS, vol. 2, pp. 205–219. Springer, Cham (2017)
15. Macioszek, E.: The application of HCM 2010 in the determination of capacity of traffic lanes at turbo roundabout entries. Transp. Probl. **11**(3), 77–89 (2016)
16. Macioszek, E.: Geometrical determinants of car equivalents for heavy vehicles crossing circular intersections. In: Mikulski, J. (ed.) Transport Systems Telematics. CCIS, vol. 329, pp. 221–228. Springer, Heidelberg (2012)

Evaluation of Changes in Drivers Behaviour Due to Introduction of Countdown Timers at Signalized Intersections Using UAV Data

Wieslaw Pamula(✉) and Marcin Jacek Klos

Faculty of Transport, Silesian University of Technology, Katowice, Poland
{wieslaw.pamula,marcin.j.klos}@polsl.pl

Abstract. The introduction of countdown timers at signalized intersections changes the perception of traffic control signals by drivers. Devices can have negative impact on safety, manifested by an increased number of dangerous behaviour events such as early starts during red signals and rear end collisions. On the other hand countdown timers can affect the traffic conditions at intersections, as drivers receive advance information on the changes of traffic lights. This information favours drivers earlier starts and lower time losses for intersection entries. The problem is analysed using video data collected at intersections using UAVs. Intersections with varying traffic conditions are chosen as test sites. Traffic is observed at whole intersections including approaches with queues of up to several vehicles. Measures of drivers behaviour changes such as: start time and intersection travel through speed related to the intersection traffic conditions are discussed.

Keywords: Countdown timer · Driver behaviour · Signalized intersections · Traffic parameters

1 Introduction

The scope of the information perceived by the driver, in the course of driving a vehicle, highly affects his behaviour. A smooth and explicit drive is an important factor determining the safety and influencing traffic conditions in road traffic networks. Road signs, traffic lights signals constitute the basic information sources, these are supplemented by a plethora of other sources among them: variable message signs, traffic information broadcasts, countdown timers. Countdown timers are devices tightly coupled with traffic light signals in the sense that the presented information is derived from data provided by road traffic lights controllers.

Countdown timers (CTs) are regarded as supporting devices at signalized intersections. CTs display elapsing time values indicating moments of traffic lights changes. The current CT constructions are not fully integrated with the functioning of traffic controllers [1]. The countdown procedures are triggered by signals from the traffic controllers but it is not possible to dynamically change the initial time values presented by the counters. Traffic controllers implementing fixed time control traffic plans can be supplemented with CTs.

E. Macioszek et al. (Eds.): TSTP 2019, LNITI, pp. 115–124, 2020.
https://doi.org/10.1007/978-3-030-39109-6_9

The introduction of countdown timers at signalized intersections changes the perception of traffic control signals by drivers [2]. Drivers receive information on the operation of the traffic lights controller at the intersection. Depending on the drivers nature this can be a source of stress or motivation to act when the lights change. Nervous drivers may initiate dangerous behaviours such as intersections entries at red signals or rear end collisions. Motivated drivers can increase the efficiency of the intersection by diminishing start times thus allowing a larger number of vehicles to pass through the intersection during green times.

The impact of CT on drivers behaviour is not only the outcome of drivers nature but is also determined by the circumstances of travelling. Traffic conditions and the operation of traffic controllers play a significant role in defining the factors describing the CT impact.

The aim of the study is to determine and analyse the factors affecting the drivers behaviour when CTs are introduced. The results can be used to justify the introduction of CTs at newly designed intersections or in order to enhance the performance of existing ones. Manual collection of drivers behaviour data is laborious and may not be accurate so automatic collection is preferred. Video data is chosen as the basic source of data. This can be analysed off-line and provide the most comprehensive set of description parameters of drivers behaviour. Traffic is observed at whole intersections including approaches with queues of up to several vehicles. UAVs equipped with high resolution cameras are used to collect traffic data.

The paper is organized as follows: Sect. 2 discusses the current results of studies in the field of CTs effects and places the proposed approach in this field. Section 3 presents the method of data processing for determining the significance of factors affecting the drivers behaviour. Three factors are chosen: start time, intersection travel through speed, intersection traffic conditions. This is followed by Sect. 4, which discusses the results of the analysis of the impact of the CTs on drivers behaviour. Section 5 of the paper contains conclusions and propositions for future work.

2 Related Works

The perception of traffic control signals supported by CTs affects three main driving decisions that is:

- to stop when the green light signal ends,
- to continue driving when the green signal ends and pass the intersection,
- to pass the stop line at the beginning of the red light signal.

The consequences of these decisions may contribute to the reduction of the intersection safety and bring about changes in traffic conditions at the intersection [3]. Overall important are also consecutive decisions made by drivers in vehicle queues at the intersection approaches.

The authors of the study presented in [4] give an analysis of the impact of the CT on the behaviour of the drivers in a queue of vehicles. The results of the study indicate that CTs improve the ability of the drivers to decide whether to stop or to enter the intersection. The number of hesitant decisions is reduced when CTs are introduced.

The influence of the countdown timers on intersection safety is discussed in the study [5]. Results show that CTs reduce the total number of vehicles drivers, who drive through stop lines at the beginning of the red light signal. Countdown timers impact on safety is larger in the case of non-urban traffic intersections [6, 7], especially red light violations are reduced [8, 9].

Countdown timers, which show green light elapsed time improve the safety at the intersections with low traffic flow. The use of the CTs information speeds up the decisions to enter the intersection and halt safely, before the end of the green signal, at the stop line [10].

Reported studies discuss the effects of countdown timers application for the following traffic parameters [11]:

- intersection capacity,
- queue discharge rate,
- intersection approach speed.

A wide range of traffic intersections with variable traffic conditions is examined. Some authors carry out experiments using driving simulators for establishing strictly controlled test environments. Authors focus on the way CT change the behaviour of drivers and in consequence affect the functioning of intersections.

Intersection capacity is determined by the readiness of drivers to shorten distances between vehicles when travelling through the intersection [12]. The count value of green signal CT encourages the driver to reduce his distance to the preceding vehicle to increase the chance of passing through the intersection. Red signal CT causes the reduction of start-up lost time by 33% and this contributes to the increase in intersection capacity. The evaluation of intersection capacity is closely related to the way vehicle queues at the intersection are discharged.

Queue discharge rate is important for managing traffic congestion and so draws more attention. Liu et al. [13] notes headway compressions, which means increasing discharge rates, at the end of discharge of queues when CT are functioning. Only a small change in saturation headways is attributed to CT. A study of effects of green signal CT [14] shows that discharges have unstable saturation flow, increased start-up lost time and reduced clearance lost time. The conventional intersection capacity estimation methods require a modification to account for such characteristics of the queue discharge process. Red signal CT reduces the saturation headway by 5% is reported in [15] which leads to an increase of the intersection capacity. The studied traffic database consisted of several thousand measurements done on tens of intersections. The biggest of the impact of CT is noted in response time to changing signal by the first and second vehicle waiting in the queue [4, 16, 17].

Devalla et al. report [18] that green signal CT encourage higher approach speeds during the lights transition phase. This improves the efficiency of the intersection but may lead to accidents. Authors in [19] confirm this result indicating a 24% increase of the number of early starts before the lights change. No evaluation was done on the impact of changing traffic conditions on the rate of change of the approach speed.

The reports do not attempt to analyse the changes of CT effects dependent on traffic conditions although careful examination of the results may indicate some change trends. For instance the plots of discharge rates [14] have a large number of outliers, their origin is not explained. Separate analysis of these could suggest some relations with the values of traffic flow.

3 Collection of Traffic Data

The aim of the study is to derive the relation of changes, in the drivers behaviour due to introduction of CTs, to traffic conditions Two factors are chosen which describe the drivers behaviour that is: start time and intersection travel through speed. These factors directly indicate the way in which CTs affect driving characteristics and intersection capacity. The task is to collect start times and intersection travel through speeds of vehicles in different traffic conditions. Three measurement sites are chosen, which differ in the volume of traffic, for tests.

Manual registration of traffic data is laborious and requires, in this case, a large number of observers. Video recording highly reduces the collection effort but requires several camera sites to survey the whole intersection when it is done on the ground. To save on cameras a UAV equipped with one high resolution camera is used. Previous measurement experience and examples referenced in literature for instance in [20] indicate that this approach is sufficient to obtain the necessary data.

The field of view of the camera mounted on the UAV covers the area of the intersection with approaches of approximately 300 × 160 m when it hangs at 100 m over the ground. A camera with the resolution 4 K (4096 × 2160) is used which maps an average car using 30 × 70 pixels. 25 frames per second are registered which gives a time resolution of 40 ms.

Object tracking software is used for processing the registered video data. The resulting set of trajectories is a complete description of the movement of objects, in this case vehicles moving through the intersection. In order to obtain start times and travel through speeds the trajectories are filtered and synchronised with the timings of the traffic lights controllers.

The trajectories of the first vehicles stopping at the intersections are analysed. Other drivers in the approach queues follow the first vehicle and their behaviour copies the behaviour of the first one in the queue.

Drivers approaching the intersection stop at different distances from the beginning of the intersection area, usually marked with a stop line. In order to obtain a uniform measure of the beginning of the unloading of the vehicle queue, the area boundaries are slightly moved to leave a start up path of approximately a few meters.

Start time t_s is defined as the travel time from the place of stopping of the vehicle to the boundary of the intersection area. Travel through the intersection speed v_s is defined as the average speed of crossing the intersection and calculated as:

$$v_s = \frac{s + s_s}{t_p + t_s} \tag{1}$$

where:

s - distance between the intersection boundaries [m],

t_p - travel time between the intersection boundaries [s],

s_s - average distance between the stopping place and the intersection border [m],
t_s - travel time from the place of stopping to the boundaries of the intersection at the beginning of the green signal [s]

Tracking software compensates the UAV air movements in result gives an accuracy of ±2 pixel that is ±0,015 [m] for determining positions of the vehicles.

Figure 1 presents video frames of the measured intersections. Red rectangles limit the intersection areas, while blue rectangles cover start up paths.

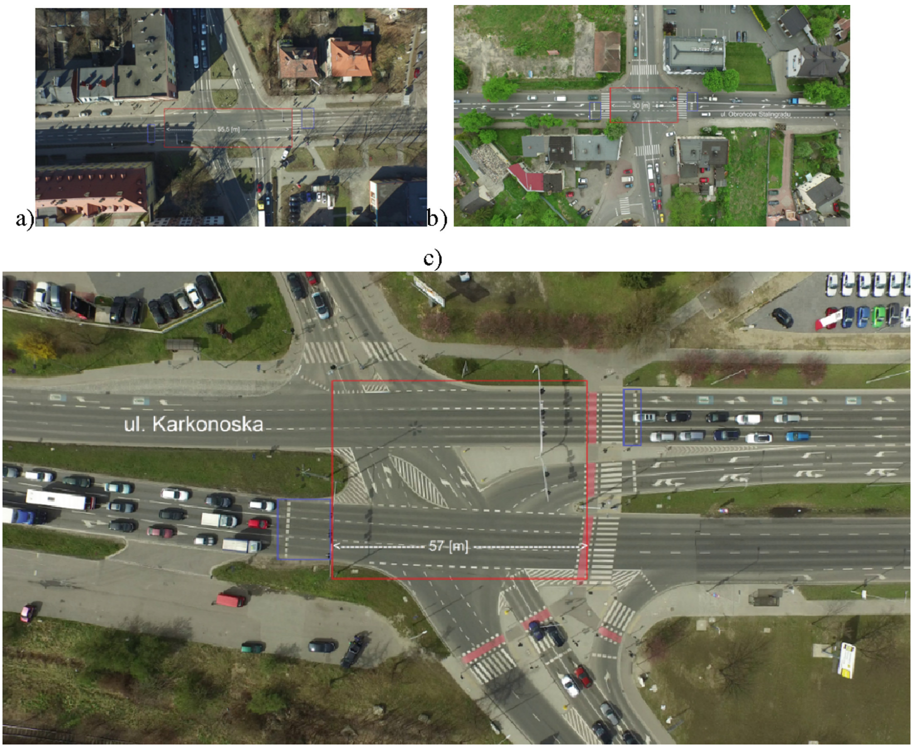


Fig. 1. Traffic sites (a) Zabrze, (b) Opole, (c) Wrocław (images recorded by camera on UAV)

The following measurement sites are chosen for tests:

- urban traffic located in Zabrze city, characterized by the dominant and high share of passenger cars as well as delivery trucks in traffic,
- mixed traffic located in Opole city, characterized by the presence of trucks, trucks with trailers and passenger cars,
- non-urban traffic located in Wrocław city, characterized by a high proportion of trucks and trucks with trailers [7, 8].

Table 1 contains real world sizes of these areas. At each site two measurement sessions are carried out: with CTs on and with CTs switched off. At the studied intersections, traffic is controlled using fixed time signals with an average cycle time of 100 s and 2 or 3 phases. In all over 650 signalling cycles are examined.

Table 1. Sizes of intersection areas and start up paths.

Sites	s - distance between the intersection boundaries [m]	s_s - average distance between the stopping place and the intersection border [m]
Zabrze	55.5	7.0
Opole	30.0	7.0
Wrocław	57.0	10.0

The largest sizes of s and s_s are noted for the Wroclaw site. The start up paths are similar at all of the sites.

4 Measures of Drivers Behaviour

Measurements of t_s are done for two measurement sessions with CTs on and off for all the sites. In order to observe the changes in drivers behaviour t_s histograms are prepared. The range of values of t_s is divided into intervals with a 0.5 s step and numbers of drivers with drive times falling in the intervals are counted. The result represents the distribution of the t_s values. Normalisation is omitted.

Figure 2 presents the histogram of t_s values measured in Zabrze. The introduction of CTs shifts the histogram towards smaller values of t_s which indicates that drivers decided not to wait for the green signal but start at small values shown by the counter. Characteristic is a small second maximum which may be accounted for drivers not reading the counters.

Histogram of the t_s values in mixed traffic site located in Opole city is presented in Fig. 3. The shift to the smaller values is much more significant and a second maximum is also noted but it is much higher.

Histogram of the t_s values in non-urban traffic site located in Wrocław city in Fig. 4. is flattened when the CTs are switched on. A large number of drivers ignores traffic lights and starts much earlier than at the other intersections but there is also a significant number of late drivers which may be accounted to heavy vehicles as the site has a high share of such vehicles in the total volume of traffic.

Table 2 summarises the average t_s and speeds v_s at the measuring sites. The average values are chosen as the measures. These measures adequately illustrate the impacts of CTs on the drivers behaviour. Values in round brackets after the averages approximate the spread of the values which is significant in all t_s cases especially when CTs are switched on. It means that the behaviour of drivers is not uniform.

The large spread of t_s may be accounted to drivers of heavy vehicles who are not accustomed to reading of CTs as these are seldom used on routes the drivers use.

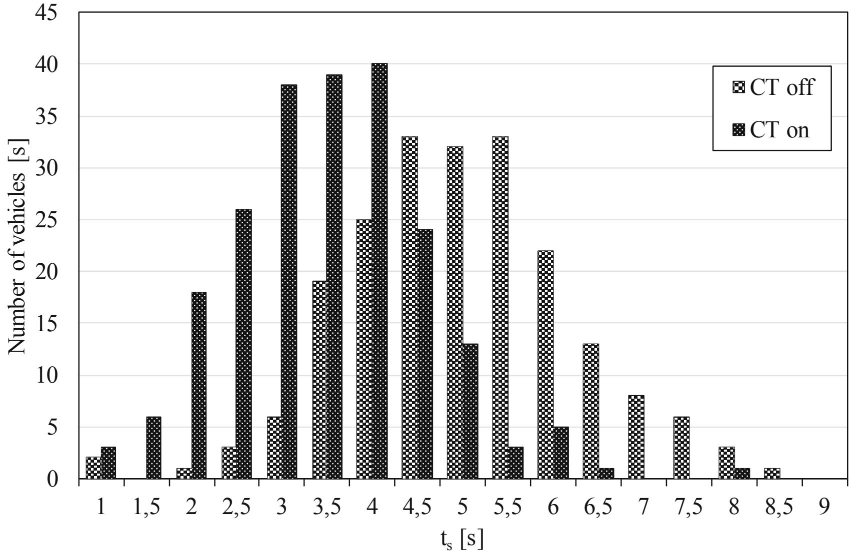


Fig. 2. Histogram of the t_s values in urban traffic site located in Zabrze city

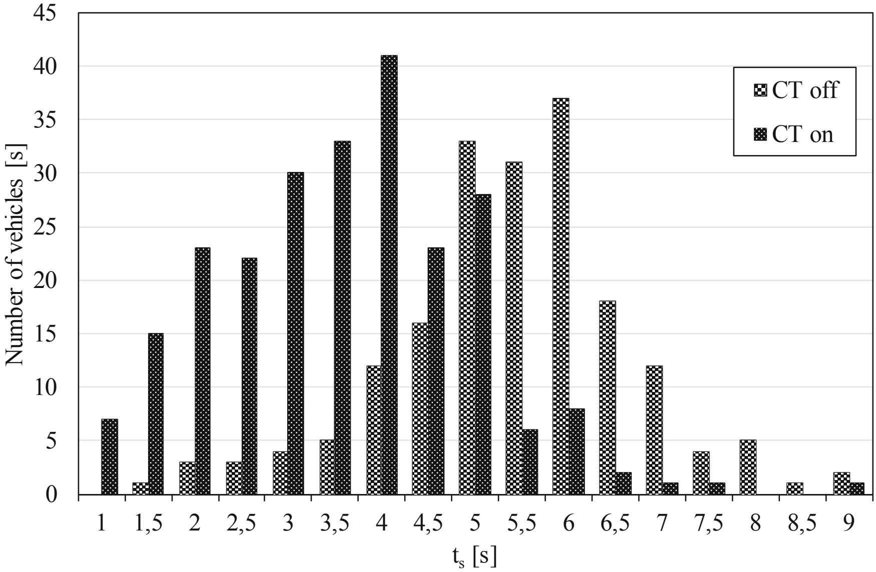


Fig. 3. Histogram of the t_s values in mixed traffic site located in Opole city

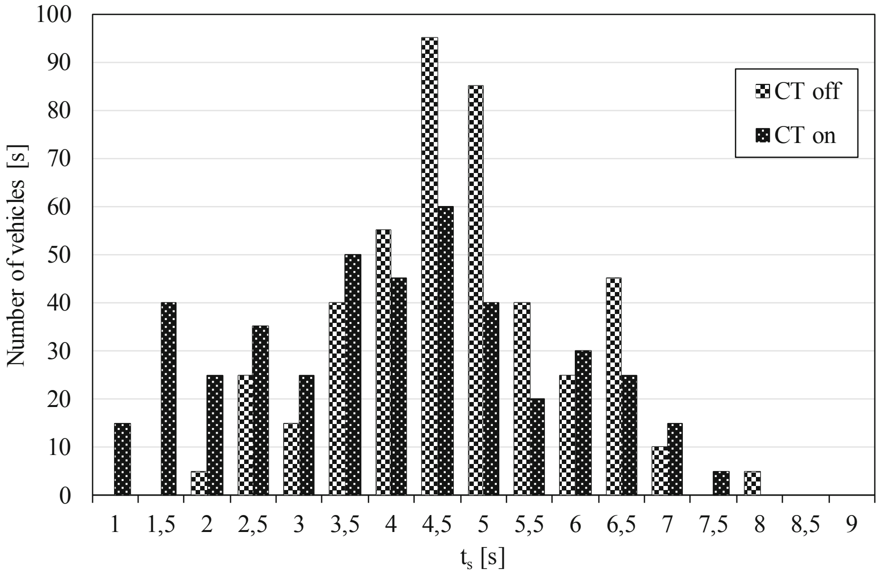


Fig. 4. Histogram of the t_s values in non-urban traffic site located in Wrocław city

Table 2. Measured traffic characteristics for the analysed intersections.

Traffic parameters	CT OFF	CT ON	The difference between the values obtained with CT ON and CT OFF	
$\overline{t_s}$ - average travel time from the place of stopping to the boundary of the intersection at the beginning of the green signal [s] (Δ t_s) - standard deviation [s]				
Zabrze	4.9 (1.6)	3.3 (1.1)	−1.6	33%
Opole	5.4 (1.9)	3.3 (1.3)	−2.1	39%
Wrocław	4.5 (1.2)	3.8 (1.6)	−0.7	16%
v_s - average speed of crossing the intersection [km/h] (Δ v_s) - standard deviation (value spread) [km/h]				
Zabrze	19.5 (3.2)	22.6 (4.8)	3.1	16%
Opole	14.4 (2.3)	18.4 (2.8)	4.0	28%
Wrocław	26.0 (3.9)	28.5 (5.1)	2.5	10%

The average travel time from the place of stopping to the boundaries of the intersection at the beginning of the green signal in the case of CT on is shorter by an average of about 36% except for the Wrocław site. This site has a high share of heavy vehicles and the effect is less than half of this value. The CTs cause a reduction of loss time when starting off, i.e. at the beginning of the green signal. The reductions are related to traffic conditions at the intersections. Traffic with a higher share of heavy vehicles in the total volume is less sensitive to the introduction of the CTs. The behaviour of drivers is dominated by the start up characteristics of the vehicles.

Drivers of vehicles also travel faster through the intersections, when the CT are switched on, on average it is about 22% for intersections with much urban traffic but the prevalence of non-urban traffic reduces this effect more than twice.

Studies done in parallel with, the UAV based measurements, reported in [6–8] confirm the change of impact of CTs related to traffic conditions.

5 Summary

Countdown timers have the biggest impact on the behaviour of drivers of passenger cars and utility vehicles. The influence diminishes with the decrease of dynamic parameters of the vehicles. Start up times of heavy vehicles are much larger than noted reductions in start up times due to introduction of CTs. A large share of heavy vehicles in the total volume of traffic in consequence changes the statistics of the traffic.

Drivers reading CTs more precisely select the moment of starting and this reduces the time losses at the start. The overall effect depends on the dynamic characteristics of the driven vehicles. Further work is required to determine the dependence of the size of CTs impact on the share of heavy vehicles in the total volume of traffic. A microsimulation model of intersection with countdown timers can be a base for studies. Onsite studies have a limited capability for changing traffic conditions.

References

1. Biswas, S., Ghosh, I., Chandra, S.: Influence of signal countdown timer on efficiency and safety at signalized intersections. Can. J. Civ. Eng. **44**(4), 308–318 (2017)
2. Fua, C., Zhang, Y., Bie, Y., Hu, L.: Comparative analysis of driver's brake perception-reaction time at signalized intersections with and without countdown timer using parametric duration models. Accid. Anal. Prev. **95**, 448–460 (2016)
3. Ying, N., Keping, L.: Estimating rear-end accident probabilities at signalized intersections: a comparison study of intersections with and without green signal countdown devices. Traffic Inj. Prev. **15**(6), 583–590 (2014)
4. Yu, S., Shi, Z.: Analysis of car-following behaviours considering the green signal countdown device. Nonlinear Dyn. **82**, 731–740 (2015)
5. Sobota, A., Klos, M.J., Karoń, G.: The influence of countdown timers on the traffic safety of pedestrians and vehicles at the signalized intersection. In: Sierpiński, G. (ed.) Intelligent Transport Systems and Travel Behaviour. AISC, vol. 505, pp. 13–21. Springer International Publishing (2017)
6. Warunki techniczne infrastruktury drogowej stosowanych w organizacji ruchu na drogach. Tom I Prawne, społeczno-ekonomiczne i techniczne uwarunkowania poprawy bezpieczeństwa i warunków ruchu drogowego w odniesieniu do znaków i sygnałów drogowych oraz urządzeń bezpieczeństwa ruchu drogowego stosowanych w organizacji ruchu na drogach. Część IV Wyniki badań laboratoryjnych i empirycznych w odniesieniu do proponowanych rozwiązań. https://www.gov.pl/web/infrastruktura/propozycja-wymagan-dla-oznakowania-drogowego

7. Sobota, A., Żochowska, R., Karoń, G., Klos, M.J.: Methodology for research on traffic safety at signalized intersections with countdown timers. Sci. J. Silesian Univ. Technol. Ser. Transp. **100**, 191–201 (2018)
8. Sobota, A., Żochowska, R., Karoń, G., Klos, M.J.: Results of research of the traffic safety at signalized intersection with countdown timers. In: Sierpiński, G. (ed.) Integration as Solution for Advanced Smart Urban Transport Systems. AISC, vol. 844, pp. 173–183. Springer, Cham (2018)
9. Lum, K., Halim, H.A.: Before-and-after study on green signal countdown device installation. Transp. Res. Part F: Psychol. Behav. **9**, 29–41 (2006)
10. Anjana, S.: Safety analysis of urban signalized intersection under mixed traffic. J. Saf. Res. **52**, 9–14 (2015)
11. Milaszewicz, B.: The issue of using countdown timers at intersections with traffic lights: a literature review. In: Proceedings of XI International Science-Technical Conference Automotive Safety, pp. 1–7. IEEE, Casta (2018)
12. Raksuntorn, W.: The effects of countdown signals on intersection capacity. Int. Trans. J. Eng., Manage. Appl. Sci. Technol. **3**(2), 159–165 (2012)
13. Liu, P., Yu, H., Wang, W., Ma, J., Wang, S.: Evaluating the effects of signal countdown timers on queue discharge characteristics at signalized intersections in China. Transp. Res. Rec. **2286**, 39–48 (2012)
14. Tang, K., Dong, K., Chung, E.: Queue discharge patterns at signalized intersections with green signal countdown device and long cycle length. J. Adv. Transp. **50**, 2100–2115 (2016)
15. Wenbo, S., Zhaocheng, H., Xi, X., Feifei, X.: Exploring impacts of countdown timers on queue discharge characteristics of through movement at signalized intersections. Procedia-Soc. Behav. Sci. **96**, 255–264 (2013)
16. Islam, M.A., Wyman, A.A., Hurwitz, D.S.: Safer driver responses at intersections with green signal countdown timers. Transp. Res. Part F **51**, 1–13 (2017)
17. Islam, M.A., Hurwitz, D.S., Macuga, K.L.: Improved driver responses at intersections with red signal countdown timers. Transp. Res. Part C **63**, 207–221 (2016)
18. Devalla, J., Biswas, S., Ghosh, I.: The effect of countdown timer on the approach speed at signalised intersections. Procedia Comput. Sci. **52**, 920–925 (2015)
19. Papaioannou, P., Politis, I.: Preliminary impact analysis of countdown signal timer installations at two intersections in Greece. Procedia Eng. **84**, 634–647 (2014)
20. Ke, R., Li, Z., Tang, J., Pan, Z., Wang, Y.: Real-time traffic flow parameter estimation from UAV video based on ensemble classifier and optical flow. IEEE Trans. Intell. Transp. Syst. **20**(1), 54–64 (2019)

Side Collisions Causes - Case Study Based on Chosen Intersections in Sosnowiec City

Agata Kurek(✉) and Jakub Jużyniec

SKN Signalis, Faculty of Transport, Silesian University of Technology, Katowice, Poland
skn.signalis@gmail.com

Abstract. The article presents the level of road traffic safety at selected intersections. The authors focused on side collisions that are most often road accident effect in Poland. In the paper are presented localisation of analysed areas on the transport network of Sosnowiec (Silesian Province, Poland), intersections geometry and the number of collision points. Analysis was performed of causes and effects of road accidents at selected intersections. For this purpose, the data was used from SEWiK database. Additionally local visions were carried out. They allowed to identify conflict situations. Also was analysed the level of visibility from the point of view of every road users. Side collisions causes was characterised. The authors proposed solutions, that should increase road traffic safety.

Keywords: Side collision · Road traffic safety · Intersection

1 Introduction

The level of road traffic safety in Poland is low in comparison to other European countries. People die on the roads every day and a lot of people are injured. 60% of road traffic accidents in urban networks take place at intersections. The reason is the occurrence in the area of intersections of frequent interweaving of traffic flows. It leads to the dangerous situations that have a significant impact on the decreasing of road traffic safety. The increasing number of vehicles on roads in provinces in Poland lead to increase the probability of participation in a road accident [1, 2].

The road traffic safety is the subject of many studies of authors in the country and abroad and is discussed in the literature, e.g. [3–11]. In addition, in publications [12–15] were described the road traffic safety at road intersections.

When the road traffic safety was analyzed, attention should be paid to the division of road accidents according to [16] into: collisions and road accidents. It takes into account the type of losses incurred in the conflict. Moreover, in this document are also definitions of: a person slightly injured, a person seriously injured and a person killed. The classification depends on the damage incurred and duration.

The aim of road traffic safety analyses is searching places, where is a risk occurrence of a road traffic accident. Then it is carried out their analysis, including analysis of the causes of road traffic accidents. At the end is searching for solutions that could cause their reduction. An important system that should be considered in the case of

E. Macioszek et al. (Eds.): TSTP 2019, LNITI, pp. 125–134, 2020.
https://doi.org/10.1007/978-3-030-39109-6_10

road traffic safety analyses is the "human-road-vehicle". According to accident cards provided by the police after accident happened, road is the cause of 2–3% of road accidents, vehicle - 2% ant the rest - human mistake [17]. This may be caused by incorrect assessment of the traffic situation, which leads to road accidents. It can concern the unclear places, wrong interpretation of them or high congestion etc. [18].

It was decided to analyze types of traffic accidents (mainly at intersections), which include vehicle collisions. Three most frequency vehicle crashes are:

- side crashes,
- head-on crashes,
- rear-end crashes.

The most frequently type of collisions from those listed are side crashes [19]. It is confirmed by statistical data (Fig. 1) at the roads in Poland. Number of side collisions is still on high level. Despite the decreasing number of their in 2017, in comparison to 2007.

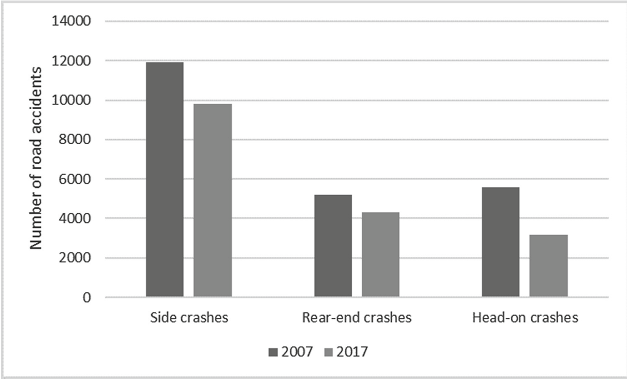


Fig. 1. Number of road accidents in Poland with division into different collision types (Source: own elaboration based on [19, 20])

Vehicles side collision occurs while front part of one vehicle hits into a side part of another [8]. In the Table 1 are shown the most frequently types of traffic accidents at the typical intersections.

Table 1. The most frequently types of traffic accidents at the typical intersections (Source: own elaboration based on [13, 21, 22]).

Intersection type	Road accidents types
With major road	Head-on, Rear-end and side crashes, collisions with pedestrians
With traffic lights	Rear-end and side crashes, collisions with pedestrians, collisions at an angle
Roundabout	Rear-end and side crashes, collisions at an angle

At the every type of intersection (Table 1), one of the groups of road accident types are side collisions. It affect the number of road accidents and collisions. Attention should be paid to the problem of occurrence of road accidents that they are vehicle side collisions.

The authors of this article presented a case study of two selected intersections in the city of Sosnowiec (Silesian Province, Poland). The focus was on side collisions and possible causes of their occurrence.

2 Characteristic of Selected Intersections

Selected intersections are located through of the one of the major communication route in the city of Sosnowiec:

- crossroads: 3 maja Street, Staszica Street, Narutowicza Street,
- crossroads: 3 maja Street, Blachnickiego Street, Prusa Street.

Localization of them are presented in the Fig. 2. Intersections are located nearby Sosnowiec City Centre.

Fig. 2. Localisation of analysed intersections on the transport network of the city of Sosnowiec (Source: own elaboration based on [23])

They allow drive to/from 3-Maja Street, that leads to the national road to Katowice, Dąbrowa Górnicza (DK94).

3 Road Accidents Analysis at Selected Intersections

The data was used from Record Keeping System of Accidents and Collisions (in Polish: SEWiK). It was concerning causes, effects and perpetrators of road accidents at selected intersections. The data was from period of time 2008–2017 years. In this chapter was presented the analysis of these data.

3.1 Intersection of 3 Maja Street, Staszica Street and Narutowicza Street

The Fig. 3 shows the road accidents causes at the intersection of the three roads: 3 Maja Street, Narutowicza Street and Staszica Street, at the analyzed period of 10 years. 119 road accidents (72%) occurred, because drivers fail to yield the right of way. Disregarding minimal safety distance between vehicles caused 22 accidents (13%). Incorrect reversing, turning back and not respecting with another signals represented a very low percent of road accidents causes.

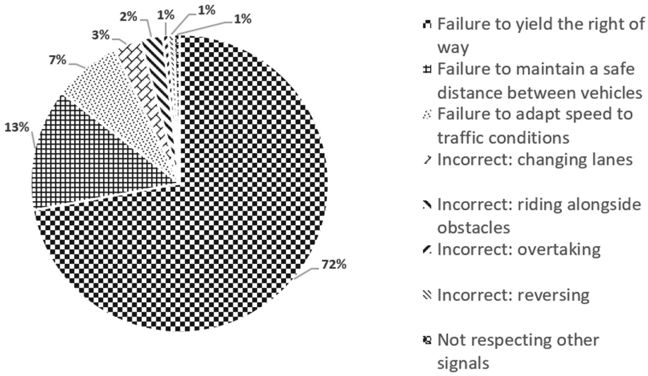


Fig. 3. Total number of road accidents causes at intersection of 3 Maja Street, Narutowicza Street and Staszica Street at the analysed period between 2008 and 2017 years

Figure 4 presents percent participation of different types of road accidents. These accidents were noticed at intersection of the roads: 3 Maja Street, Narutowicza Street and Staszica Street. The highest value is for vehicle side crashes (121 road accidents). The second highest value is for rear-end crashes with the number of 25 accidents. Values of the other road accidents are lower than 8.

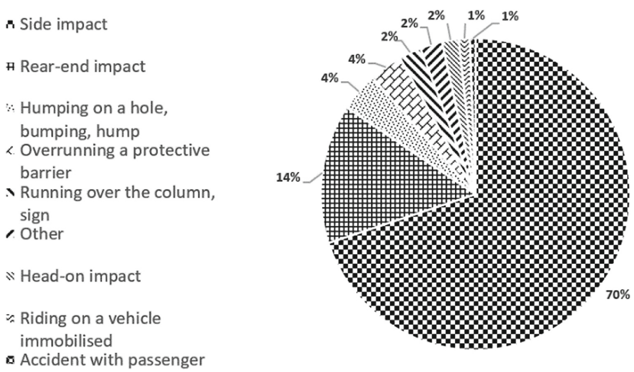


Fig. 4. Types of the road accidents at the intersection of 3 Maja Street, Narutowicza Street and Staszica Street between 2008 and 2017 years

3.2 Intersection of 3 Maja Street, Prusa Street and Blachnickiego Street

Figure 5 shows the road accidents causes at the intersection of the three roads: 3 Maja Street, Blachnickiego Street and Prusa Street, at the analysed period of 10 years.

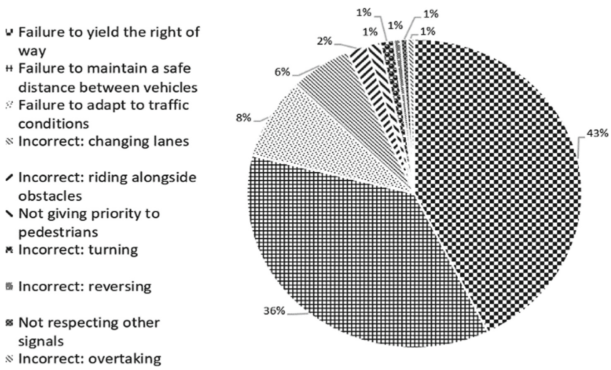


Fig. 5. Total number of road accidents causes at intersection of 3 Maja Street, Prusa Street and Blachnickiego Street at the analyzed period between 2008 and 2017 years

Based on the Fig. 5, we could noticed that 65 road accidents, which are caused by drivers who fail to yield the right of way. While disregarding of minimal safety distance between vehicles caused 55 road accidents. Total number of road accidents caused by incorrect overtaking, reversing, turning, fail to yielding the right of way to pedestrian and non-compliance with another signals was represented by 7 road accidents at analyzed intersection.

Figure 6 presents percent participation of different types of road accidents. These accidents were noticed at intersection of the roads: 3 Maja Street, Prusa Street and Blachnickiego Street.

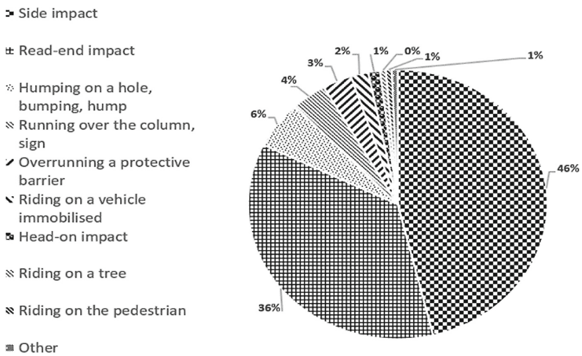


Fig. 6. Types of the road accidents at the intersection of 3 Maja Street, Prusa Street and Blachnickiego Street between 2008 and 2017 years

The most frequently group among road accidents were side crashes (73). Rear end collisions represent 57 road accidents. The lowest values noticed in cases of head-on crashes, collision with tree, pedestrian and another causes - 5 road accidents (Fig. 9).

4 Local Vision

Local vision was carried out at 20th of January 2019 at intersections of 3 Maja Street, Staszica Street and Narutowicza Street. While at the intersection of 3 Maja Street, Prusa Street and Blachnickiego Street local vision was carried out at 18th of February 2019. Area inventory was allowed to identify elements affecting to decrease the road traffic safety. During the analysis it was focused on: pavement condition, visibility from the point of view of every road users, places of occurring traffic conflicts.

Characteristic for analyzed intersections is road inclination at minor inlet. There are located sign B-20 “STOP”.

4.1 Intersection of 3 Maja Street, Staszica Street and Narutowicza Street

One of the critical points is tram rail (Fig. 7). The minor relations have to yield the right of way at first to the road vehicles. Then they crossing the tram rails and is forgotten by the drivers very often. Moreover, coming tram can be invisible for drivers. This is caused by localization of entrances to the underground crossing for pedestrians.

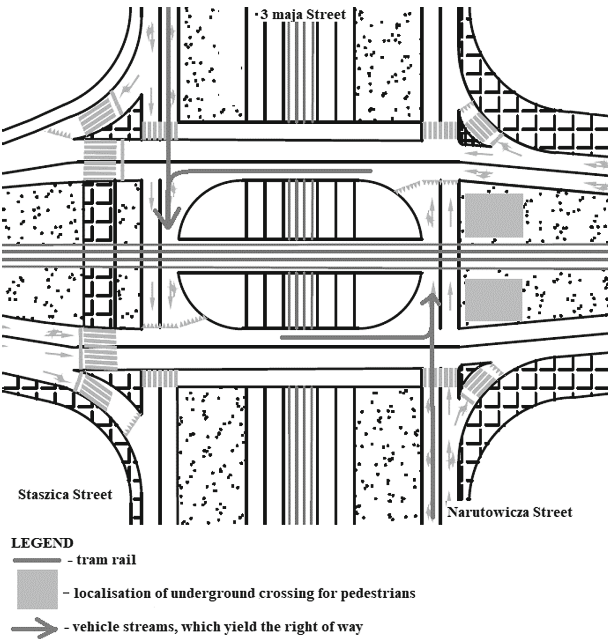


Fig. 7. Conflict situation caused by tramway track crossing and localization of underground pedestrian crossing

The analysis visibility shown negative impact of energy-absorbing barriers location, at the central part of the intersection (Fig. 8). Additional, it was noticed negative impact of barriers securing pedestrian traffic (Fig. 9). The drivers, who must give the right of way, could not see conflicting streams because of them.

Fig. 8. Insufficient visibility caused by localization of energy-absorbing barriers

Fig. 9. Insufficient visibility caused by barriers securing pedestrian traffic

The Figs. 10 and 11 are presented insufficient visibility for drivers. It is caused impact of barriers (Figs. 8 and 9). In these places occur the conflict traffic streams.

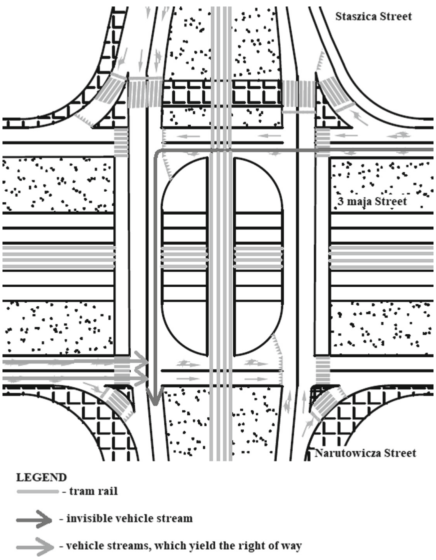


Fig. 10. Conflict situation caused by the occurrence of barriers and improper localization of them

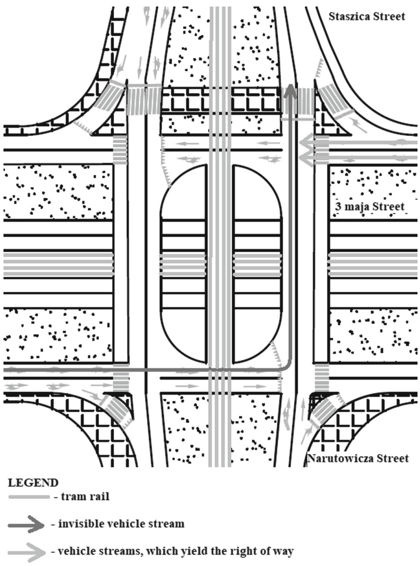


Fig. 11. Conflict situation caused by the occurrence of barriers and improper localization of them

4.2 Intersection of 3 Maja Street, Prusa Street and Blachnickiego Street

Visibility the conflicting streams is limited for drivers because of energy-absorbing barriers located at the central part of the intersection (Fig. 12) and barriers securing pedestrians traffic (Fig. 13). This situation is also observed at the intersection of road crossing: 3 Maja Street, Staszica Street and Nartowicza Street.

Fig. 12. Insufficient visibility caused by barriers securing pedestrian traffic

Fig. 13. Insufficient visibility caused by localization of energy-absorbing barriers

Figures 14 and 15 presented insufficient visibility for drivers impact of barriers (Figs. 12 and 13). It was caused occurrence in these places the conflict traffic streams.

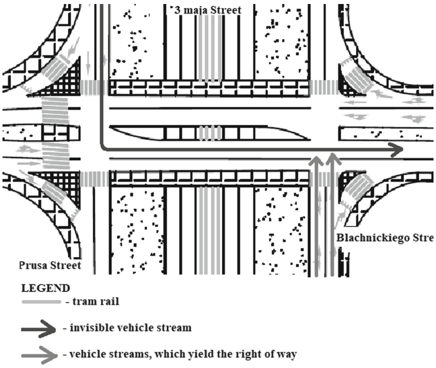


Fig. 14. Conflict situation caused by the occurrence of barriers and improper localization of them

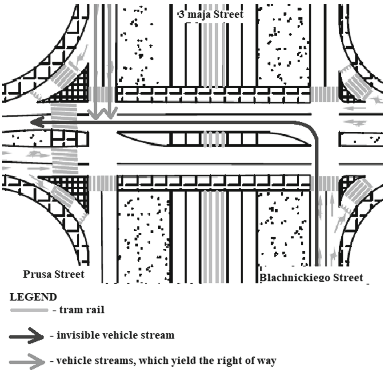


Fig. 15. Conflict situation caused by the occurrence of barriers and improper localization of them

5 Conclusions

The most frequently occurring effect is side collision. That was showed on the basis of carried out analysis at the selected intersections. It was observed: crossroads: 3 Maja Street, Narutowicza Street, Staszica Street - 70% and crossroads: 3 Maja Street, Prusa Street and Blachnickiego Street - 46%.

The most frequently reason the road accidents, at both intersections, was fail to yield the right of way. It was observed: crossroads: 3 maja Street, Narutowicza Street, Staszic Street - 72% and crossroads: 3 Maja Street, Prusa Street and Blachnickiego Street - 43%.

The second most frequently reason was not maintaining a safe distance between vehicles. It was observed: crossroads: 3 Maja Street, Narutowicza Street, Staszica Street - 13% and crossroads: 3 Maja Street, Prusa Street and Blachnickiego Street - 36%.

Characterized situation was noticed when the minor street visibility is insufficient and limited by some obstructions (e.g. barriers). Another factor affecting refuse to yield the right of way could be unclear markings.

Other causes, for example: failure to adapt speed to traffic conditions (7–8% at the analysis intersections) or incorrect turn, can influence on the dangerous situations. These situations could result in side collisions, because of refuse to the right of way, as well as rear-end collisions, because of hard braking. Moreover, the analyzed intersections are similar to roundabouts, what could affect incorrect interpretation of the traffic organization by drivers.

The dangerous situations at the selected intersections were confirmed during driving in the road traffic and sometimes need rapid reaction (e.g. hard braking). Moreover, local vision showed bad condition the road surface and incorrect localization of elements of the road traffic safety. Energy-absorbing barriers are necessary because of the road traffic safety (they secure vehicles from falling from the viaduct). However, they hamper on minor entry assessment of the situation for drivers. These components could have a negative impact on the road traffic safety at the intersection. Drivers on the major street are forced to hard braking, just in the front of vehicle from minor road. It causes a lot of dangerous situations, such as rear-end and side collisions.

Changes geometry at the analyzed intersections could have influence on decreasing the number of road accidents. It would reduce the number of collision points. Also the traffic lights would affect positively to the level of the road traffic safety. According to researches, application of the traffic lights influence to reduction of side collisions about 43–57% [6].

References

1. Macioszek, E., Lach, D.: Analysis of the results of general traffic measurements in the West Pomeranian Voivodeship from 2005 to 2015. Sci. J. Sil. Univ. Technol. **97**, 93–104 (2017). Series Transport

2. Macioszek, E., Lach, D.: Comparative analysis of the results of general traffic measurements for the Silesian Voivodeship and Poland. Sci. J. Sil. Univ. Technol. **100**, 105–113 (2018). Series Transport
3. Jamroz, K., Smolarek, L.: Driver fatigue and road safety on Poland's national roads. Int. J. Occup. Saf. Ergon. **19**, 297–309 (2013)
4. Jones-Lee, M.W., Jones-Lee, M.: The value of transport safety. Oxf. Rev. Econ. Policy **6**, 39–60 (2016)
5. Kadiyali, L.R.: Traffic Engineering and Transport Planning. Khanna Publishers, Delhi (2011)
6. Laberge-Nadeau, C., Bellavance, F., Messier, S., Vezina, L., Pichette, F.: Occupant injury severity from lateral collisions: a literature review. J. Saf. Res. **40**, 427–435 (2009)
7. Quimby, A., Hills, B., Baguley, C., Fletcher, J.: Urban safety management: guidelines for developing countries. Project Report. Department for International Development, London (2005)
8. Society of Automotive Engineers: Safety: rear impact, rollover, side impact, crashworthiness, air bags and bumper systems. Society of Automotive Engineers, Warrendale (2007)
9. Tiwari, G., Mohan, D.: Transport Planning and Traffic Safety: Making Cities, Roads, and Vehicles Safer. CRC Press, Taylor & Francis Group, Boca Raton (2016)
10. Kurek, A., Juzyniec, J., Kielc, B.: Analysis of road safety in the city of Sosnowiec in period 2006–2016. Sci. J. Sil. Univ. Technol. Ser. Transp. **100**, 69–79 (2018)
11. Villarreal Chavez, D.B., Kurek, A., Sierpiński, G., Jużyniec, J., Kielc, B.: Review and comparison of traffic calming solutions - A case study for Mexico City and Katowice. Sci. J. Sil. Univ. Technol. **93**, 11–21 (2016). Series Transport
12. Macioszek, E., Lach, D.: Analysis of Traffic Conditions at the Brzezinska and Nowochrzanowska Intersection in Myslowice (Silesian Province, Poland). Scientific Journal of Silesian University of Technology. Series Transport 98, 81–88 (2018)
13. Ogden, K.W., Newstead, S.V.: Analysis of Crash Patterns at Victorian Signalized Intersections. Transportation Research Board, Washington (1994)
14. Preusser, D.F., Williams, A.F., Ferguson, S.A., Ulmer, R.G., Weinstein, H.B.: Fatal crash risk for older drivers at intersections. Accid. Anal. Prev. **30**, 151–159 (1998)
15. Macioszek, E.: Analysis of significance of differences between psychotechnical parameters for drivers at the entries to one-lane and turbo roundabouts in Poland. In: Sierpiński, G. (ed.) Intelligent Transport Systems and Travel Behaviour. AISC, vol. 505, pp. 149–161. Springer International Publishing, Switzerland (2017)
16. Zarządzenie nr 31 Komendanta Głównego Policji z dnia 22 października 2015 r. w sprawie metod i form prowadzenia przez Policję statystyki zdarzeń drogowych. https://www.infor.pl/akt-prawny/U27.2015.048.0000085,metryka,zarzadzenie-nr-31-komendanta-glownego-policji-w-sprawie-metod-i-form-prowadzenia-przez-policje-statystyki-zdarzen-drogowych.html
17. Pande, A., Wolshon, B.: Traffic Engineering Handbook. Wiley, New York (2016)
18. MacKay, W.: Transport in the Urban Environment. Institution of Highways & Transportation, London (1997)
19. National Road Safety Council. http://www.krbrd.gov.pl/pl/72-badania.html
20. Annual Police accident reports. http://statystyka.policja.pl/st/ruch-drogowy/76562,Wypadki-drogowe-raporty-roczne.html
21. Report on the state of road traffic safety in Bydgoszcz. https://bip.um.bydgoszcz.pl/binary/5_tcm30-133297.pdf
22. Global awareness-raising on road safety. https://www.arrivealive.co.za/Intersections-and-Safe-Driving
23. Open Street Map Website. https://www.openstreetmap.org/#map=6/52.018/19.137

Traffic Organization and Control at Transport Nodes

Speed Adviser for Pedestrians to Choose the Optimal Path at Signaled Intersections

Feng Xie, Sebastian Naumann(✉), and Olaf Czogalla

Institute of Automation and Communication, Department of Transport and Assistance, Magdeburg, Germany
{Feng.Xie,Sebastian.Naumann,Olaf.Czogalla}@ifak.eu

Abstract. With the progress of modern technology, more and more vehicles arise on the road, which may cause some congestion and a high level of exhaust emission, such as CO_2 and NO_x. As an environment friendly trip mode, walking should be encouraged. And pedestrians are definitely a non-negligible group participating especially in urban traffic. Therefore, a control system of pedestrian-crossing speed is proposed in this work, which is similar to the "Green Light Optimal Speed Advisory (GLOSA)" for motor vehicles. It can not only provide pedestrians with the dependable speed recommendation to walk but also the optimal path to follow. A smart-phone-app is finally designed to validate and test such system. The result comes out that such app works significantly fine especially when pedestrians are faced with multiple choices at intersections. The result indicates that crossing with the app with GLOSA can reduce respectively 41.62% and 35.21% of used time on average, compared with crossing in the fixed paths. It can still save 27.86% of the average time, compared with the behavior of choosing the path in green time first.

Keywords: GLOSA · Pedestrian-crossing · Speed recommendation · Optimal path

1 Introduction

The purpose of traffic signals is to conduct complex flows of traffic, including motor vehicles, non-motor vehicles and pedestrians [1]. As the amount of vehicles rises day by day, the conflict between motorists and pedestrians is increasingly prominent [2]. Pedestrians are also one of the main factors, which influence the capacity of roundabouts [3]. In traffic research, pedestrians are often neglected [4], generally the only focus on walkers is safety rather than time saving [5].

Nevertheless, even if there are pedestrian crossing signals, they can still not meet the requirements of different groups of people. For elders and handicapped people, sometimes they just follow others, when the crossing signal is going to change color but others can finish crossing in the clearance interval. This can usually trap the vulnerable groups in discomfiture and danger, when they get stuck in the middle of the road. Especially when pedestrians can not predict the residual time to still wait, it might cause jaywalking. It also makes them feel uncomfortable, when people are standing at the intersections, faced with multiple paths to choose. It is such an annoyance to find an

E. Macioszek et al. (Eds.): TSTP 2019, LNITI, pp. 137–153, 2020.
https://doi.org/10.1007/978-3-030-39109-6_11

optimal path to avoid more crosswalks and save more time. To add all desired functions to pedestrian crossing signals is not practical and the cost could be significantly high. It is estimated that [6], only a Countdown Timer Module can cost $740 on average. Taking all these factors into account, an intelligent assistance system for pedestrians crossing is immensely needed, which can be finally installed on smart phones instead.

Within this work, this kind of system is designed referring to a green light optimal speed advisory model (GLOSA) [7] for vehicles. It can predict the remaining time to wait, and give an appropriate speed recommendation to catch green time for an optimal path beforehand. By means of predicting the upcoming phase of pedestrian signals and calculation of the crossing time, this app can effectively provide walkers with an optimal path to choose and judge whether the remaining time to finish crossing enough or not. In the long run, it saves a lot of waiting time, and improves the safety, degree of comfort and satisfaction of pedestrians. On the other hand, it regulates felicitously the traffic order, improving the whole efficiency of traffic system, which results in a higher satisfaction of motorists. Obviously, such an assistance system for pedestrians can make walking more attractive and comfortable. When more people join in walking, not only do they choose a healthier way to live, but also there will be less people driving cars, which causes less noise, less fuel consumption and less pollution.

2 Signal Control of Pedestrian Crossing

Nowadays, GLOSA for motor vehicles has been put into use in some cities. And varieties of driver-centric GLOSA are proposed, such as multi-segment GLOSA [8], genetic algorithmic GLOSA [9] and platoon-based GLOSA [10]. There is no reason why pedestrians should not take advantage of new technologies in the same way.

Making reference to several studies about the speed of different groups of pedestrians and also in different environment, overall researches have the similar result as the German Guidelines for Traffic Signals (RiLSA) [11], the speed of pedestrians mainly ranges from 1.2 m/s to 1.5 m/s. And the speed of 1.0 m/s is used mainly for handicapped and elderly. Also the speed of 1.2 m/s is defined as a reference velocity to design the clearance time. Griffiths et al. [12] got the result that average crossing speed at unsignalized crosswalk of the young is 1.72 m/s, the crossing speed of the middle-aged is 1.47 m/s while for the elderly it is 1.16 m/s. The result in some ways extends the range of the crossing speed which can be normally reached by most pedestrians. In 2013, Ma et al. [13] found that the average crossing speed impacted by a countdown for pedestrian signals is 0.53 m/s higher than that without countdown.

Therefore, there are ample reasons to make such an assumption, the default speed of pedestrians is 1.2 m/s, and the minimum and maximum speed are respectively 1.0 m/s and 1.5 m/s.

2.1 Signalization at Successive Crossings

Simultaneous Signalization

Under the control of simultaneous signalization at successive crossings, the 4 groups of pedestrian signal lights have the same display all the time [11], distributed on both sides of crosswalks. And the whole simultaneous signalization at a successive crossing is interpreted in Fig. 1.

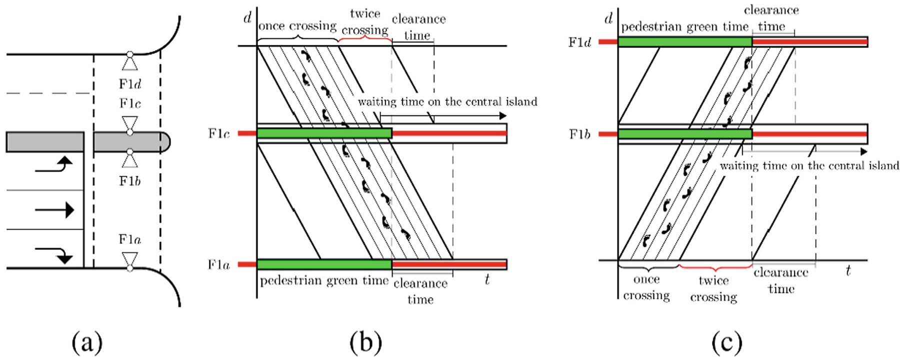


Fig. 1. (a) Crosswalk with simultaneous signalization, (b) F1a and F1c signalization, and (c) F1b and F1d signalization (Source: [11])

As shown in Fig. 1a, there is a central island separating the carriageway into two segments. And the distance between F1*a* and F1*b* is longer than that between F1*c* and F1*d*. In Fig. 1b, it shows the phase at F1*a* and F1*c* which are used to conduct the pedestrians to cross from F1*d* to F1*a*. Pedestrians get the right of way as long as the signal is green, and when they reach the central island seeing F1*a* is still green, they can continue to cross. As a result, they will finish the complete crossing with only one chance, without waiting on the central island. In the duration of time which is marked as twice crossing, pedestrians have to wait on the island from when they reach the separating strip to the next start of a green signal. This means they need two chances to finish the crossing. Even if at the last moment of green phase, can pedestrians get the right of way to start to move. However, in Fig. 1c, it shows another situation that pedestrians move in the opposing direction.

Progressive Signalization

In order to solve the problem in simultaneous signalization, progressive signalization is raised [11]. Under the control of progressive signalization, the 2 groups of signals on the central island always have the same display, and also the 2 groups on the sides of road have the same display. However, the green signal of the latter should end after the former. The details of the control principle are presented in Fig. 2.

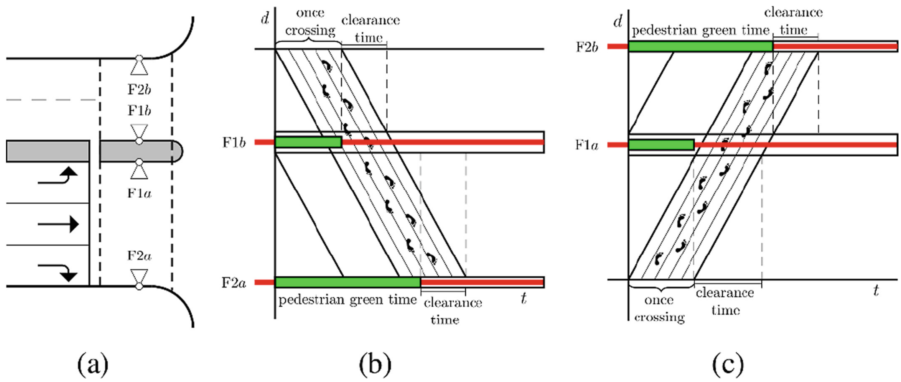


Fig. 2. (a) Crosswalk with progressive signalization, (b) F1b and F2a signalization, and (c) F1a and F2b signalization (Source: [11])

It is clearly shown that under the control of progressive signalization, the twice crossing duration is gone, because all the pedestrians who enter the crosswalk legally will reach the other side without stopping on the central island (see Fig. 2b and Fig. 2c).

Separate Signalization
Another way of signal control for pedestrians is separate signalization. Under this kind of control, the pedestrian signals of two segments of crosswalks separated by the central island have respectively the same display [11], which can be thought as two independent once-crossing crosswalks in Fig. 3. In this work, such case is not viewed as a kind of successive crossing only for the purpose of calculation.

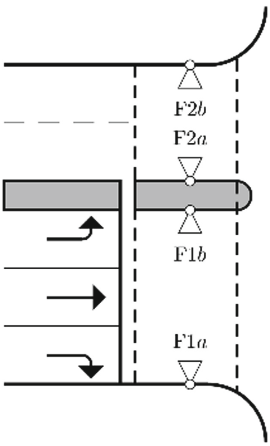


Fig. 3. Signal phase of separate signalization (Source: [11])

2.2 A Typical Intersection in Magdeburg

The selected typical intersection locates at (52.14141, 11.65374), the crossing of Sandtorstraße, Wittenberger Straße, Theodor-Kozlowski-Straße and Joseph-von-Fraunhofer-Straße, see Fig. 4. The points with circle are destination points for choosing, such as ⓐ, ⓑ, ⓒ and so on, which is the middle point of the path along the same roadside of neighboring signals. The variant *l* represents the length of the path connecting two induction points. However *Dn* is the crossing-distance of crosswalk at phase F*n*. Obviously, the strips which separate F1 and F2, in the same way, F3 and F4, result in successive crossings.

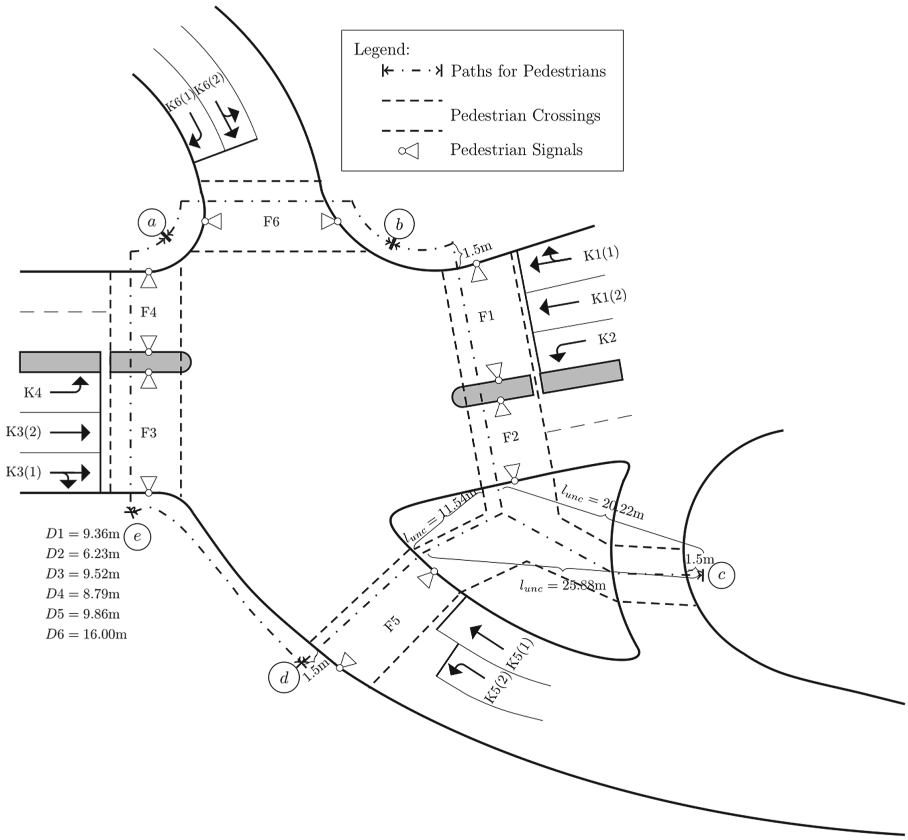


Fig. 4. A skewed intersection with a triangular island and successive crossings (Source: [14])

Though there is only a part of path segment is not controlled by traffic lights, a flag named as *uncontrol* is still needed to mark the part. The path elements are presented in Table 1. For example, segment ⓑ - ⓒ and segment ⓒ - ⓓ contain a part of uncontrolled segment, which makes *uncontrol* equal 1.

With the complex circumstance of this intersection, the phase plan can be more complicated, because more situations will arise. As shown in Fig. 5, SP3 is extracted as a standard signal timing plan. And it is easily seen that the successive crossings are both controlled by separate signalization, because pedestrian signals of the entrance lane at phase F1 is actuated earlier than phase F2. While the group of signals of another entrance lane at phase F3 ends a few seconds later than phase F4.

Table 1. Path elements of the typical intersection.

Segment ID	From	To	t_{start}	*uncontrol*	l_{unc} [m]	l [m]
S1-1	ⓐ	ⓑ	Not null	0	0.00	30.21
S1-2	ⓐ	ⓔ	Not null	0	0.00	24.86
S2-1	ⓑ	ⓐ	not null	0	0.00	30.21
S2-2	ⓑ	ⓒ	not null	1	20.22	50.53
S2-3	ⓑ	ⓓ	not null	1	11.54	53.73
S3-1	ⓒ	ⓑ	not null	1	20.22	50.53
S3-2	ⓒ	ⓓ	not null	1	25.88	37.24
S4-1	ⓓ	ⓑ	not null	1	11.54	53.73
S4-2	ⓓ	ⓒ	not null	1	25.88	37.24
S4-3	ⓓ	ⓔ	null	0	31.56	31.56
S5-1	ⓔ	ⓐ	not null	0	0.00	24.86
S5-2	ⓔ	ⓓ	null	0	31.56	31.56

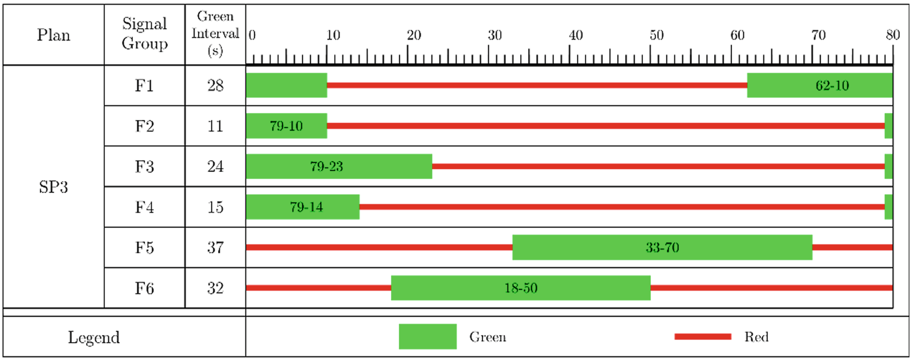


Fig. 5. Signal timing plan for the typical intersection (Source: [15])

3 Models and Algorithms Design

3.1 Mobility Models of Pedestrians

Jeong et al. (2014) proposed six relevant mobility models [7] to give suggestions on an optimal speed for motorists. But for pedestrians, the average acceleration for walking is 0.68 m/s^2 [16], to accelerate from normal speed of 1.2 m/s to 1.5 m/s needs (1.5 - 1.2)/

0.68 = 0.44 s. Therefore, the time required to accelerate or decelerate can be ignored to be zero. Also it seems dangerous to cross with a speed lower than normal current speed. As a result, it simplifies largely the mobility models for pedestrians to these modes, which are presented in Fig. 6. D represents the distance needed to be crossed in green time, t_{acc} is the time consumed to cross D with the accelerated speed v_{acc}, t_{cur} is the time needed with the current speed v_{cur}, and t_{min} is the minimum time resulted by the maximum speed v_{max}.

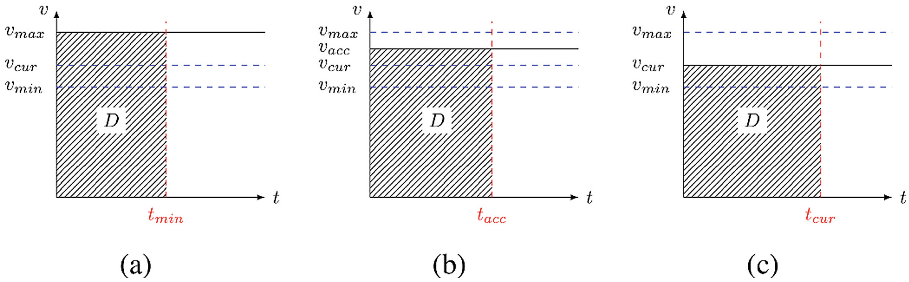


Fig. 6. Mobility models for pedestrians: (a) MS model, (b) AS model, and (c) CS model (Source: [7])

There are two applications of such model in this work, one is the GLOSA part for pedestrians to catch the green time, the other one is the speed recommendation for crossing.

For the GLOSA part, D represents the reference distance between the location of the pedestrian to the intersection, which is long enough to forecast the state of signals and give a speed recommendation to catch the green light.

However, as for crossing speed recommendation, taking clearance time into account, it is an important stipulation that the duration of a green light should guarantee pedestrians can cross at least half of the crosswalk [10]. Therefore, an assumption is made that if pedestrians are able to arrive at least at the medium point of a crosswalk in green time, this case is thought to be a kind of safe and successful crossing. While for successive crossings controlled by simultaneous signalization, it should be the medium point of the second segment of the crosswalk. So it is evident that the area which is marked by D does not stand for the real length of the crosswalk, while the residual value after taking out the half length of the second segment. And the interpretation for each mode is as follows:

1. Maximum Speed (MS) Model

In MS model (see Fig. 6a), the shortest crossing time t_{min} is given by:

$$t_{min} = D \div v_{max}$$

2. Accelerated Speed (AS) Model

In AS model (see Fig. 6b), v_{acc} is defined as the average value of v_{max} and v_{cur}. Therefore, t_{acc} is calculated by:

$$v_{acc} = (v_{cur} + v_{max}) \div 2$$
$$t_{acc} \div v_{acc}$$

3. Current Speed (CS) Model

In CS model (see Fig. 6c), pedestrians can cross at the current speed without accelerating, which means the green time is sufficient. As a result, a longer time t_{cur} is obtained, which is given by:

$$t_{cur} = D \div v_{cur}$$

In mobility models, t_0 is used to represent the present moment, t_{start} and t_{end} are used to represent respectively the start and end time of the green light. However, the parameters such as t_{min}, t_{acc} and t_{cur} are a period of time intervals needed to cross D. And another variate t_{res} is used to represent the rest time of the green interval, in another word, it is the residual time for crossing. These models can be viewed as the criteria to give pedestrians a recommended speed to finish crossing successfully and safely, which is described as a function named Crossing Speed Selector (CSS) in Algorithm 1.

Algorithm 1: *Crossing Speed Selector* (CSS)

```
Input: t_min, t_acc, t_cur, t_res
Output: v_cross
if (t_min > t_res) then
    stop: v_cross ← 0;
else
    if t_acc > t_res then
        accelerate aggressively: v_cross ← v_max;
    else
        if t_cur > t_res then
            accelerate mildly: v_cross ← v_acc;
        else
            normal crossing: v_cross ← v_cur;
        end
    end
end
```

Now it comes to the question how to calculate the rest time t_{res} and the waiting time t_{wait} for the next start of a green time to cross. Taking into account the reaction time for pedestrians to distinguish and choose optimal path and the calculating time of the system, therefore, a time interval Δt is adopted to reserve a few seconds to forecast the state of signals, which is the time consumed by pedestrians to walk from the starting induction area to the side of crosswalk, acquiescently is set to be 5 s. There are respectively several specific cases to be discussed as follows:

(1) $t_{start} < t_{end}$:

There are three possible occasions of $t_0 + \Delta t$ (see Fig. 7):

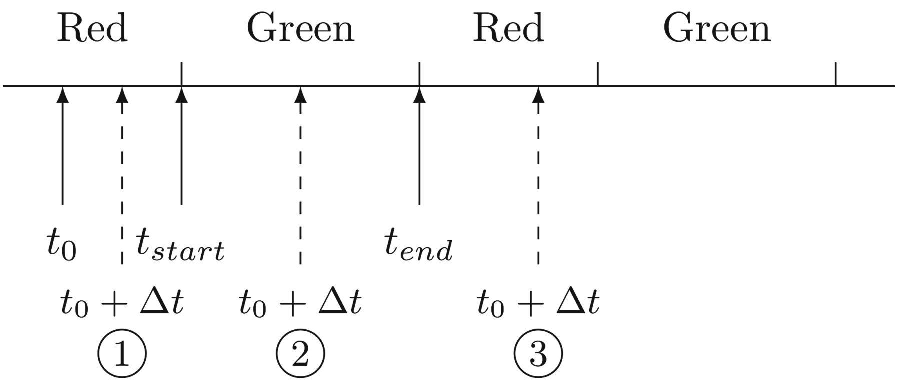


Fig. 7. Current moment in red interval.

- $$t_0 + \Delta t < t_{start} < t_{end}.$$

When pedestrians arrive at the crosswalk, it is still in the red interval (marked as ② in Fig. 7), so people have to stop to wait for the start of a green signal. The waiting time t_{wait} and residual time t_{res}, which is equal to the whole green time t_{green} of the signal, can be calculated by:

$$t_{wait} = t_{start} - (t_0 + \Delta t)$$
$$t_{res} = t_{green} = t_{end} - t_{start}$$

The green interval is the maximum time to permit pedestrians to pass the crosswalk. So after waiting, at the start of a green signal, the pedestrians have to cross, even though the time may not designed sufficient for pedestrians to finish crossing. In another word, in such case, even if $t_{min} > t_{res}$, pedestrians should still continue to cross with the maximum speed. As a result, v_{cross} equals v_{max}.

- $$t_{start} < t_0 + \Delta t < t_{end}.$$

When pedestrians arrive at the crosswalk, the signal has already changed to green (marked as ② in Fig. 7). In such case, there are two possibilities, one is that the residual time is enough for pedestrians to cross, which is given by:

$$\begin{aligned} t_{wait} &= 0\,\mathrm{s} \\ v_{cross} &= v_{max} \text{ or } v_{acc} \text{ or } v_{cur} \\ t_{res} &= t_{end} - (t_0 + \Delta t) \end{aligned}$$

Another case is that t_{res} is too short to finish crossing, so pedestrians have to stop to wait for the next green signal. T is the cycle time of the traffic light. And the variates can be calculated by:

$$\begin{aligned} t_{res} &= t_{end} - (t_0 + \Delta t) \\ t_{wait} &= T + (t_{start} - t_0) - \Delta t \\ v_{cross} &= 0\ \mathrm{m/s} \end{aligned}$$

- $$t_{start} < t_{end} < t_0 + \Delta t.$$

It has to be taken into account that if in time Δt, pedestrians miss a whole period of green time, which is marked by ③ in Fig. 7. In such case, pedestrians also have to wait for the next green signal, and relevant parameters are given by:

$$\begin{aligned} t_{wait} &= T + (t_{start} - t_0) - \Delta t \\ t_{res} &= t_{green} = t_{end} - t_{start} \end{aligned}$$

(2) $t_{end} < t_{start}$:

As shown in Fig. 8, there are also three possibilities of $t_0 + \Delta t$:

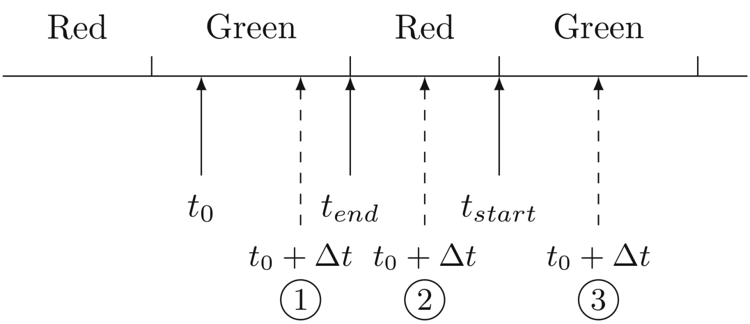


Fig. 8. Current moment in green interval

- $$t_0 + \Delta t < t_{end} < t_{start}.$$

In such case, the time point of $t_0 + \Delta t$ is marked by ① in Fig. 8 with two cases. One is that t_{res} is till enough for pedestrians to finish crossing, relevant variates are given by:

$$\begin{aligned} t_{wait} &= 0\,s \\ v_{cross} &= v_{max} \text{ or } v_{acc} \text{ or } v_{cur} \\ t_{res} &= t_{end} - (t_0 + \Delta t) \end{aligned}$$

Another situation is when t_{res} is too short, pedestrians have to stop to wait for the start of the next coming green signal, which is described by:

$$\begin{aligned} t_{res} &= t_{end} - (t_0 + \Delta t) \\ t_{wait} &= t_{start} - (t_0 + \Delta t) \\ v_{cross} &= 0\,\text{m/s} \end{aligned}$$

- $$t_{end} < t_0 + \Delta t < t_{start}.$$

This case is marked by ② in Fig. 8, which means that when pedestrians arrive at the crosswalk, the green signal has turned to red. Therefore pedestrians have to stop to wait for the start of another green signal, and variates are given by:

$$\begin{aligned} t_{wait} &= t_{start} - (t_0 + \Delta t) \\ t_{res} &= t_{green} = T - (t_{start} - t_{end}) \end{aligned}$$

The case after waiting is similar to what has been explained before, pedestrians have to cross no matter how long the green time is.

- $$t_{end} < t_{start} < t_0 + \Delta t.$$

When pedestrians reach the crosswalk, it happens to be the next green signal again (marked by ③ in Fig. 8). So things come like the first subcase, it has to be discussed whether the rest of green time is sufficient or not. One case is that it is not necessary to wait, with relevant variates given by:

$$\begin{aligned} t_{wait} &= 0\,s \\ v_{cross} &= v_{max} \text{ or } v_{acc} \text{ or } v_{cur} \\ t_{res} &= T + (t_{end} - t_0) - \Delta t \end{aligned}$$

Another situation is that pedestrians are not able to finish crossing in the residual time. Relevant parameters are calculated by:

$$t_{res} = T + (t_{end} - t_0) - \Delta t$$
$$t_{wait} = T + (t_{start} - t_0) - \mathrm{c}$$
$$v_{cross} = 0\ \mathrm{m/s}$$

For one-segment crosswalk, D is the half length of the real distance D_{real} of the crosswalk, which means pedestrians only need to reach the medium point in green time. But at successive crossings, things become more complicated. For simultaneous successive crossings, it can be calculated as:

$$D = D_{seg1} + D_{seg2} \div 2$$

In such case, D_{seg1} and D_{seg2} are respectively the length of the first and second segment, where pedestrians actually need to reach the medium of the second segment.

However, at progressive successive crossings, as long as the pedestrians reach the medium point of the first segment, it means they can accomplish crossing the whole crosswalk in one green time. So D is given as:

$$D = D_{seg1} \div 2$$

For separate successive crossings, they are viewed as two crosswalks which are controlled separately by two groups of signals. It has to be judged separately whether it is necessary to wait for green time or not. Such function is called D Determiner (DD) in this work.

Considering all these subcases, together with the functions CSS and DD, the crossing time t_{cross} can be calculated by $t_{cross} = D \div v_{cross}$.

3.2 Algorithm Design of GLOSA for Pedestrians

The main function of GLOSA is to help pedestrians adjust walking speed in advance to catch the green time, reducing waiting time largely. It will be activated when the distance between the pedestrian and the starting induction point is less than 50 m. The reason to set the reference distance as 50 m is that for vehicles in the model of Jeong et al. [7], the maximum speed chosen in real experiments is 40 km/h and the current speed is 30 km/h. Therefore, when the reference distance is 200 m, the time difference between these two speeds is 6 s, which is viewed as effective data. As mentioned before, the maximum and normal speed of pedestrians are respectively 1.5 m/s and 1.2 m/s, and the time difference is (50/1.2–50/1.5)=8.34 s, which is similar to the effective data.

In general, the number of groups of signals at an induction area can be 0–2, there is a special case that when the pedestrian can reach one group of signal in green time with current speed, but can catch the green of another group with an accelerated speed, which means the time difference between the end time of the green interval of a signal and the start time of the other group is less than 8.34 s. In such case, the system should encourage the pedestrian to accelerate to catch the green signal. Because even if it is not a part of the optimal path, the pedestrian will just wait at most 8.34 s. Also when pedestrians can avoid the waiting time of the first signal, which reduces largely the time of the whole path, it will be the optimal path in most cases.

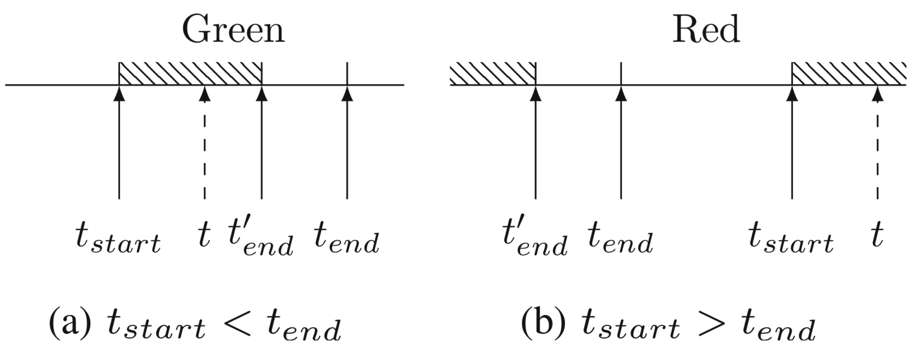


Fig. 9. Types of signal clocks in GLOSA

Similar to the crossing model discussed before, the signal clocks can be classified into two types: $t_{start} < t_{end}$ and $t_{start} > t_{end}$. As shown in Fig. 9, t represents the time when the pedestrian reaches the signal, with three possible values as follows:

$$\begin{aligned} t1 &= t_0 + 50\text{ m } / v_{cur} + \Delta t \\ t2 &= t_0 + 50\text{ m } / v_{acc} + \Delta t \\ t3 &= t_0 + 50\text{ m } / v_{max} + \Delta t \end{aligned}$$

There is one thing has to be taken into account is that it must spare enough residual time for pedestrians to accomplish at least half of the first segment of crosswalk, which is different from vehicles. Therefore, a new end time t'_{end} is calculated by:

$$t'_{end} = t_{end} - D_{seg1} / (2 \cdot v_{cross})$$

In a word, as long as the pedestrian can reach the signal within the valid range between t_{start} and $t'_{end,}$ it is judged as a successful catching of GLOSA. And the recommended walking speed can be given by Algorithm 2.

The path time for one single route can be therefore calculated by the summation of the consumed time of all segments:

$$t = \Delta t + \sum t_{talk} + \sum t_{talk} + \sum t_{cross}$$

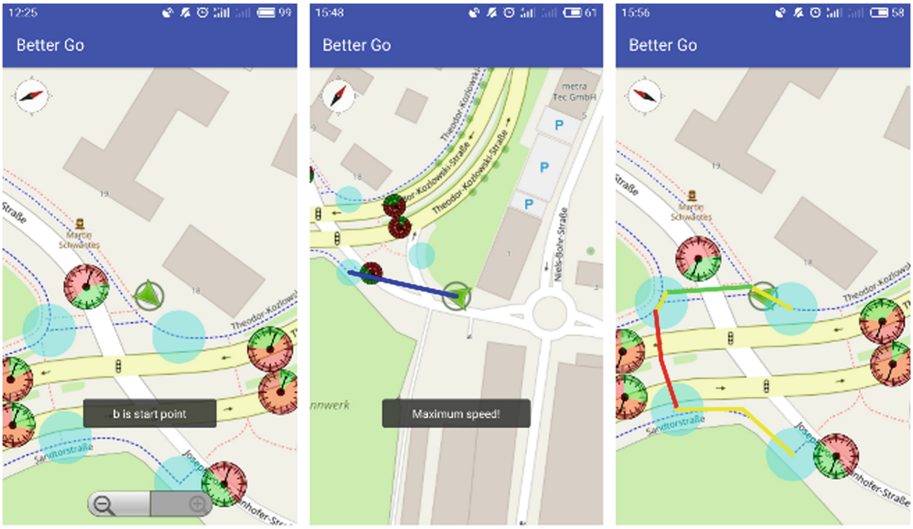
With the result, the GLOSA system can present the optimal path with the least consumed time.

Algorithm 2: *GLOSA*

Input: t_{start}, t'_{end}
Output: v_{walk}
if $(t_{start} < t'_{end})$ **then**
  if $t_{start} < t1 < t'_{end}$ **then**
    normal walking: $v_{walk} \leftarrow v_{cur}$;
  else
    if $t_{start} < t2 < t'_{end}$ **then**
      accelerate mildly: $v_{walk} \leftarrow v_{acc}$;
    else
      if $t_{start} < t3 < t'_{end}$ **then**
        accelerate aggressively: $v_{walk} \leftarrow v_{max}$;
      else
        normal walking: $v_{walk} \leftarrow v_{cur}$;
      end
    end
  end
else
  if $t1 < t'_{end}$ ***or*** $t1 > t_{start}$ **then**
    normal walking: $v_{walk} \leftarrow v_{cur}$;
  else
    if $t2 < t'_{end}$ ***or*** $t2 > t_{start}$ **then**
      accelerate mildly: $v_{walk} \leftarrow v_{acc}$;
    else
      if $t3 < t'_{end}$ ***or*** $t3 > t_{start}$ **then**
        accelerate aggressively: $v_{walk} \leftarrow v_{max}$;
      else
        normal walking: $v_{walk} \leftarrow v_{cur}$;
      end
    end
  end
end

4 Experiments and Results

In order to evaluate this GLOSA system, an app named “Better Go” is developed with OpenStreetMap library. As shown in Fig. 10, the testing app is designed based on the typical intersection in Magdeburg. There are five cyan induction areas, whose centers locate clockwise respectively at points of ⓐ to ⓔ. Because the normal current speed is set to be 1.2 m/s, the reserved time for pedestrians to reach the road side of crosswalk is 5 s, the radius of induction areas is $1.2 \times 5 = 6$ m. Therefore, no matter which path the pedestrians choose, they have to go through the induction area to activate the function. Firstly, pedestrians have to select the start and the terminal point as shown in Fig. 10a. Then if the distance to the start point is less than 50 m, it will recommend a speed for the pedestrian to catch the green light, see Fig. 10b. When the pedestrian enters the induction area, an optimal path will be presented with different colors. Red means “stop”, yellow means “normal speed”, green means “accelerate mildly”, and blue means “accelerate aggressively”.



(a) point selection (b) speed suggestion (c) optimal path

Fig. 10. Main view of “Better Go”

For safety, the experiment was carried out on a flat ground without vehicles. Therefore, the pedestrian has to strictly follow the path and signal clocks.

In order to simulate real conditions, four types of pedestrian behaviors are tested. And 12 tests are conducted either from ⓑ to ⓓ or from ⓓ to ⓑ, which can be combined together as one group of testing data. The timekeeping starts when pedestrians enter the starting induction area, and ends at the moment arriving at the destination induction area. The average time is calculated after removing the maximum and minimum data. The first testing behavior is crossing with the app without catching-green function, whose average time is 80.19 s. The second type is walking without any suggestions, always following one fixed path. The two fixed paths have respectively 110.49 s and 99.56 s as the average result. The third behavior is walking without any app either, but always choosing the path whose signal turns to green first, with an average result of 89.41 s. The last testing behavior is walking with the app in a distance more than 50 m to catch the green light. The five groups of data are shown in Fig. 11.

It is not difficult to find out that all groups of data appear different degrees of fluctuation. Except for rare special values, the two groups of data for one fixed path show a relative stability, because the path selection is fixed. As for the pedestrians who prefer to choose the path in green time first, it seems that the data distributes uniformly in the fluctuating range, including both low and high values.

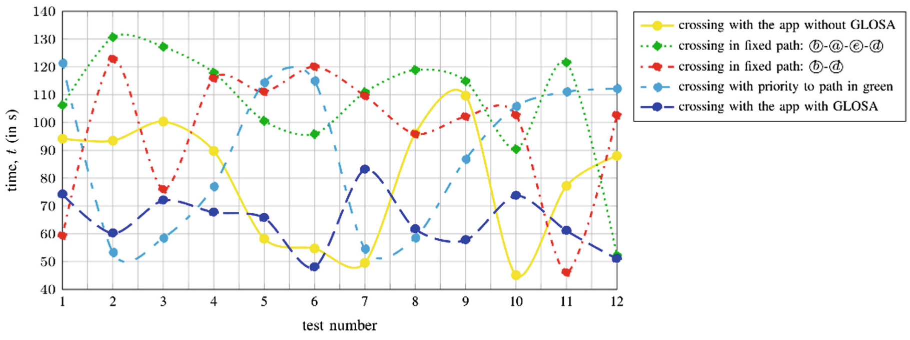


Fig. 11. Integration of all testing data

However, as for the crossing behavior with the app without GLOSA, it divides the time into two levels, and each level has only a narrow fluctuation range. The level of high values is limited, which means the behavior of crossing could be controllable. Obviously, crossing with the app with GLOSA has a better result. Not only the fluctuation range is very narrow but also the high value limitation is low.

5 Conclusion

Apparently, different choices of paths consume varieties of durations. By means of the suggestion on the optimal path and crossing speed, the used time can be predictable and controllable. After avoiding the waiting time at the first signal, crossing with the app with GLOSA saves 19.57% the time of that without GLOSA. Compared with crossing in the fixed path of ⓑ - ⓐ - ⓔ - ⓓ, it saves time by 41.62%. And compared with another choice of fixed path of ⓑ - ⓓ, it saves time by 35.21%. Even compared with the behavior of choosing the path in green time first, the algorithm can still save time by 27.86%. Taking all into account, this test tallies with the actual situation, the result is genuine and believable. However, there is one problem has to be pointed that if pedestrians focus too much on the app, less concentration would be put on the road circumstance. This could be improved by the audio cue and vibrating of the mobile phone, which can help walkers cross the intersection without watching the app.

References

1. He, Q., Head, K.L., Ding, J.: Multi-modal traffic signal control with priority, signal actuation and coordination. Transp. Res. Part C: Emerg. Technol. **46**, 65–82 (2014)
2. Lee, C., Abdel-Aty, M.: Comprehensive analysis of vehicle-pedestrian crashes at intersections in Florida. Accid. Anal. Prev. **37**(4), 775–786 (2005)
3. Małecki, K.: The roundabout micro-simulator based on the cellular automaton model. In: Sierpiński, G. (ed.) Advanced Solutions of Transport Systems for Growing Mobility. AISC, vol. 631, pp. 40–49. Springer, Cham (2018)

4. Ishaque, M.M., Noland, R.B.: Multimodal microsimulation of vehicle and pedestrian signal timings. Transp. Res. Rec.: J. Transp. Res. Board **1939**, 107–114 (2005)
5. Rietveld, P.: Non-motorised modes in transport systems: a multimodal chain perspective for the Netherlands. Transp. Res. Part D: Transp. Environ. **5**(1), 31–36 (2000)
6. Bushell, M.A., Poole, B.W., Zegeer, C.V., Rodriguez, D.A.: Costs for pedestrian and bicyclist infrastructure improvements. UNC Highway Safety Research Center, Technical report (2013). https://www.ssti.us/wp/wp-content/uploads/2013/10/PedBikeCosts.pdf
7. Suramardhana, T.A., Jeong, H.Y.: A driver-centric green light optimal speed advisory (DC-GLOSA) for improving road traffic congestion at urban intersections. In: 2014 IEEE Asia Pacific Conference on Wireless and Mobile, pp. 304–309. IEEE, Bali (2014)
8. Seredynski, M., Mazurczyk, W., Khadraoui, D.: Multi-segment green light optimal speed advisory. In: 2013 IEEE International Symposium on Parallel Distributed Processing, Workshops and Phd Forum, pp. 459–465. IEEE, Cambridge (2013)
9. Li, J., Dridi, M., El-Moudni, A.: Multi-vehicles green light optimal speed advisory based on the augmented lagrangian genetic algorithm. In: 17th International IEEE Conference on Intelligent Transportation Systems (ITSC), pp. 2434–2439. IEEE, Qindao (2014)
10. Stebbins, S., Hickman, M., Kim, J., Vu, H.L.: Characterising green light optimal speed advisory trajectories for platoon-based optimisation. Transp. Res. Part C: Emerg. Technol. **82**, 43–62 (2017)
11. Forschungsgesellschaft für Straßen-und Verkehrswesen: Arbeitsausschuss Verkehrs-beeinflussung Innerorts. Guidelines for Traffic Signals: RiLSA. English Version, ser. FGSV. FGSV, Verlag (2003)
12. Griffiths, J., Hunt, J., Marlow, M.: Delays at pedestrian crossings: site observations and the interpretation of data. Traffic Eng. Control **25**(7/8), 365–371 (1984)
13. Ma, Y., Qin, X., Liu, Y., Wu, Y.: Characteristics of Pedestrian Speeds at Urban Road Crosswalks. http://ascelibrary.org/doi/abs/10.1061/9780784413159.452
14. Google Maps. https://www.google.de/maps/@52.115492,11.6376038,13z
15. Keitel, R.: Signalzeitenpläne (Th.-Kozlowski-Str./Sandtorstr./W Kn274). Tiefbauamt, Magdeburg (2014)
16. Teknomo, K.: Microscopic pedestrian flow characteristics: development of an image processing data collection and simulation model. Ph.D. dissertation. Department of Human Social Information Sciences, Graduate School of Information Sciences, Tohoku University, Tohuku (2002)

The Influence of the Type of Traffic Organization on the Behaviour of Pedestrians at Tram Tracks Crossings

Mateusz Rydlewski(✉) and Emilia Skupień

Faculty of Mechanical Engineering, Wroclaw University of Science and Technology, Wroclaw, Poland
{mateusz.rydlewski,emilia.skupien}@pwr.edu.pl

Abstract. The paper focuses on the influence of the type of traffic organization on the behaviour of pedestrians at tram tracks crossings on an example of two Polish cities: Wroclaw and Gdańsk. Authors indicates the differences in pedestrian behaviour depending on the type of traffic organization - especially taking into account if it contains traffic lights or not. The conclusions, made on a basis of field tests, are the basis for making a suggestion to change pedestrian traffic organization at the crossings of tram tracks in most Polish cities. Authors suggest to minimize to use of traffic lights at pedestrian crossings.

Keywords: Pedestrians · Pedestrians crossing · Tram tracks crossings

1 Introduction

The way the pedestrian traffic in cities is organized depends on many factors. Most obvious are: traffic intensity and resulting - pedestrian safety. The organization of pedestrian traffic on road crossings may be divided into two groups: with or without traffic lights (Fig. 1). Crossings without traffic lights may be lead above - and underground, which is the safest (if pedestrians use it), and on the ground, which is used in the case of low traffic intensity.

Using traffic lights may include traffic control programme: constant in time, accommodative, induced and warning. Constant in time traffic control is used usually in places where the traffic is constant and no more complicated solutions are used to control the traffic. Where the system lets it (using Intelligent Transport Systems) or where the changes in the traffic flow are known in advance, the accommodative program may be used. In the places where the car traffic is high and the pedestrian traffic is low, or in places far from the crossroad where pedestrian need to cross the street - the inducted traffic lights may be placed. In places of not good visibility or with low rate of traffic of pedestrian or vehicles warning lights may be sufficient (respectively for pedestrian or for vehicles).

Pedestrian crossings are the most dangerous place for pedestrian in city traffic. The type of organization of pedestrian traffic at pedestrian crossings may influence the safety of its users. This is a reason for researchers to investigate infrastructure of this places and also human behaviours, giving it for example a special pedestrian safety

E. Macioszek et al. (Eds.): TSTP 2019, LNITI, pp. 154–170, 2020.
https://doi.org/10.1007/978-3-030-39109-6_12

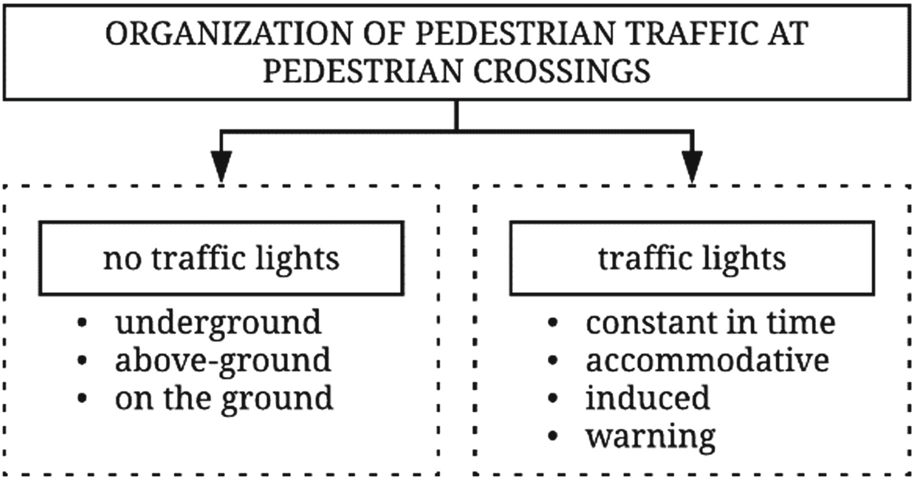


Fig. 1. Types of organization of pedestrian traffic at pedestrian crossings

index [1] or examining the knowledge about the safety on the road [2]. Other factor influencing the safety is a tendency to risk behaviour. This problem, with reference to crossings at tram stops has been already discussed [3].

Pedestrian crossings in cities may cross: a roadway (single- and multiroad), a tram track or both at the same time. Researches show, that the longer the way the more dangerous for pedestrian it gets [4]. Also [5] indicates that the speed of pedestrian on non-signalled pedestrian crossings is higher than on those which traffic is regulated by traffic lights. This may be due to the sense of security provided by the traffic lights, which at the time of displaying the green signal for pedestrians is synonymous with the information that vehicles on the lanes which traffic path passes through the pedestrian crossing have a prohibited signal displayed. Taking into account the human factor, it is important to mention that the age of a pedestrian has a significant effect both on safety margin and crossing time (more unlawful behaviour is noticed when a vehicle is more than 50 m away from a pedestrian) [6]. Other thing is the way walking by the streets and crossings is seen by pedestrian themselves. [7, 8] examined a group of pedestrian after asking them to take a few walk trips. The surveys indicated that most pedestrians have positive attitudes, preferences and behaviours.

Many aspects of pedestrian traffic has already been examined and described. This article focuses on the influence of the type of traffic organization on the behaviour of pedestrians at tram tracks crossings in Wroclaw and Gdańsk (Poland).

2 Pedestrian Behaviour on Pedestrian Crossings Leading Through Tram Tracks with Traffic Lights

The studies on pedestrian crossings taken into account in this paper, cover the years 2018–2019. Most of them were carried out in Wroclaw and were described in several publications, including [9, 10]. In these studies, a particularly high proportion of unlawful behaviours was observed on the crossing with traffic lights leading through tram tracks. This part of the article will compare the referenced research with the newly conducted research in Gdańsk.

2.1 Test Method for Pedestrian Crossings with Traffic Lights

Tests carried out on the pedestrian crossings relied on direct observation and the use of a specially prepared form. The person carrying out the research was in the vicinity of the crossing, in a place where its presence did not affect the behaviour of pedestrians (it was not visible). The place of observation chosen by the investigator required clear visibility of the entire pedestrian crossing along with the currently displayed traffic signal. In Poland, three types of pedestrian signal can be distinguished:

- green signal displayed permanently - allowing to start crossing the road,
- green blinking signal - allowing to start crossing the road and informing that after a while a signal will change into prohibiting entering the road. This signal is displaying usually for 3 s,
- red signal displayed constantly - it does not allow crossing the road.

The form for the research carried out distinguished two types of green signal: constantly displayed and blinking. Due to the fact that both of these signals allow to start crossing the road, in the presented results they are treated as one, general green signal.

Before starting tests of pedestrian behaviour at selected crossings by tram tracks, the researcher became acquainted with the nature of traffic within the entire intersection. It was necessary to analyse the location of tram and bus stops, the program of the traffic lights, and in particular the length of display of individual phases and the entire cycle. The observation was conducted till obtain a representative group of people, however, never less than 10 full cycles of traffic lights.

2.2 Tests Conducted in Wroclaw

From research carried out in Wroclaw on pedestrian crossings [9, 10] below selected and presented are the results of those that were carried out on crossings with trams.

In most cases, these were crossings located next to stops of public transport. Only some of the tracks were allowed to be used by buses. In total, the results from 18 pedestrian crossings leading through the tracks crossings were collected. The study involved a group of 5,540 people. Figure 2 shows the average share of pedestrians crossings by tram tracks in Wroclaw, depending on the displayed signal.

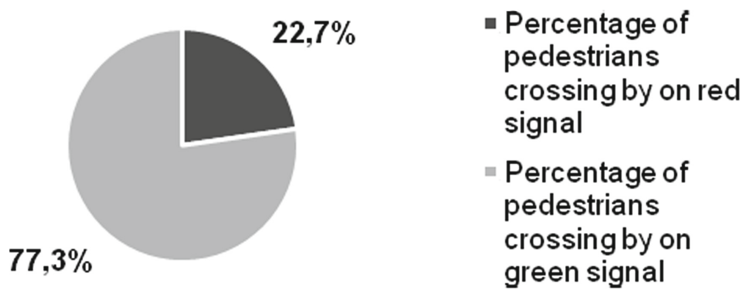


Fig. 2. General share of transitions on selected signals at pedestrian crossings leading through tram tracks in Wroclaw

On average, nearly every fourth person crossing the tram track in Wroclaw does not apply to the signalling indications and passes on the red signal. Such a high proportion indicates abnormality in the functioning of traffic lights.

Detailed locations along with the characteristics of the pedestrian crossings tested in this paper were collected in Table 1.

The graph below (Fig. 3) shows the share of crossings on various signals at crossings leading through tram tracks in Wroclaw.

The standard deviation of results obtained at crossings in Wroclaw is 15.26 percentage points. This indicates discrepancies between individual pedestrian crossings.

The smallest shares of unlawful behaviours are characterized by the following transitions:

- pedestrian crossing no. 2–4.69%,
- pedestrian crossing no. 3–4.91%,
- pedestrian crossing no. 13–5.36%.

Crossing 2 and 13 are crossings near to which there is no tram stop and in the case of crossing 3, traffic lights activate the red signal when the tram approaches the crossing. Only two tram lines with the frequency of 12 min in rush hours are moving along the track in this street.

The largest proportions of unlawful behaviours were noticed on the following crossings:

- pedestrian crossing no. 11–50.00%,
- pedestrian crossing no. 18–45.03%,
- pedestrian crossing no. 4–44.32%,
- pedestrian crossing no. 15–42.31%,
- pedestrian crossing no. 5–40.00%.

Crossings number 5, 15 and 16 are located in the area of large interchanges between trams and buses. They are characterized by a very high flow of passengers and a high traffic, both car and public transport. Studies at the crossings at the Reagan roundabout (numbers 15–17) have been discussed in detail in [9]. This research indicate that the most percentage of pedestrians who cross a pedestrian crossing on red signal is on the central island of roundabout. Crossings 4 is located near to a large shopping centre and crossing 11 characterized by the largest share and runs through a tram track located on one of the most dangerous streets of Wroclaw (according to police statistics). In the vicinity of the analysed crossings in 2018, an accident occurred in which a person crossing the road in a prohibited place was mortally struck by a tram. Research in this place was carried out a few months before this accident.

Table 1. Basic information about the pedestrian crossings tested in Wroclaw.

Number of pedestrian crossing	Localization	The name of the stop	Sample size [Number of people]	Additional information
1.	Plac Dominikański	Galeria Dominikańska	708	Interchange node/city center
2.	Plac Dominikański	–	256	No stop in neighborhood/city center
3.	Hallera street	Mielecka	326	Neighborhood of the shopping center
4.	Legnicka street	Niedźwiedzia	607	Neighborhood of the shopping center
5.	Squere of John Paul II	Jana Pawła II	145	Interchange node
6.	Peronowa street	Dworzec Główny PKP	684	Neighborhood of the main railway station
7.	Powstańców Śląskich street	Zaolziańska	232	Induced traffic lights
8.	Roundabout Powstańców Śląskich	Rondo	60	–
9.	Roundabout Powstańców Śląskich	Rondo	95	–
10.	Powstańców Śląskich street	Orla	79	–
11.	Grabiszyńska street	Pereca	120	–
12.	Borowska street	Dworzec autobusowy	637	Neighborhood of the main bus station
13.	Borowska street	–	56	No stop in neighborhood/neighborhood of the main bus station
14.	Kazimierza Wielkiego street	Świdnicka	916	Pedestrian crossing along the promenade in the city center
15.	Reagan's roundabout	Plac Grunwaldzki	234	Large interchange node
16.	Reagan's roundabout	Plac Grunwaldzki	84	Large interchange node
17.	Reagan's roundabout	Plac Grunwaldzki	150	Large interchange node
18.	Reagan's roundabout	Plac Grunwaldzki	151	Large interchange node

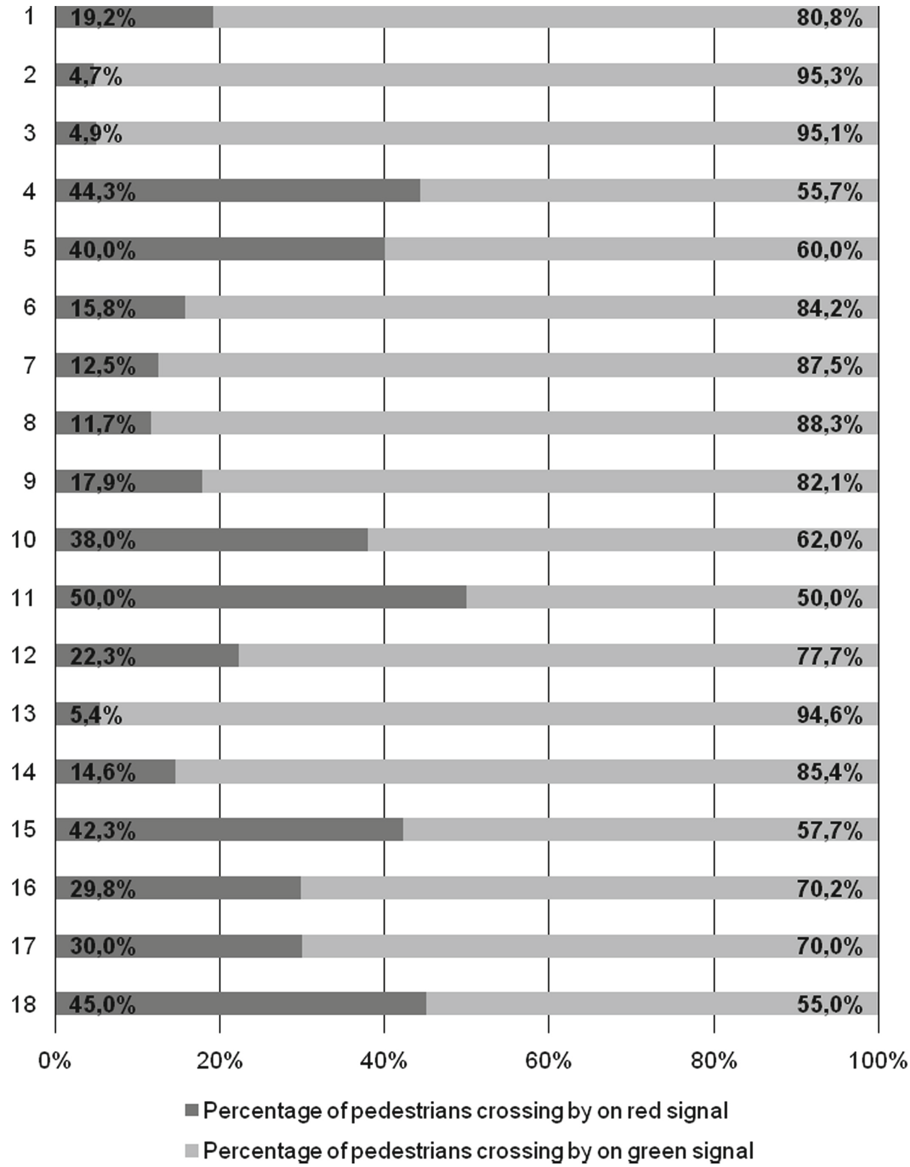


Fig. 3. Share of transitions on selected signals on the pedestrian crossings led through tram tracks in Wroclaw

2.3 Tests Conducted in Gdańsk

The research conducted in Gdańsk was based on the same methodology as previously described. The tests were carried out on February 2019. The results from 3 pedestrian crossings leading through the tracks were collected. The research involved a group of

728 people. Figure 4 shows the average share of pedestrian crossings by tram tracks in Gdańsk, depending on the displayed signal.

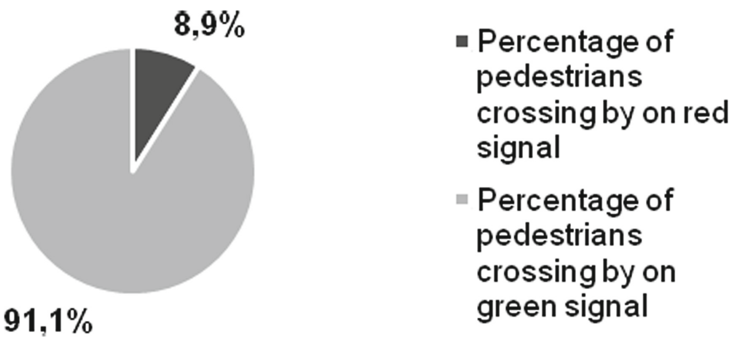


Fig. 4. General share of transitions on selected signals at pedestrian crossings leading through tram tracks in Gdańsk

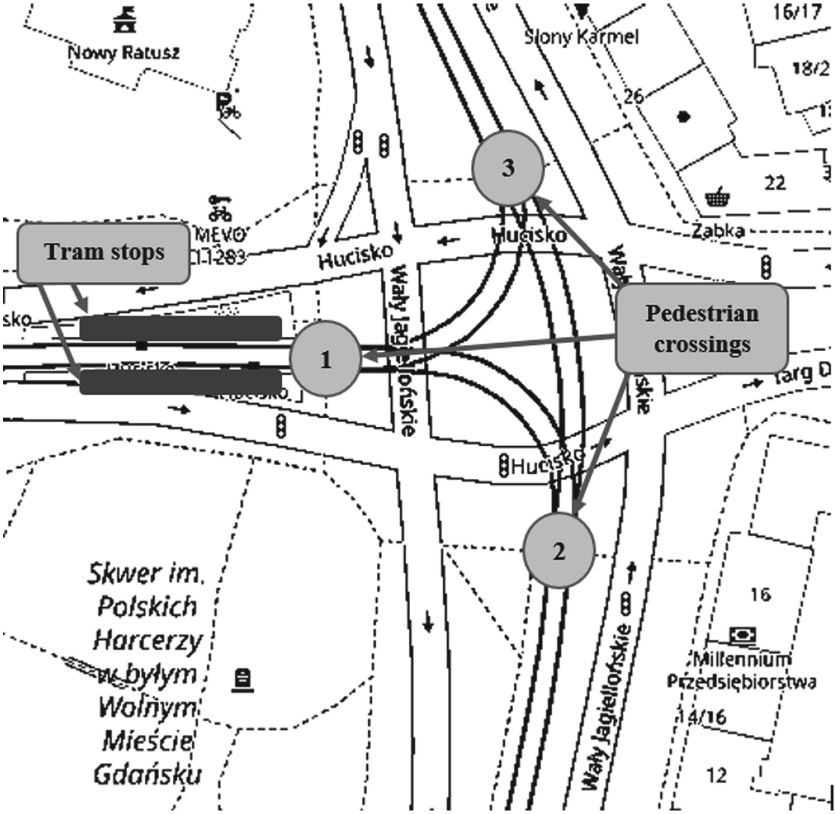


Fig. 5. Intersection of the Wały Jagiellońskie with Hucisko Street in Gdańsk (Source: [11])

Studies on pedestrian behaviour in Gdańsk were carried out at the crossings located within the intersection of Wały Jagiellońskie and Hucisko Street, the national road No. 91. Tram stops are located at one of the intersection inlet. The sketch of the intersection is shown on Fig. 5. The location of the stops and the analysed pedestrian crossings are indicated.

All pedestrian crossings leading through tram tracks within the analysed intersection are characterized by the lack of traditional marking of white lines. Within the place to cross the track there are full triangles painted along the axis of the track (analogy to the signs ‘give way’). Between the rails of the tracks there is a tram graphic and two arrows showing the direction of the tram within the passage (as shown in Fig. 6). This type of solution is commonly used at such crossings in Gdańsk.

Fig. 6. Pictograms within pedestrian crossings leading through tram tracks within the analysed intersection

Detailed information on pedestrian crossings (as numbered on Fig. 5) is collected below:

- pedestrian crossing no. 1 - crossing in the vicinity of two tram stops where trams of two lines stop. Within the crossing, pictograms are painted as in Fig. 6. At the crossing, in addition to the standard traffic lights, audible warning repeating ‘attention, tram’ was used at the time when the tram was approaching. The message is repeated until the tram travels and moments after that,
- pedestrian crossing no. 2 - a crossing at which there is no tram stop in the immediate vicinity. Six regular tram lines pass this route. This crossing is one of the three stages necessary to cross the national road 91 from one side to the other. Between the roadways there is a pavement led in the axis of the road being an additional generator of people crossing the discussed crossing,

- pedestrian crossing no. 3 - a crossing at which there is no tram stop in the immediate vicinity. 8 regular tram lines pass this route. This crossing is one of the three stages necessary to cross the national road 91 from one side to the other. The pedestrian generators within this crossing are only crossings leading across the road from both sides.

Figure 7 shows the share of pedestrians crossing the street at the aforementioned crossings on green and red signal.

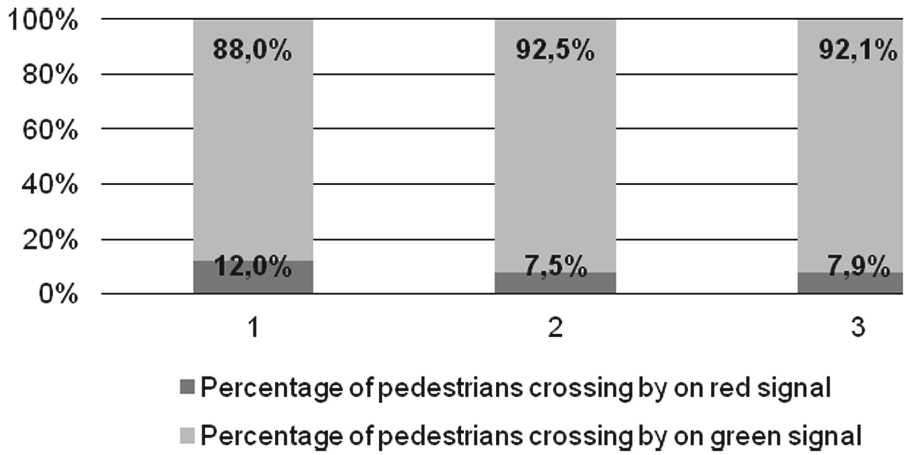


Fig. 7. Share of transitions on selected signals at pedestrian crossings led through tram tracks in Gdańsk

Despite the much smaller share of unlawful behaviour at the crossings in Gdańsk, more than 50% higher share of this type of behaviour in the area of crossings located near tram stops is still observed. This is a confirmation of the results of research carried out in Wroclaw.

2.4 Summary of Research on Pedestrian Crossings with Traffic Lights

Analysing the obtained results, both in Wroclaw and in Gdańsk, one can observe a clear increase in unlawful behaviour in the immediate vicinity of tram stops. In [9], 4 factors favouring unlawful behaviours at the crossings leading through tramway tracks and bus lanes in the immediate vicinity of the stops are indicated:

- the arrival of the vehicle on which the pedestrian waits, to be on tram (or bus) stop,
- no worries to cross the narrow section of the road,
- very good visibility of public transport vehicles due to their dimensions,
- the specificity of public transport vehicles movement is small acceleration and low speed of both starting (when starting from the stop) as well as access to the stop where all vehicles are pausing to stop.

A reason about high level of pedestrians who crossing by on red signal, is probably due to a very small section of road to be overcome and the haste resulting from the direct neighborhood of public transport stops. Wherefore it is very important to ensure pedestrian safety. One of the solution to this problem may be a warning traffic lights instead of traditional ones.

Both in Wroclaw as in Gdańsk (Poland) can be observed that at pedestrian crossings which are located near stops, percentage of people crossing by on red signal is higher than in other types of crossings.

3 Pedestrian Behaviour on Pedestrian Crossings, Without Traffic Lights, Leading Through Tram Tracks

Studies on pedestrian crossings without traffic lights, as previously described, cover the years 2018–19. Research carried out in Wroclaw [9] covered various types of pedestrian crossings, including those leading only through a tramway track. The results observed in these studies prompted the authors to extend their observations to other cities. Complementary research was carried out in Gdańsk due to the solutions widely used in this city regulating the traffic at the crossings of tram tracks. In this city, innovative regulation of pedestrian traffic on this type of crossing is used on a large scale, which gives grounds for the assessment of such solutions.

Research carried out at such crossings allows to assess the behaviour of pedestrian in situations in which their passage through the road depends on the traffic of vehicles on the road, and the decision on the possibility of crossing is undertaken individually by each of the respondents.

3.1 Test Method for Pedestrian Crossings Without Traffic Lights

The research conducted on pedestrian crossings without traffic lights is similar to the previous one: direct observation combined with the recording of results on the special form. The tests were carried out from the place where the person carrying out the research was not visible to the people taking part. The research method distinguished in total 7 different behaviour types of pedestrian crossing the road. The types of behaviour were strictly dependent on the presence of the vehicle near the crossing. In the case of the tests described here, the vehicle was a tram. Figure 8 presents the types of behaviours highlighted in the part of the research being carried out.

Due to the Polish law, a pedestrian located on a pedestrian crossing has absolute priority over all other vehicles. It is necessary to comment on a group of behaviours described as: forcing the passage. Forcing is considered entering the pedestrian crossing, which requires a marked (often sudden) speed limitation or complete stopping of the vehicle approaching the crossing. In the case of being forced by a pedestrian, it is also important whether the pedestrian stopped before crossing or not. Additionally, by adapting the descriptions of selected behaviours to the nature of the studied transitions, the described below means:

- 'passage between moving vehicles (without forcing)' - crossing the track by pedestrians, at such time and pace, which does not force the tram driver to reduce speed because of this. Decreasing the speed at crossings is most often caused by the need of stopping at the tram stop,
- 'passing a pedestrian by a driver' - marked speed limitation or stopping of the tram affecting the start of crossing the road by the pedestrian, which has the priority given,
- 'passage between standing vehicles' - also pedestrian crossing the track at the moment of stopping the tram at the stop, which is in a process of exchanging passengers (this applies to passes near tram stops).

The test method as well as the form itself also provide for situations in which the track is crossed by more than one person. In such circumstances, the study records two information. The assigned behaviour regarding the way of crossing the track is recorded on the basis of the behaviour of the person initiating the transition - the first person starting the transition through the track. The form also records information on the number of people crossing the track. The number of people 'additionally crossing the track' is not added to all individual behaviours' and can only provide information about the amount of pedestrian traffic and not their behaviour when crossing the track. Information on the number of people crossing the road will not be provided in this paper.

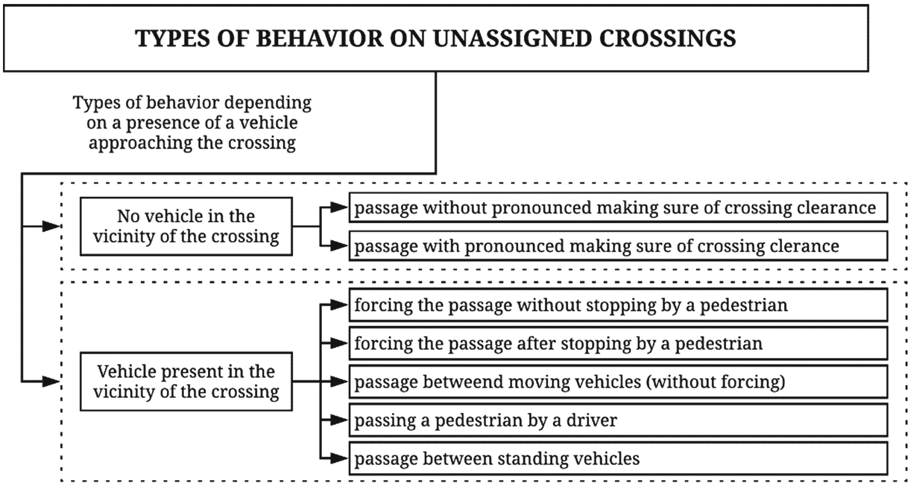


Fig. 8. Types of behaviour distinguished in studies on unassigned pedestrian crossings (Source: [9])

3.2 Tests Conducted in Wroclaw

As mentioned, the research [9] on crossings without traffic lights in Wroclaw, covered various types of crossings. The tests were conducted in 2018. The results were collected with a record of behaviour of over 660 people (not including people crossing in the group). Research carried out in Wroclaw on pedestrian crossings without traffic lights referred to three types of transitions:

- crossings leading only through the tram track - crossings A,
- crossings leading through a single carriageway with a separate track - crossings B,
- crossings leading across the road without a tram track - crossings C.

Figure 9 is a graph showing shares of individual pedestrian behaviour when crossing the roadway. What is important, the study distinguished two groups of behaviours depending on the presence of the vehicle near the crossing. Each group is a separate pool of behaviours and the number of behaviours within a single group is added up to 100%.

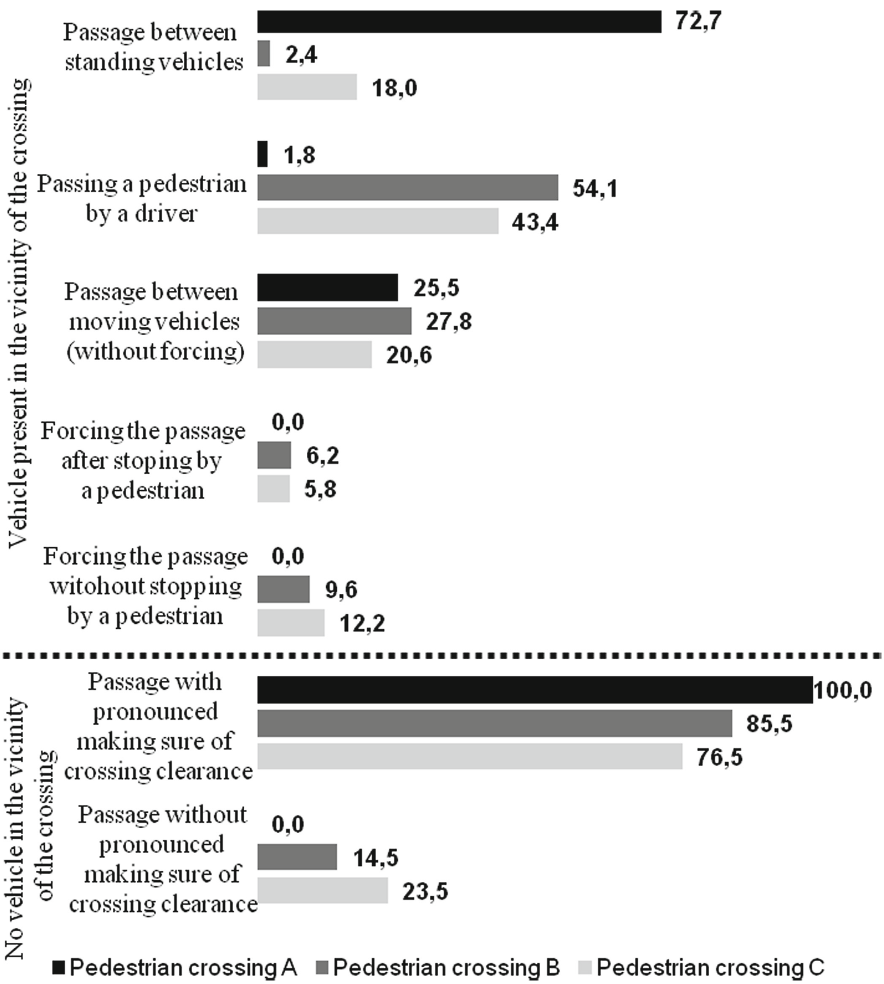


Fig. 9. Percentage share of pedestrian behaviour on various types of pedestrian crossings without traffic lights in Wroclaw (Source: own study based on [9])

Analysis of the results collected on different types of crossings led to the following conclusions:

- there were no forcing of priority for crossings leading only through tram tracks and the share of forcing for crossings, on which in addition to cars, there were also trams, was also lower than in the case of crossing the road for individual vehicles. Observations carried out during the investigations at B crossings have allowed to observe that forcing the priority of pedestrian crossing was mainly related to individual vehicles. The presence of the tram approaching the passage resulted in further waiting of the pedestrian before the crossing,
- in the case of pedestrians crossing a track, pedestrians always make sure that they can pass safely. This share is equally high for the other two types of crossings,
- passing the pedestrians by drivers consisting in a significant reduction of speed or total stoppage of the vehicle by the driver often combined with a gesture of invitation to cross the road is very common among drivers. Passing the pedestrians by tram-drivers is very rare.

3.3 Tests Conducted in Gdańsk

Tests in Gdańsk were carried out on three pedestrian crossings leading only through the tram track. These crossings are characterized by a different type of traffic organization. The tests were based on the registration of the behaviour of 300 people crossing the street. This number does not include people crossing the road additionally (in a group). The study selected the transitions at the stops located within Aleja Grunwaldzka and its extension on Aleja Zwycięstwa. A characteristic feature of the examined crossings is the immediate vicinity of two tram stops (both directions) within a given passage. These stops are as follows: Jaśkowa Dolina (1), Miszewskiego (2) and Politechnika (3).

Fig. 10. Example of a traffic light used in Gdańsk for warning traffic lights located at pedestrian crossings leading through tram tracks

Each of tested pedestrian crossings is a part of a group of three crossings leading from one side of the road to the other. The road system at the test site is characterized by a dual carriageway, which is crossed by technological belts with a separate track. Within intersections, the road lane is widened, thanks to which it is possible to create asylums between individual crossings providing access to stops and waiting for the possibility of further passage.

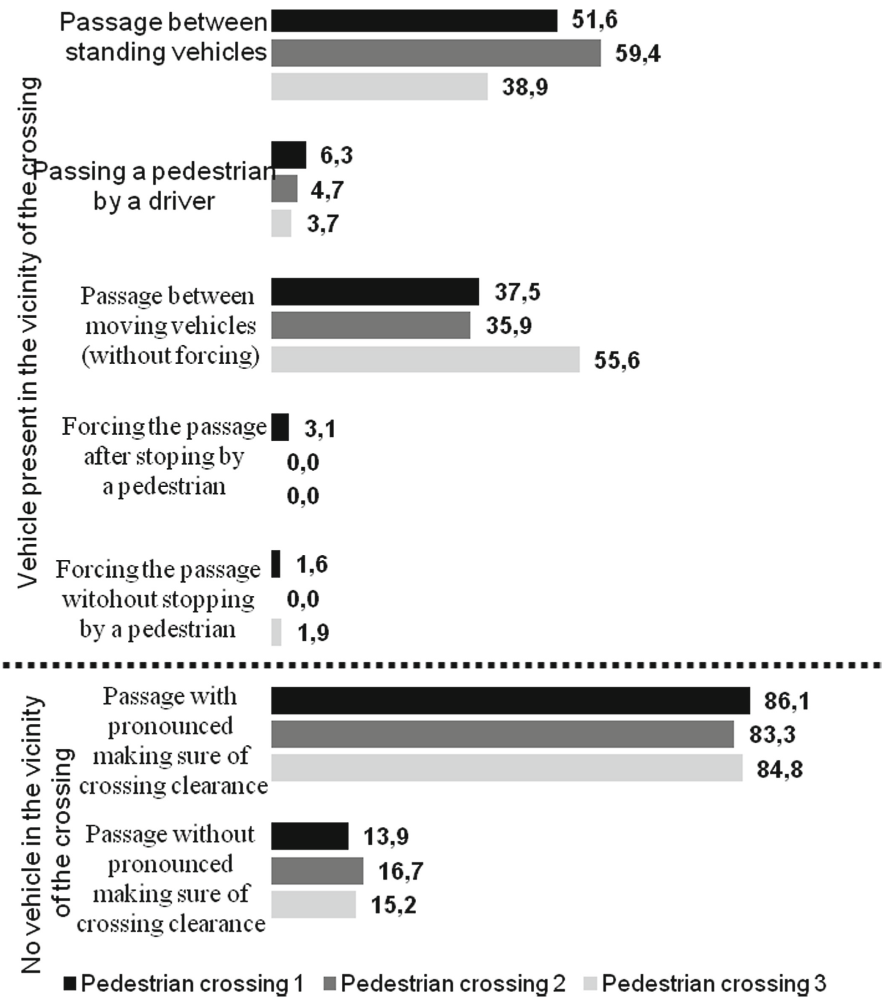


Fig. 11. Percentage share of pedestrian behaviour on pedestrian crossings without traffic lights in Gdańsk (Source: own study based on [9])

The regulation of crossing the road is carried out by means of traffic lights and passages through the track are examples of crossings without traffic lights, marked as in Fig. 6, with the exception of passage 3. On this transition, the traffic regulation is made by means of warning signal which switches on when the tram approaches crossing. At the moment of sending a warning, a flashing light signal with tram graphics appears on the siren (Fig. 10) and a repeating recording 'attention, tram' is emitted in the crossing area. Both signals are transmitted until the tram travels through the track. In spite of the use of warning traffic lights on this particular passage, the study of pedestrian behaviour was carried out using the test method of crossings without traffic lights. This is dictated by the lack of legal conditions in Polish law regulating the traffic warning lights for pedestrians.

The results of the tests carried out are presented on Fig. 11.

In the case of analysing the behaviour of pedestrians crossing the tram track in Gdańsk at the time when no tram was approaching, one can observe a decrease (in relation to research in Wroclaw) the percentage of people pronounced making sure of the possibility of crossing the track safely. Forced priorities are in all cases very low and are isolated cases. The resignation of priority by the tram drivers is higher than in Wroclaw, however they still constitute a low share, on average 5% of these behaviours. In each case, the majority of behaviours constitute a crossing between moving vehicles (without forces) or standing at the stop (passenger service). The location of a pair of stops on one side of the intersection makes it very easy to assess the safety of crossing the track because during passenger service, it is important to consider only one not two vehicles by pedestrian traffic.

3.4 Summary of Tests on Crossings Without Traffic Lights

Based on the conducted research, it can be observed that the behaviour of pedestrians on crossings without traffic lights is characterized by a high percentage of lawful behaviours. Very low share of forcing and very high level of explicit making sure by pedestrians about the possibility of crossing the road safely was observed. In the case of forcing of priority by pedestrians crossing tram tracks their low share is motivated by [9]:

- a greater sense of danger when crossing the road when forcing a priority over the tram with respect to analogous behaviour in front of an individual vehicle,
- awareness of the need to privilege public transport vehicles, passengers of which are very often pedestrians - no need to stop in front of the crossing results with no (or smaller) delay,
- in the case of a stop in the immediate vicinity of the crossing, pedestrians are sure about the possibility of entering the public transport vehicle because the tram will stop at the stop, therefore pedestrian access to the vehicle may take place at the time of passenger exchange and there is no need to force a priority to get to the stop before the tram.

4 Summary

A high share of unlawful behaviours at crossings regulated by traffic lights and test results on crossings by tracks without traffic lights indicate the lawfulness of pedestrian behaviour at the moment of crossing the road. This allows to state that it is reasonable to depart from the traffic control by traditional traffic lights at crossings through tracks. What is important, this approach also significantly affects the flow of trams and their communication speed, which is not decreased as a result of the need to reduce the speed or total stopping of vehicles in front of the crossing.

Research carried out in two Polish cities both on crossings through the tracks with and without traffic lights, indicate mutual correlations of the obtained results. This may testify to the global significance of the presented research. Gdańsk as an example of a city which over recent years has left from signalling at crossings through a track, is an example in which the behaviour of pedestrians at crossings through the track are consolidated by experience. This ensures that the tests carried out at crossings with the form of pedestrian warning are not new to the group of respondents and they have adapted to the existing solutions.

Comprehensive analysis of data allows to conclude that undertaking alert actions better fulfil its function than only restrictive actions. Comparing the shares of crossings on the red signal in Wroclaw and Gdańsk, it can be noted that in the case of Wroclaw, where most of the crossings are regulated by traffic lights, the share of crossings on the red signal is higher than in Gdańsk. The difference in average results is almost 14 percentage points. This indicates that compliance with signalling indications in Gdańsk is much higher than in Wroclaw. It may also affects the perception of the essence of signalling and the rightness of adherence to its indications on all types of crossings. Limiting confidence in the legitimacy of traffic lights, especially among pedestrians, can lead to very dangerous situations. Therefore, the advantage over traditional signalling has warning signalling.

Elements that complement warning lights are also pictograms placed within the crossings by tracks, which clearly distinguish the traditional zebra. The signs used clearly indicate possible danger and therefore a need for extreme caution. Some additional voice or light warnings appearing at some of Gdańsk's passages, or both at once, complete the horizontal signage to create a warning signal that is activated only at the moment of danger. Awareness that transmitted signals inform about the actually approaching tram and not only limit the traffic, ensure greater security and greater freedom of movement for both groups of traffic users. In the case of standard signalling, there is no clear information whether the tram will appear at all on the crossing, which is likely with the specificity of trams. Situations in which, despite the red signal being displayed by the crossing, no tram passes, adversely affect the behavior of pedestrians. This is evidenced by, inter alia, high shares of crossing the track on the prohibitory signal.

The research carried out and presented in this article is the basis for making decisions to change the way pedestrian traffic is organized at the crossings of tram tracks. Recommended solutions are characterized by much higher lawfulness of pedestrian behaviour and at the same time provide them with a higher level of security than in the case of solutions used traditionally.

References

1. Asadi-Shekari, Z., Moeinaddini, M., Zaly Shah, M.: Pedestrian safety index for evaluating street facilities in urban areas. Saf. Sci. **74**, 1–14 (2015)
2. Nesoff, E.D., Pollac Porter, K.M., Bailey, M., Gielen, A.C.: Knowledge and beliefs about pedestrian safety in an urban community: implications for promoting safe walking. Commun. Health **44**, 103–111 (2019)
3. Bauer, M., Dźwigoń, W.: Study method for pedestrian behaviour in the area of pedestrian crossings located at tram stops. MATEC Web Conf. **122**, 1–6 (2017)
4. Budzynski, M., Jamroz, K., Mackun, T.: Pedestrian safety in road traffic in Poland. IOP Conf. Ser.: Mater. Sci. Eng. **245**, 1–9 (2017)
5. Mrozik, M.: Badania i ocena prędkości poruszania się pieszych użytkowników ruchu drogowego. Postępy Nauki i Techniki **5**, 138–144 (2010)
6. Demiroz, Y.I., Onelcin, P., Alver, Y.: Illegal road crossing behavior of pedestrians at overpass locations: factors affecting gap acceptance, crossing times and overpass use. Accid. Anal. Prev. **80**, 220–228 (2015)
7. Papadimitriou, E., Lassarre, S., Yannis, G.: Introducing human factors in pedestrian crossing behaviour models. Transp. Res. Part F: Traffic Psychol. Behav. **36**, 69–82 (2016)
8. Papadimitriou, E., Lassarreb, S., Yannisa, G.: Human factors of pedestrian walking and crossing behaviour. Transp. Res. Procedia **25**, 2002–2005 (2017)
9. Skupień, E., Rydlewski, M.: Analysis of pedestrian behavior at pedestrian crossings with public transport vehicle. In: Macioszek, E., Akçelik, R., Sierpiński, G. (eds.) Roundabouts as Safe and Modern Solutions in Transport Networks and Systems. LNNS, vol. 52, pp. 157–166. Springer, Cham (2019)
10. Rydlewski, M: The influence of the traffic lights on behavior of pedestrians at the road crossings. In: Proceedings from Conference Zimowa Szkoła Niezawodności, Szczyrk (2019, in print)
11. Google maps website. https://www.google.com/maps

Traffic Organization Issues at Signalized Intersections - Case Study Related to Traffic Distribution Over Lanes

Grzegorz Sierpiński(✉) and Marcin Staniek

Faculty of Transport, Silesian University of Technology, Katowice, Poland
{grzegorz.sierpinski,marcin.staniek}@polsl.pl

Abstract. Signalized traffic control may significantly improve traffic safety by eliminating potential collision points within a specified time frame (signalling phase). Traffic organization on multiple-lane inlets requires an appropriate division of traffic over lanes. It is also very important to make it legible and eliminate ambiguity of signals and road signs. The article presents selected aspects of the problem. It discusses real-life examples and simulations aimed at analysing different solutions for multiple lane inlets to signalized intersections. Comparative analysis covers, inter alia, the length of vehicle queues and delays at accesses.

Keywords: Traffic organization · Road safety · Traffic control · Traffic signalization · Traffic simulation

1 Introduction

Every transport network should convey the traffic [1] in a safe and uninterrupted manner [2–4]. This applies to all modes of transport moving both people [5] and cargo [6–10]. At the same time, the reduction of the negative impact of transport on the environment remains equally important [11–14]. Planning and analysis of the transport network can be carried out at the macro, or comprehensive, level [15–18], or it can be a subject of a micro analysis that focuses on segments and nodal points (e.g. [19, 20]).

Intersections are bottlenecks on the transport network in cities. These locations cause significant restrictions to the volume of traffic going in different directions with many collision points along the way [21]. Therefore, efficient traffic handling and safety are particularly important. The organization of traffic at such points should be orderly and legible to drivers.

Traffic lights are a fixed element of the transport infrastructure that causes intermittent breaks in the flow of traffic. This enhances safety and controls the traffic at intersections while reducing the number of collision points at the same time. The efficiency of signalling depends primarily on the length of individual signals.

The article focuses on selected issues related to the distribution of traffic over lanes. Simulation-based research has delivered findings for different solutions applied at inlets to intersections.

E. Macioszek et al. (Eds.): TSTP 2019, LNITI, pp. 171–179, 2020.
https://doi.org/10.1007/978-3-030-39109-6_13

2 Problem Identification

An intersection with multiple-lane inlet roads can be frequently found along the main routes in cities. This necessitates a division of the traffic (straight ahead, left turn and right turn) over two or more lanes. The most transparent solution is to designate a separate lane for each traffic direction. Then the traffic is distributed already before entering the intersection and vehicles enter it in an uninterrupted manner. However, such a solution is not always possible. Its drawbacks include the need to reserve more space and it leads to a loss of time due to separate phases in the signalling scheme for particular inlets to eliminate collision points. Therefore, intermediate solutions, which involve reduced number of lanes and several directions mixed within one lane (e.g. common lane for left turn and straight ahead or straight ahead and right turn traffic) are more frequently used. A specific direction can be supported over more than one lane. In this case, while selecting a direction that is assigned to more than one lane in a calculation group, the driver needs to take into account the following [22]:

- traffic volume on the lane, and select the lane with a shorter queue, and
- designation of lanes with preference of a lane with a single direction traffic.

This leads to a more even traffic spread over the lanes in the same calculation group.

However, some cities apply solutions that are less clear for drivers, e.g. a common lane with a possibility of enter the intersection and travel in two directions, with each direction controlled by an independent traffic light (i.e. green light) in a specific phase (or sub-phase). This solution is used in several locations in Katowice, Poland. One of them is the intersection of Chorzowska, Bracka and Złota streets. At the inlet of Chorzowska Street, we have two left turn lanes, one as a separate lane, and the second lane where the left turn traffic is combined with the straight ahead traffic (Fig. 1). In this particular traffic organization, the green light for turning left ends earlier than for going straight ahead. Thus, vehicles moving straight along the mixed-direction lane need to wait for the green light longer due to vehicles turning left which failed to enter the intersection during the previous phase. In this example, one lane uses two traffic light signalization for each direction separately.

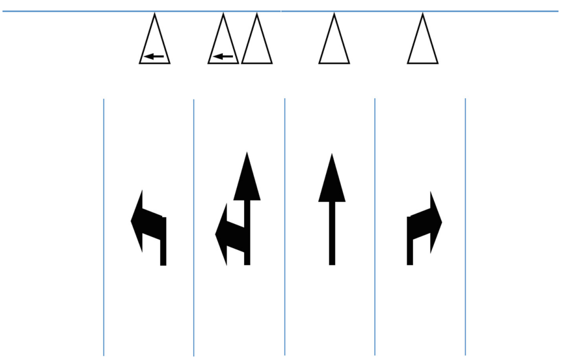


Fig. 1. Simplified diagram of the arrangement at the inlet to the Chorzowska-Bracka-Złota intersection with breakdown by directions and traffic light signalling

According to research [23], the interrupted vehicle flow causes hazardous situations, particularly due to a significant volume of traffic going straight ahead. Table 1 shows the most frequently observed inappropriate behaviour that has led to collisions. When drivers going straight ahead notice cars stop at the mixed-direction lane, they start braking which causes additional risk.

Table 1. Summary of road incident causes at the intersection of Chorzowska-Bracka-Złota in Katowice (Source: Own research based on [23])

Cause of road incident	2016	2017	Total
Failure to keep safe distance	17	8	25
Incorrect change of lanes	1	3	4
Failure to give way	2	1	3
Failure to follow traffic lights	2	–	2
Failure to adjust speed to traffic conditions	1	–	1
Incorrect overtaking	–	1	1
Total	23	13	36

A similar solution has been applied at the intersection of 1 Maja and Bohaterów Monte Cassino streets. In this case, there are two mixed-designation lanes. One for left turn traffic and straight ahead traffic and the other for straight ahead and right turn traffic. The first lane is controlled by two signalling devices with the same sequence of signals displayed (Fig. 2).

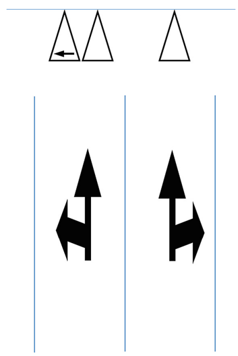


Fig. 2. Inlet to intersection of 1 Maja and Bohaterów Monte Cassino streets with traffic light signalling devices for the left-turn lane

It is possible to eliminate traffic control ambiguity in two ways:

- traffic organization with mixed-designation lanes but with one common signal assigned in the traffic light signalling scheme,
- change of traffic organization by separating left turn from straight ahead traffic.

Although the second solution increases legibility of signals, it causes considerable delays for the straight ahead traffic. Considering the above, the article presents a digital analysis based on simulation models for the first solution only.

3 Research Method and Simulations

In Poland, the capacity of intersections with traffic lights is assessed using the 2004 method which takes into account national empirical data, results of simulations, and adjustments in line with changes to international methodologies. It also includes updates imposed by the Regulation of the Minister of Infrastructure on detailed technical conditions for road signs and signals, and road safety equipment and conditions for placing such equipment on roads. This method is applied for intersections controlled by fixed-time accommodative traffic lights with non-cyclical switching patterns. The accommodative and non-cyclical algorithm is used and the traffic volume is examined for the maximum programme during peak time and temporary accumulation of traffic at intersections [24].

The methodology, however, does not take into account the impact of the queue of vehicles at the outlet and accumulation areas of intersections with a central isle or a wide buffer strip on their operation. Moreover, it also does not take into account unusual arrangements (e.g. railway passes near road intersections). All the above cases have required to apply simulation models to assess traffic conditions at intersections.

3.1 Preliminary Assumptions

Commonly used traffic simulation environments can be classified into three categories: micro, mezzo and macro. Simulations available are based on the correlation of two of the three models to eliminate drawbacks attributable to individual models. In general, the microscopic, continuous or discrete models provide information about the status of individual vehicles while describing traffic parameters for those vehicles and their locations. The macroscopic model covers traffic intensity (flow speed) and density [25], the latter is the measure of efficiency.

The VISSIM is a microscopic model of traffic flow that includes the car following logic and lane changes logic. A key element of the traffic description is the quality of data pertaining to the current behaviour of vehicles or the pattern of vehicle movement in the network. Comparing with simple models based on a constant speed and a deterministic logic of a vehicle following the leader, the VISSIM uses a psychophysical model for driver's behaviour developed by Wiedemann (1974) [26].

The Wiedemann's model assumes that the driver of a vehicle moving faster starts braking when he notices a vehicle ahead moving at a slower rate. Assuming that the driver cannot accurately determine the speed of the vehicle ahead, he starts braking and continues the process until the speed falls below the speed of the preceding vehicle. In the next phase, acceleration begins until the next speed perception threshold is reached. In consequence, acceleration and deceleration occur in iterations. The stochastic distribution of speed and spatial thresholds, which are editable by the software user, reflect characteristics of individual driver's behaviours. The baseline traffic model has been calibrated against multiple field measurements at the Karlsruhe Technical University [26]. Periodical measurements and the update of model parameters ensure that changes of field conditions, preferences of drivers and the vehicle construction are taken into account.

3.2 Joint Lane for Two Directions and Separate Phases

In this case, it has been assumed that the inlet consists of two lanes. Each of the two lanes conveys combined left and straight ahead and right and straight ahead traffic. Two independent traffic lights are assigned to the inner lane for each direction. The green light signal starts to be transmitted at the same time by all traffic lights at the inlet. The length of the green signal for the left turn traffic is 26 s and 40 s for other directions. Simulation parameters are shown in Table 2. Simulations have been repeated for various straight ahead and left turn traffic volumes.

Table 2. Summary of simulation results for the mixed direction lane and separate green light signals depending on the volume of traffic [Veh/h].

Parameter	L = 100 W = 200 P = 200	L = 200 W = 400 P = 200	L = 300 W = 600 P = 200	L = 400 W = 800 P = 200
Average time to turn left	52.1	57.9	70.7	127.3
Average time to pass straight	43.7	45.8	51.5	100.1
Average time to turn right	44.2	46.1	50.9	89.0
Average queue length	7.4	13.1	23.9	200.4
Number of stops	330.1	581.6	931.2	3818.9

Where: *L* - left turn traffic; *W* - straight ahead traffic; *P* - right turn traffic.

Results show an increased interruption to the traffic flow with the growing traffic volume.

3.3 Joint Lane for Two Directions and a Common Phase

In this case, the same traffic organization has been adopted as in solution 3.2, i.e. two mixed-direction lanes at the inlet. The same green light signal of 40 s has been adopted for all directions (both lanes). Parameters from the simulation are shown in Table 3. Simulations have been repeated for various values straight and left turn traffic volumes.

In this case, we can observe a growing interruption to traffic with the increase in the traffic volume. Comparison with Table 1 shows a smaller rate of changes. According to the solution simulated, the straight ahead traffic lane is blocked by vehicles turning left to a lesser degree than in the case described in 3.2.

Table 3. Summary of simulation results for the mixed direction lane and common green light signals depending on the volume of traffic [Veh/h].

Parameter	L = 100 W = 200 P = 200	L = 200 W = 400 P = 200	L = 300 W = 600 P = 200	L = 400 W = 800 P = 200
Average time to turn left	41.6	47.7	50.0	69.5
Average time to pass straight	43.4	45.1	47.8	66.4
Average time to turn right	43.9	45.8	48.3	65.7
Average queue length	7.1	11.8	18.7	51.9
Number of stops	317.1	552.6	820.6	1593.8

Where: *L* - left turn traffic; *W* - straight ahead traffic; *P* - right turn traffic.

4 Analysis of Results

Time delay is a basic measure that determines the level of service at an intersection. Essentially, it is an additional time needed to cross the signalized intersection comparing with the time required to cross the intersection without any interruption (without a stop at the inlet) [22]. The measure determines the efficiency of a solution.

The summary of time delays for the simulation described in 3.2 and 3.3 is presented in Fig. 3.

Figure 3a shows the drop in the time delay when we extend the duration of a green light (from 26 to 40 s per phase). At the same time, the comparison of results for both solutions enables to estimate the traffic volume above which the obstruction of the straight ahead traffic significantly increases due to the left turn traffic on the same lane (Fig. 3b). Moreover, the right turn traffic on the adjacent lane is also interrupted, since more drivers choose the external lane in the case of the first solution (Sect. 3.2).

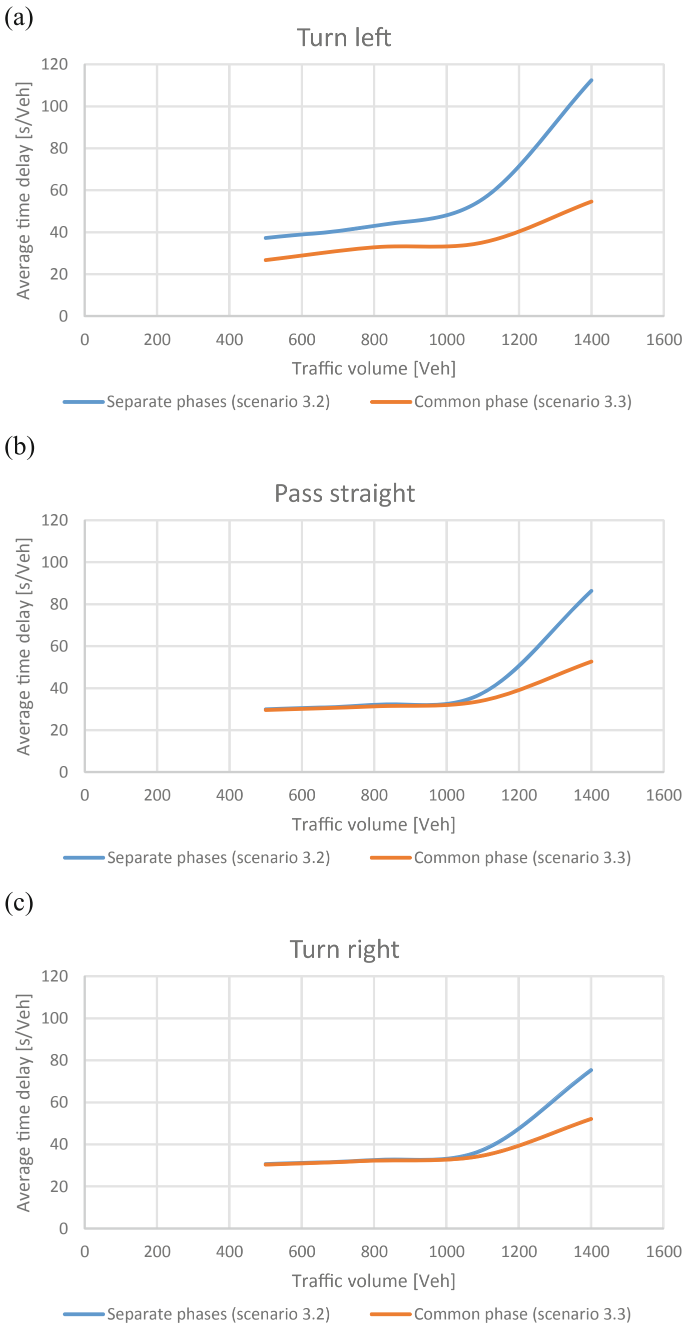


Fig. 3. Change of time delays depending on traffic volumes and directions at simulated inlet: (a) left turn, (b) straight ahead; (c) right turn

5 Conclusion and Further Research

Breakdown of the directional traffic into lanes is one of issues faced by a person responsible for the traffic organization and traffic control algorithm. It should be noted that methods that may support the process include computing procedures. Simulation models that also take into account speed profiles, operating characteristics and driver behaviour can be used while testing different scenarios. The article has focused on selected aspects of the problem. In instances examined, two different traffic light signals for one lane might be problematic in terms of their clarity and ambiguity. This may lead to hazardous situations, such as emergency braking or an abrupt change of lane. We also observe increased delays in such a constrained directional traffic. Further research is going to extend the simulation model to cover other solutions, as well as specify additional dependencies in the traffic structure.

References

1. White Paper: Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system. COM, p. 144 (2011). https://ec.europa.eu/transport/sites/transport/files/themes/strategies/doc/2011_white_paper/white-paper-illustrated-brochure_en.pdf
2. Celiński, I.: Evaluation method of impact between road traffic in a traffic control area and in its surroundings. Ph.D. dissertation. Oficyna Wydawnicza Politechniki Warszawskiej, Warsaw (2018)
3. Galińska, B.: Multiple criteria evaluation of global transportation systems - analysis of case study. In: Sierpiński, G. (ed.) Advanced Solutions of Transport Systems for Growing Mobility. AISC, vol. 631, pp. 155–171 (2018)
4. Celiński, I.: Using GT planner to improve the functioning of public transport. recent advances in traffic engineering for transport networks and systems. In: Macioszek, E., Sierpiński, G. (eds.) Recent Advances in Traffic Engineering for Transport Networks and Systems. LNNS, vol. 21, pp. 151–160 (2018)
5. Turoń, K., Golba, D., Czech, P.: The analysis of progress CSR good practices areas in logistic companies based on reports “responsible business in poland. good practices” in 2010–2014. Sci. J. Silesian Univ. Technol. Ser. Transp. **89**, 163–171 (2015)
6. Golba, D., Turoń, K., Czech, P.: Diversity as an opportunity and challenge of modern organizations in TSL area. Sci. J. Silesian Univ. Technol. Ser. Transp. **90**, 63–69 (2016)
7. Wątróbski, J., Małecki, K., Kijewska, K., Iwan, S., Karczmarczyk, A., Thompson, R.G.: Multi-criteria analysis of electric vans for city logistics. Sustainability **9**(8), 1–34 (2017)
8. Żak, J., Galińska, B.: Design and evaluation of global freight transportation solutions (corridors). analysis of a real world case study. Transp. Res. Procedia **30**, 350–362 (2018)
9. Galińska, B.: Intelligent decision making in transport. evaluation of transportation modes (types of vehicles) based on multiple criteria methodology. In: Sierpiński, G. (ed.) Integration as Solution for Advanced Smart Urban Transport Systems. AISC, vol. 844, pp. 161–172. Springer, Switzerland (2019)
10. Jacyna, M., Żak, J., Jacyna-Gołda, I., Merkisz, J., Merkisz-Guranowska, A., Pielucha, J.: Selected aspects of the model of proecological transport system. J. KONES, Powertrain Transp. **20**, 193–202 (2013)

11. Turoń, K., Czech, P., Juzek, M.: The concept of Walkable City as an alternative form of urban mobility. Sci. J. Silesian Univ. Technol. Ser. Transp. **95**, 223–230 (2017)
12. Małecki, K.: The importance of automatic traffic lights time algorithms to reduce the negative impact of transport on the urban environment. Transp. Res. Procedia **16**, 329–342 (2016)
13. Santos, G.: Road transport and CO2 emissions: what are the challenges? Transp. Policy **59**, 71–74 (2017)
14. Kauf, S.: City logistics - a strategic element of sustainable urban development. Transp. Res. Procedia **16**, 158–164 (2016)
15. Macioszek, E., Lach, D.: Analysis of the results of general traffic measurements in the west pomeranian voivodeship from 2005 to 2015. Sci. J. Silesian Univ. Technol. Ser. Transp. **97**, 93–104 (2017)
16. Celiński, I.: GT planner used as a tool for sustainable development of transport infrastructure. In: Suchanek, M. (ed.) New Research Trends in Transport Sustainability and Innovation. SPBE, pp. 15–27. Springer, Cham (2018)
17. Macioszek, E., Lach, D.: Comparative analysis of the results of general traffic measurements for the Silesian voivodeship and Poland. Sci. J. Silesian Univ. Technol. Ser. Transp. **100**, 105–113 (2018)
18. Cárdenas, O., Valencia, A., Montt, C.: Congestion minimization through sustainable traffic management. a micro-simulation approach. LogForum **14**(1), 21–31 (2018)
19. Macioszek, E., Lach, D.: Analysis of traffic conditions at the Brzezinska and Nowochrzanowska intersection in Myslowice (Silesian Province, Poland). Sci. J. Silesian Univ. Technol. Ser. Transp. **98**, 81–88 (2018)
20. Gartner, N., Messer, C.J., Rathi, A.K.: Traffic Flow Theory. A State-of-the-Art Report. Transportation Research Board, Washington (2001)
21. Chodur, J. (ed.): The method of capacity estimation for signalized intersection. General Directorate for National Roads and Motorways, Warsaw (2004). [in Polish]
22. Duda, K.: Research on the impact of incorrect marking and traffic organization on road safety. Master of Science Thesis. Supervisor: Grzegorz Sierpinski. Silesian University of Technology, Faculty of Transport, Katowice (2018)
23. Ministry of Infrastructure: Regulation of the Minister of Infrastructure of 3 July 2003, on detailed technical conditions for road signs and signals as well as road safety devices and conditions for placing them on the roads. Dz.U. 220, poz. 2181. Ministry of Infrastructure, Warsaw (2003). [in Polish]
24. Boxill, S.A., Yu, L.: An Evaluation on of Traffic Simulator on Models for Supporting ITS Development. Center for Transportation on Training and Research, Texas Southern University, Houston (2000)
25. Higgs, B., Abbas, M., Medina, A.: Analysis of the Wiedemann car following model over different speeds using naturalistic data. http://onlinepubs.trb.org/onlinepubs/conferences/2011/RSS/3/Higgs,B.pdf
26. VISSIM. http://vision-traffic.ptvgroup.com/en-us/products/ptv-vissim/

Analysis of the Methods of Traffic Evaluation at the Approaches of Urban Signalised Intersections

Damian Iwanowicz(✉) and Jacek Chmielewski

Faculty of Construction, Architecture and Environmental Engineering,
University of Technology and Life Sciences, Bydgoszcz, Poland
{damian.iwanowicz, jacek-ch}@utp.edu.pl

Abstract. The paper presents conclusions drawn from an analysis of available methods of evaluation of road traffic conditions at approaches of signalized intersections and at interchanges. The analysis was performed due to the need to evaluate changes in the length and reach of vehicle queues, in order to gain insight into the process of development (accumulation, dispersion, concentration and relief) of the queues. The analysed methods included: conventional recording of the number of vehicles in a queue using a form, methods that involve the use of a voice recorder, photo camera, UAV (drone) and individual miniature video cameras (with built-in power supply) installed on streetlight poles along the relevant road section. Ultimately, the latter was chosen to evaluate the process of queue formation, having confronted the advantages and disadvantages of all the methods considered. The paper also describes the course of analysis and processing of measurement data using specially-developed computer software for the selected method.

Keywords: Road traffic evaluation · Traffic-light intersection · Road interchanges · Vehicle queues

1 Introduction

Correct identification of traffic conditions in an urban road network is important for the assessment of the overall network traffic efficiency and the efficiency of its crucial elements - intersections - in particular. A similar problem is in the case of the evaluation of traffic conditions on road interchanges in urban areas. The most common measure of traffic conditions consists in the determination of the mean loss of travel time per vehicle. Other measures include the mean number of traffic stoppages and the mean length of vehicle queues formed on individual lanes at an intersection approach.

Determination of the above-mentioned measures of traffic conditions enables planners, designers and road administration authorities to evaluate the quality solutions applied to a relevant element of the road network in terms of the layout of the intersection approach, the organization and channelization of traffic, the kind of traffic control software etc. Moreover, such measures are used to design new solutions for traffic flows within a relevant road network area, either to upgrade the existing ones or to provide alternative routes and their connection to the existing road structure [1–4].

E. Macioszek et al. (Eds.): TSTP 2019, LNITI, pp. 180–198, 2020.
https://doi.org/10.1007/978-3-030-39109-6_14

In the past, a mean rate of traffic flow whose value was assigned to established classes was considered a reliable measure enabling classification of traffic conditions. Nowadays the main measure of actual traffic conditions in a road network is a mean loss of travel time per vehicle, either moving along a road section or crossing an intersection. A mean loss of time crossing an intersection obviously reflects theoretically valid effects of traffic disturbances but it does not show their causes. It should be noted that the length or reach of vehicle queues are verifiable measures enabling identification of the causes of traffic disturbances and their effects. This has a major influence on the undertaking of measures aiming at improvement of traffic within an analysed approach of a signalized intersection, or an exit road of an interchange [5, 6].

The observable increase in traffic congestion in cities, both in Poland and abroad [7–10], leads to a speculation that in the near future we are likely to accept further losses of time when travelling (in particular as far as generated trips and absorbed trips in cities and intra-city trips when crossing the intersections of major arterial roads). Consequently, in order to establish the methodology and tools to evaluate and optimize traffic flows in the condition of considerable congestion, solutions have been sought to measure road traffic density at intersection approaches and along the road section leading to the intersection. The objective was to find a research method that would enable an analysis of traffic conditions along the entire section under consideration, starting from the intersection approach. Based on experience gathered from research work, this paper presents the conclusions from a selection of methods to evaluate traffic conditions in permanent vehicular traffic congestion of urban road networks, mainly including the length and reach of vehicle queues at the approaches to intersections with traffic lights.

2 Evaluation of Road Conditions - A Common Practice

As indicate in the introduction, the most common method of evaluation of road conditions consists now in the determination of mean losses of travel time per vehicle. The planners and designers of road infrastructure, including traffic signalling software, use a variety of instructions and manuals to determine the measures for this purpose [1–4]. Thanks to such tools they are able to specify the so-called "Level of Service" (LOS) for a given element of road infrastructure, on the basis of which a developed solution is admitted (or not) as regards its structural design, geometry, organization etc. The other measures of traffic condition in the planning and design processes are used only to check possible blocking of accumulation zones or adjacent intersections (using the value of maximum reach of a queue of vehicles in metric units) [1–4].

In present circumstances road authorities of large cities increasingly aggregate the data on mean travel time it takes vehicles to cross a road section to establish a deviation from a reference value. There are a few methods of acquisition of data to determine road conditions, however detecting vehicles passing specific road sections remains one of the most common of these. The data comprises vehicle registration numbers read using automatic vehicle identification (ARCP) cameras, most often installed at the intersection departures/exit legs [11]. The data is then statistically processed. In this way, recording the time taken to transit a road section provides information on the mean time of travel along the corresponding section of a route (or the mean speed of travel). Thanks to that road and traffic authorities can determine various scenarios of service for vehicles crossing the intersections covered by signalized control as part of an Intelligent Transportation System (ITS), depending on current traffic requirements. Presentation of such data in a graphic form to drivers enables them to select alternative routes where messages about unfavourable traffic conditions in a specific section or an exit from an interchange are displayed. Such as system of acquisition and presentation of date is being implemented in a growing number of cities, including Bydgoszcz (Fig. 1) [11].

Fig. 1. ITS subsystem components in Bydgoszcz used to navigate drivers to alternative routes (A, B - ARCP cameras; C, D - city traffic status displays controlled by ITS)

The problem of traffic congestion at rush hours in cities almost always takes place at intersections with traffic lights. This is why it is so important to determine reliable traffic conditions that occur or may occur at approaches to such intersections. In [12] it was observed that where substantial traffic congestion persists for a long time or where vehicle queues increase dynamically yet for a short time, the existing and commonly used mathematical calculation models overlook essential traffic conditions at intersection approaches, both where a mean length of a queue is being determined and the ensuing mean loss of travel time (which refers to a more precise method of determination of traffic conditions in multi-interval analysis). In addition, the traffic loading defined in a standard way is very often underestimated due to incorrect determination (only the values of incoming traffic and flow capacity are used whereas vehicle queues at the approach are disregarded). Therefore it is claimed that in the circumstances of increased transport demand the LOS is often substantially underestimated and does not reflect the actual traffic conditions in the given road network [12].

3 Analysis of the Methods of Measurement of Traffic Density

One of the most popular measurement methods used to determine traffic density, including vehicle queue lengths and reaches, consists in taking two local measurements at the initial and final point of an road section [13]. The idea is to register the time vehicles appear at the two points and to record their distinctive features for subsequent identification. The goal of the measurement is to establish the total time the vehicle remained between the two measuring points at the time of observation [13]. The method, however efficient it is, does not provide detailed information about the traffic conditions in the database. The only information given is the number of vehicles recorded and the time they remained within the measured section. Therefore, in order to find out more details about the behaviour of drivers in the conditions of increased traffic congestion (in a queue of vehicles) other methods had to be developed.

All of the methods described below are based on the same general idea as above. However, as a characteristic feature of measuring the length of vehicle queues at the approaches to traffic-light intersections, data is aggregated to an analytic interval equal to the duration of a single signalling cycle, including two sampling sub-intervals (the effective duration of the red and the green signal). In order to carry out detailed analysis of traffic conditions, including the parameters of vehicle queues, for the same time intervals measurements of the traffic volumes at the intersection, both incoming and outgoing during the green signal, have to be made, including the type structure and direction of the vehicle streams. It is possible to aggregate the data further according to longer sampling intervals (e.g. 15 min' long).

Considering the above, some measurement methods were applied in practice and their strengths and weaknesses are listed in Table 1.

Table 1. Advantages and disadvantages of various methods of measurement of the length and reach of vehicle queues.

Pos.	Method	Strengths	Weaknesses
1.	Measurement form	• Easy and quick to apply • Low cost • Clear tasks and results • Relatively quick analysis of data based on simple balancing	• Applicable only to traffic lights with constant signal duration (cycle duration and individual signal durations have to be known) • Only one traffic lane can be analysed • Does not consider vehicles merging and separating • Lack of details about the time of individual manoeuvres done by recorded vehicles • Recording types at increased traffic volumes may cause notational issues • Minimum 3 persons required

(*continued*)

Table 1. (*continued*)

Pos.	Method	Strengths	Weaknesses
2.	Voice recorder	• Quick and cheap to use • Recorded events are time stamped • Multiple reading of the data possible	• See above • Lengthy data processing • Personnel needs to be specially trained to use specific voice commands
3.	Photographs (camera)	• See above (Item 2) • No need to count vehicles forming the longest queue • Possible to apply to approaches with multiple lanes	• See above (Item 2) • In the case of long queues possible counting inaccuracies and the issue of larger vehicles obstructing smaller ones
4.	Digital camera (drone)	• Single video of the entire queue (if no obstacles present) • Multiple reading and processing of the data • Possible fast-forwarding and slowing of the playback • Possible zooming in and out • Covers multiple traffic lanes • (Option) possibility to implement software counting vehicles in queues (vehicle tracking)	• Two persons required: a drone pilot and a navigator • Drone pilot licence required • Pilot needs to be trained in the acquisition of required data (expected video images) • Highly sensitive to bad and changeable weather conditions • Short operation time of a single drone • High cost • Separate simultaneous recording of traffic light sequences necessary • Labour intensive data analysis
5.	Digital cameras (streetlight poles)	• No personnel required to carry out measurements • Measuring equipment can be used repeatedly • Data can be read repeatedly • Possible fast-forwarding and slowing of the playback • Possible zooming in and out (in individual cameras) • Enables simultaneous analysis of traffic conditions on a given road section	• Video recordings need to be synchronized and (if necessary) merged into one or two files • Very long and labour intensive analysis of data from a few dozen camera views at the same time • Rather expensive installation of cameras • Ample disk space required to store video data (a single 24 h recording from one camera, in Full HD and 24 fps takes about 116 GB) • Permit required to install the equipment within the RoW area

3.1 Basic Methods of Measuring Traffic Density

The first method consisted in taking down the numbers of vehicles incoming, outgoing and forming a queue (stopping) at an approach to an intersection by three people carrying out the measurements. All three measurements had to be time synchronised and one signalling cycle was used as a complete reference interval. The measurement of the incoming traffic volume took place at the departure from an intersection situated next to the one analysed, whereas the outgoing traffic volume was measured at the stop line of the approach to the analysed intersection. The queue length was determined by taking down the number of vehicles forming a queue and coming to a full stop during one signalling cycle. The person counting stationary vehicles was required to move along the queue (on a scooter, electric skateboard or bike) as it was growing or declining. During subsequent analysing the maximum length of the queue formed at the red traffic light was determined from balancing. Similarly, the balancing of the values of outgoing traffic volume and the maximum queue length at individual signalling cycles made it possible to establish the length of queues remaining at the end of the green traffic light.

The second method was very much like the first one with the only difference being the tool used to register data. Instead of a traffic count form a digital voice recorder was applied. Such a solution enabled providing accurate time reference of registered events (vehicle travel along the analysed section, stopping time). Furthermore, digital records could be processed and read repeatedly. However, this kind of measurement involved quite a long time to read the recorded data, as the files from three recorders had to be listened to and the events fed into a computer programme. Another disadvantage was that the voice commands used by the recording personnel had to be unified (vehicle features and their subsequent identification when entering data and analysing). On the other hand, considering that mobile phones are usually equipped with a digital voice recording function, the method did not require purchasing any special equipment other than an external microphone with a windshield, recommended to reduce any surrounding noise, background sounds and distortion caused by the wind. However, even without a windshield the quality of recorded sound should be good enough to clearly understand the voice commands. With the mobile phone screen backlight off, the recorder can be operated for up to 8 h.

The third method is a modified version of the two described above. This time the person measuring vehicle queue lengths does not count the number of vehicles at specific signalling cycles but takes photographs of the road section covered by the queue. Depending on requirements, the signalling cycles can also be evidenced with a camera (the corresponding times individual traffic light cycles started). The queue length is determined as an estimate (the reach of the queue from the stop line) or based on the characteristic features of the vehicles identified at the end of the queue in the photograph (comparing data from the camera and voice recorders). The other observers carry out measurements using the first or the second method described.

Methods number four and five involve the use of video recording equipment. In both methods no personnel is required to collect the samples. A complete video recording that can be played back repeatedly from any time mark is an undisputed advantage of video technology. On the other hand, the cost of such observations (including the cost of a video recorder) is much higher as compared with the methods described above.

3.2 The Use of Unmanned Aerial Vehicles

Today the use of unmanned aerial vehicles (drones) with a video camera to record vehicle flows within an analysed road section and intersection seems to be a simple procedure. However, the possibilities of using such equipment are quite restricted as far as scientific research applications are concerned because, according to current regulations (in Poland) any flights in cities require a special pilot licence (BVLOS - beyond visual line of sight flights). Moreover, operating a drone in built-up areas is classified as 'uses other than recreational or sport' [14]. The biggest drawback of the application of drones in traffic observations concerns their endurance. An experiment carried out in 2016 showed that the total flight time (hovering in position) of a high-class UAV at a height of about 100 m in almost windless conditions was merely up to 20 min, including take-off and landing. That is why at least two UAVs would have to be used to provide constant hovering at a specific location for about 15 min each. The remaining time would be used to launch and navigate the drone to the defined location. The flights would be done interchangeably; once one of the drones has returned its battery pack would be replaced. The cost of such an operation as estimated by a Bydgoszcz based company providing drone services is PLN 500 per hour [15]. The price included:

- two operators and a navigator,
- setting up of the drones,
- checking of the availability of airspace and procuring necessary permits,
- possible digital processing and editing of collected video data.

It should be note that the price above included depreciation of the equipment (so there is no extra cost of battery packs required for the operation). The price of a single drone operated by the company is about PLN 20,000. This includes a compact, lightweight video camera capable of recording in 4K resolution (4096 $\times$ 3112) at 30 fps with 'fish-eye' reduction (image rectification). Figure 2 below shows a few images from experimental flights using UAVs of various classes.

When doing a technical market research another company was found offering similar services of aerial data acquisition. The company publishes its promotional videos on one of the most popular internet sites [16]. The cost of intended observation of road traffic characteristics for a specific intersection would amount to PLN 550 per drone launch. Some results of the company's work taken from published videos are shown in Fig. 3. No technical specifications of the flight and equipment involved was available, and nor any operational time limits were provided.

The authors also considered another option: the application of a drone with constant power supply by means of a 70-m cable (tethered drone). An initial cost estimate of the use of such equipment, including a weatherproof drone with at least 6 rotors, was given by a Bydgoszcz based company at approx. PLN 70,000–100,000. In the long run attempts will be made to use equipment like this in a variety of traffic observations. At present, it is possible to use drones with combustion engines which can remain in flight for about 1 h and drones with hydrogen fuel cells with flight times reaching 4 h, however the costs of application of such equipment exceeds PLN 150,000.

3.3 The Use of Cameras Mounted on Streetlamps

Vehicle queues were also measured using digital cameras installed on streetlamps located at an intersection approach and along the entry leg to the intersection. Tests [12] demonstrated that 6.5–7.5 m is the optimum height to fit cameras to the streetlight poles. Such a height ensures good visibility of any vehicle and the distances between vehicles (no obstruction from larger vehicles). It was determined that at the specified height the spacing of cameras should not exceed 40–60 m in order to ensure complete video coverage and overlapping of the views from consecutive cameras. The spacing normally corresponds to a distance between three streetlamps. The first camera has to be installed as close to the stop line as possible to ensure correct reading of changing traffic lights.

The recording equipment had to be compact and light for easy and quick installation. When choosing the right camera type particular attention was paid to a mini action camera. Community interviews and technical considerations proved that the technical specifications of mini action cameras would be adequate to register the required traffic information for the expected time of observation.

Finally YI Action mini cameras were selected. The videos taken using those cameras can be recorded as Full HD files (1920 × 1080 PX) at 24 fps or more. The resolution is good enough for subsequent scaling and editing of the video material or adding or arranging additional graphic elements in it. The cameras are equipped with a microUSB connection which enables direct power supply and charging of the camera battery while recording. The cameras also provide Wi-Fi communication which makes it possible to view images being recorded in real time, using a tablet or smartphone.

In order to ensure continuous (24 h) recording, the cameras had to be connected to an external Li-Ion battery with a capacity of 20,000 mAh (power bank). It was also essential to ensure a high quality power supply cable connecting the camera to its power bank (resistant to bending and twisting and providing good energy performance).

The equipment includes a microSD memory card with a high writing speed (UHS-I Class 10 as a minimum), to store recorded videos. It was established from initial tests that a 128 GB card is required to store material recorded for 24 h in 1920 × 1080 PX and 24 fps.

The recording equipment was placed in a transparent and weatherproof container and fixed to a two-arm support section making the mounting bracket. Such a set-up makes it possible to install the measuring kit to a streetlamp with two metal clamps tightened by means of a worm gear. The clamps used in the measurements were metal worm gear clamps (W1 type) for diameters of about 60–650 mm, so they were suitable to fit the kits to small-diameter metal street lighting poles as well as to old type polygonal concrete poles.

Finally a measuring kit comprised the following: a miniature digital camera, an external charger (power bank), a charger cable, a camera holder with a suction cup to attach it in an enclosure, a weatherproof enclosure, a mounting bracket and two worm gear clamps. Figure 4 shows an example installation.

It should be noted that if measurements are to be taken along a road segment where there are only metal lamp poles, the brackets can be attached to them using neodymium magnets. Based on preliminary tests it was established that about 7 magnets are required per bracket (3 magnets along the length of the bracket and about 5 on the sides at different levels). The number of magnets to be used is determined by the round shape of the pole and the need to ensure appropriate holding strength in adverse weather (high winds) or random incidents (perching birds). In the case of polygonal poles, 3 neodymium magnets placed along the pole would be optimum and would be enough to attach a simple bracket providing stable and secure installation. Such a solution was applied for example in Warsaw for a camera whose only purpose was to record changes in traffic light sequences. Figure 5 shows this kind of setup.

The installation of the cameras along the measurement sections was assisted by lifting service providers (Fig. 6) or rope and ladder access contractors (Fig. 7). Both types of installation take a similar amount of time to mount and dismount the equipment. In the case of the first method the positioning of a bucket truck at the street light pole was the most time consuming, and in the second case fitting took the longest. On the basis of obtained quotations and trials the lowest cost of installation of 10 cameras along a selected road section using a bucket truck was PLN 750 and it took about 2.5 h to install and about 2.0 h to remove the equipment. In the case of rope and ladder access, the cheapest quote was for PLN 400 and the total mounting/dismounting time for 10 cameras was about 1.7 h. Therefore, rope access services proved more cost-efficient in this comparison.

It is also possible to install cameras in windows or on roofs of nearby buildings (office blocks or hotels) located at the analysed intersection. If the buildings are more than 10 storeys high, a single camera could cover the area of all approaches and entry legs. In such a case the other cameras should be installed near the stop lines at individual intersection approaches to record the sequences of traffic lights. The price of using a hotel room for this purpose usually equals the price of a night (an installation permit is also required).

The evaluation of the described measurement methods considered mainly technical capabilities to record the required characteristics of road traffic, the queue-forming process and the costs of purchase and operation of measurement equipment. Based on these it was decided that placing a few dozen cameras along the analysed section would be the preferred method.

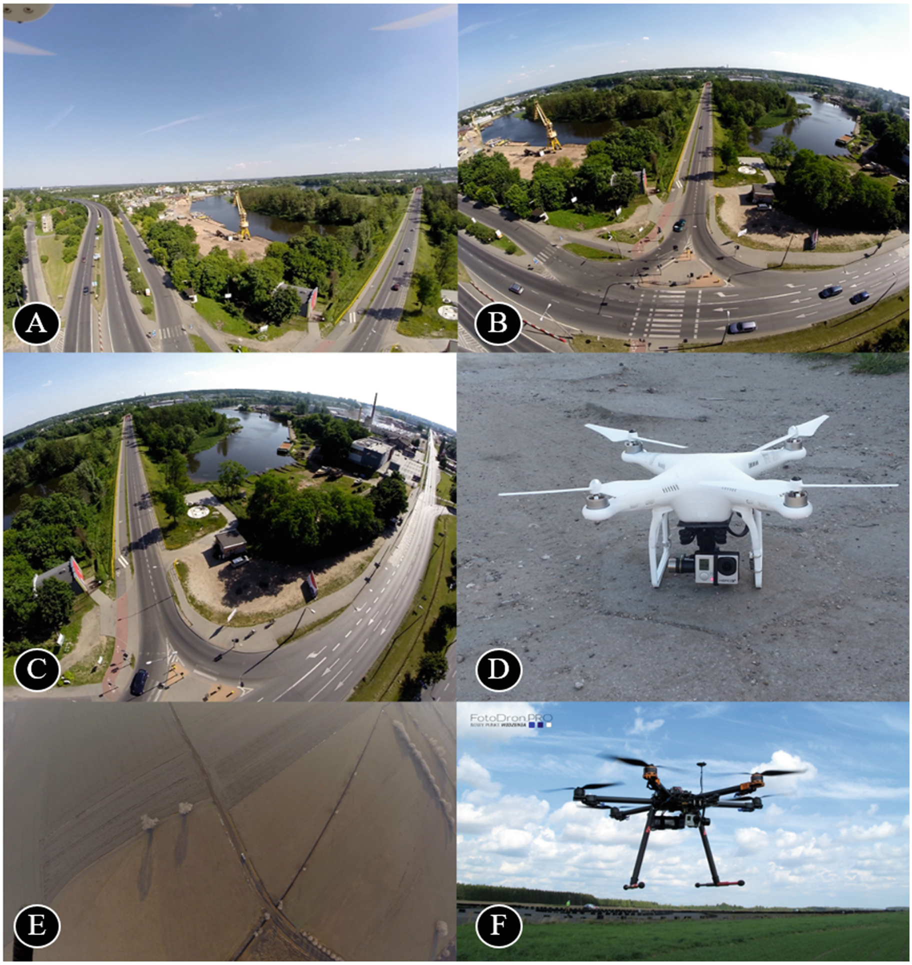


Fig. 2. View from an UAV-fitted camera (Legend: A, B, C, D - a medium-class drone and images taken at $\sim$50 m ('fish eye' effect visible) l E, F - a high-class drone and an image taken at $\sim$200 m) (Source: [15])

Fig. 3. Promotional images for traffic measurements using an UAV (Source: [16])

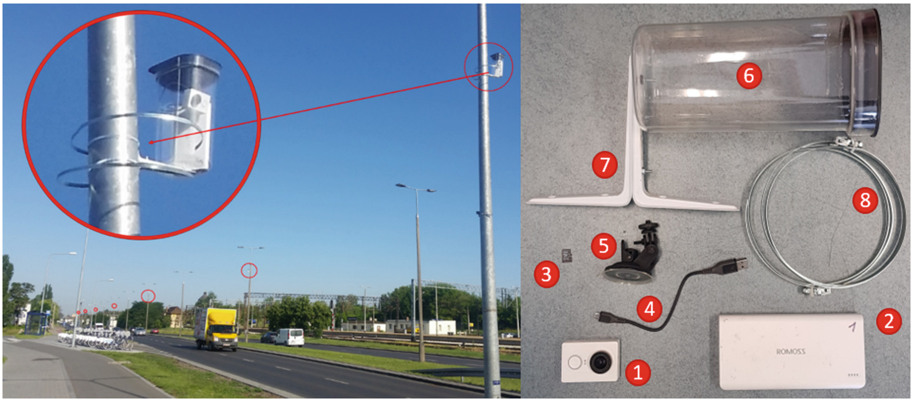


Fig. 4. Arrangement of measurement kits along Kamienna Street in Bydgoszcz (Legend: 1 - camera, 2 - power bank, 3 - memory card, 4 - power supply cable, 5 - camera holder, 6 - weatherproof enclosure, 7 - support sections, 8 - clamps) (Source: [17])

Fig. 5. Fixing a measurement kit to a road sign pole with neodymium magnets within a traffic measurement section in Warsaw (Source: [17])

Fig. 6. Mounting measurement equipment along Sporna Street in Bydgoszcz using a bucket truck (Source: [17])

Fig. 7. Mounting measurement equipment along Kamienna Street in Bydgoszcz using rope and ladder access (Source: [17])

4 Processing Measurement Data

4.1 Data Reading and Synchronizing

When measurements were completed using the fifth method (Table 1), the obtained video material had to be read from individual camera cards and synchronized. The synchronization of videos from all the cameras had to be carried out at the same time. For this reason the whole video material was compiled into a single screen. It enabled observation of the vehicle stream along the entire analysed section using one monitor.

The time synchronization of individual video recordings was possible thanks to the application of YI Action software installed in a smartphone to manage the control parameters of the cameras. When the camera was turned on, its internal clock automatically read the time (hour, minute and second) from the smartphone used to connect to the camera. As the cameras overwrite video recording start times, at the stage of processing and compiling it was possible to check the exact time each recording began (with an accuracy of 1 s). Having all the video files with embedded start times it was easy to synchronise them by means of a freeware application for video tracks which featured the function of moving them using a built-in timeline. Additionally, when a common time stamp was established the synchronization was verified regarding the timing of video images. To this end, overlapping views from different cameras were compared and the changes of traffic lights were verified.

Once the synchronization was found correct, the digital processing was completed and all the video files were exported into a single video with a resolution of 1920 $\times$ 1280 PX and a playback rate of 24 fps. This frame rate enabled slowing down of the video to half the speed if required to determine the exact moments of starting and stopping of vehicles within the measured road section. The final video included a global digital time stamp to enable precise identification of the observed characteristics of road traffic and changes of the signals emitted by the traffic lights. The time stamp provided information about the hour, minute and second, as well as milliseconds of the played video (with reference to the time of measurement). A final compilation could combine 9 full views (proportionally reduced) at the same time.

Such video material was suitable for further processing using a monitor with at least 40″ screen size. The workstation used to observe vehicle queue forming is shown in Fig. 8.

The process of changes in the length and reach of vehicle queues was recorded using a specifically-designed computer programme, fully developed by the authors. A screen from the programme is shown in Fig. 9. The programme featured the following functions:

- selection of any video playback speed,
- recording the duration of traffic light signals within a cycle,
- recording the structure of vehicle streams according to the type of vehicle at an analysed intersection approach, by means of a combination of keys on the computer keyboard (using the letters O, F, C, P, A, W, and M), where each type of vehicle was assigned a specific letter; the time was also saved,

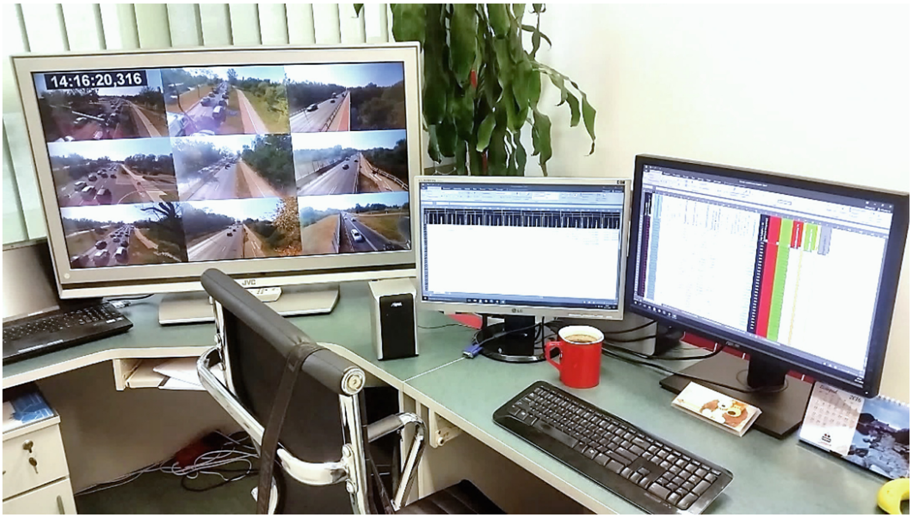


Fig. 8. View of the workstation used to analyse videos from a number of cameras installed along a measured section in W. Pileckiego Street in Bydgoszcz (Source: [17])

Fig. 9. View of a screen of the computer program developed for the analysis of vehicle queue forming process along a measured section of W. Pileckiego Street up to the approach to Rondo Maczka intersection in Bydgoszcz (Source: [17])

- recording the times of vehicles leaving the intersection during a specific cycle, by pressing the "1" key,
- recording the times of vehicles starting to move in a stationary queue during a specific cycle, by pressing the "2" key,
- recording the times of vehicles stopping in a remaining queue during a specific cycle, by pressing the "3" key.

All the data recorded for a single cycle was stored in the programme. When the analysis of a cycle was completed the data was copied into an MS Excel spreadsheet file. The copied data included times saved directly from the video file. Therefore, the displayed time stamp had to be entered in the spreadsheet to correct the data using the time of measurement shown in the video. In this manner, all the information regarding individual manoeuvres of the vehicles was collected and organised according to the time of measurement. After copying all the data the application memory buffer was cleared and the analysis of a subsequent signalling cycle could begin.

4.2 Processing of the Material

Further processing of the material obtained from the measurements consisted in the identification of the properties of traffic queue forming for a single signalling cycle. The above-described computer programme was used for this purpose, being capable of reading the requested variables. The processing was divided into a number of stages.

The first stage involved reading changes in the duration of traffic light signals during one cycle and the next one. Noting down the times of the changes was necessary. In particular, it was essential to identify the times when the green and the red light came on during a signalling cycle, so that the general properties of the applied traffic light programme could be determined.

Having determined the duration of individual traffic light signals during a cycle and a cycle that followed it, the next stage was to focus on vehicles coming to the intersection approach. This consisted in rewinding the video to the moment when the red light came on during the analysed signalling cycle. Times were noted for individual incoming vehicles which stopped to form a queue or were affected by the queue (i.e. were clearly slowing down behind the last stationary vehicle in the queue). In the case of vehicles which did not form a part of the queue during the analysed signalling cycle and managed to leave the intersection during the green light, only the fact that they crossed the section was noted. However all vehicles were identified in terms of type. This made it possible to determine the exact type structure of the incoming stream of vehicles during a given cycle, but also during a selected time interval (e.g. a quarter of an hour). The number of recorded times corresponded to the number of vehicles passing through the section concerned. Knowing the duration of the cycle and the number of vehicles on the approach to the intersection enabled the determination of the volume of incoming traffic.

At the third stage, phases of the outgoing stream of vehicles leaving the intersection were established. That stage involved rewinding the video to the moment when the green light came on during the analysed cycle. From that moment times were noted for individual vehicles which crossed the stop line. The number of times corresponded to the number of vehicles leaving the intersection. Knowing the duration of the green light the volume of outgoing traffic and the saturation volume could be determined. Since the duration of the signalling cycle was also known, the volume of outgoing traffic and the flow capacity of the given lane were established (naturally, being aware that saturation volume and flow capacity can be determined only in the condition of saturated or oversaturated flows). Additionally, the type structure of outgoing vehicle flows was determined.

The fourth stage of data processing consisted in noting down all times of vehicles starting to move from a queue formed at the intersection approach. This required rewinding the video back to the moment when the green light came on during the analysed cycle. From that moment times were noted for the starts of each subsequent vehicle until the last stationary vehicle in the queue started moving during the cycle. Some of the starting manoeuvres could take place during the next signalling cycle, so when copying the data on the starts each situation was verified to distinguish those happening during the analysed cycle (when the green light was on) from those occurring after the red light of the subsequent cycle came on. Having collected the data the values of starting volumes were determined both for the green light and when the red light came on (knowing the relevant time of the last vehicle starting at the end of the green light and the time of the last vehicle starting from the maximum queue). Similarly to the third stage, the type structure of the starting vehicles was also determined.

The fifth stage of data processing consisted in fast-forwarding the video to the moment when the red light of the subsequent signalling cycle came on. Then stopping times of individual vehicles from the remaining queue were read. Knowing the time the last vehicle in the queue stopped the value of the stopping volume was calculated. The type structure of the vehicles was determined at that stage, as well.

At the sixth stage the maximum reach of the queue was established (as the number of vehicles starting) and the initial queue (as the number of vehicles stopping) relative to a single signalling cycle. The data was considered to be the most important for the process of queue forming analysed in this study.

The individual phases of vehicle queue forming were analysed from the point of view of absolute times of doing the specific manoeuvres and intervals between manoeuvres of individual vehicles. The reference value for each analysed phase was always the assigned value of time during which a given traffic light was signalled during a specific signalling cycle.

Data read from video recordings was entered into Excel spreadsheets which formed a database for detailed analyses. Each analysed lane of the intersection approach considered was assigned its own spreadsheet. Further analysis of the data on individual phases of vehicle queue formation process was performed using Statistica software.

Figure 10 presents a diagram representing data read about the vehicle queue forming process at the approach of a traffic-light intersection during one signalling cycle.

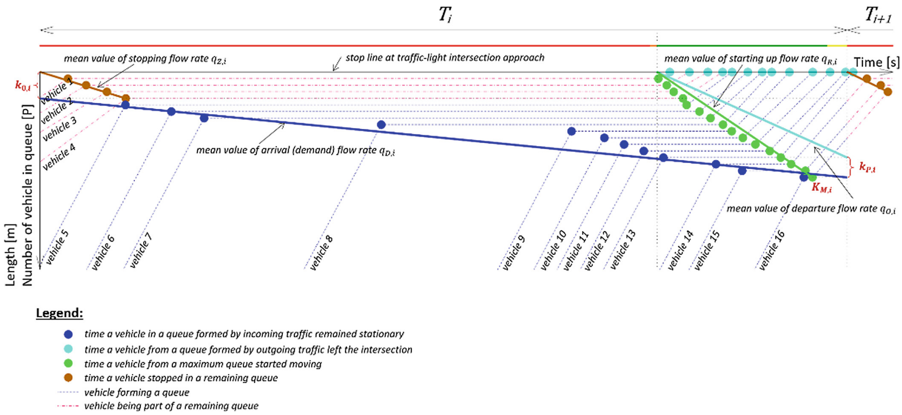


Fig. 10. Graphic representation of empirical data concerning the times when individual manoeuvres were initiated by vehicles forming a maximum queue (red light duration: 93 s, green light duration: 26 s, cycle duration: 123 s; other symbols used: i - cycle sequence, T - measurement interval (cycle duration), $k_{0,i}$ - length of initial queue during cycle i, k_P - length of remaining queue at the end of cycle i [as: length of initial queue during cycle $i + 1$], K_M - maximum reach of the vehicle queue (back-of-queue) during cycle i)

5 Conclusion

In current traffic conditions in urban and peri-urban road networks it is very difficult to carry out a precise evaluation of the characteristics of traffic whether in a single stream or an entire flow of vehicles. The difficulty consists in very high traffic volumes at the peaks of transport demand and in the density of development in large and medium-sized cities (an abundance and variety of travel origins and destinations).

The authors, in an attempt to tackle this problem, analysed a number of feasible methods of measurement of traffic density and - in particular - of the process of vehicle queue forming in arterial roads, approaches to signalised intersections and interchanges. Having assessed the methods, and assuming that the cost of implementation and purchase of measurement equipment were prioritised, the best method was found the one involving installation of a few to a dozen or so miniature digital cameras on street lighting poles along the road section to be covered by the measurements.

The authors then developed a procedure to process the data acquired by a set of cameras in the selected method. A computer programme was also developed to accelerate reading of the required data. One apparent drawback of the method was that individual types of data had to be specifically determined.

Nevertheless, in the authors' opinion, it is possible to develop a computer programme for automatic specification of the required properties of road traffic in order to identify the process of queue forming, using vehicle-tracking algorithms. The authors cannot see any major obstacles that would prevent application of the selected method to evaluate traffic density (length and range of vehicle queues) at exit roads of suburban interchanges. In such an application, however, each exit road should be clearly predefined as a separate area.

References

1. Generalna Dyrekcja Dróg Krajowych i Autostrad w Warszawie: Metoda obliczania przepustowości skrzyżowań z sygnalizacją świetlną. Katedra Budowy Dróg i Inżynierii Ruchu, Politechnika Krakowska im. T. Kościuszki, Warszawa (2004)
2. Generalna Dyrekcja Dróg Publicznych w Warszawie: Wytyczne projektowania skrzyżowań drogowych. Część I i II. Katedra Budowy Dróg i Inżynierii Ruchu, Politechnika Krakowska, Warszawa (2001)
3. Transportation Research Board: Highway Capacity Manual, Sixth Edition: A Guide for Multimodal Mobility Analysis (HCM 2016). Transportation Research Board, Washington (2016)
4. For-schungsgesellschaft für Straßen- und Verkehrswesen: Handbuch für die Bemessung von Straßenverkehrsanlagen (HBS 2015). For-schungsgesellschaft für Straßen- und Verkehrswesen, Köln (2015)
5. Transportation Research Board: National Cooperative Highway Research Program: Signal Timing Manual. Second Edition. NCHRP Report 812. Transportation Research Board, Washington (2015)
6. Macioszek, E., Lach, D.: Comparative analysis of the results of general traffic measurements for the Silesian Voivodeship and Poland. Sci. J. Silesian Univ. Technol. Ser. Transp. **100**, 105–113 (2018)
7. European Commission: EU Transport in figures. Statistical Pocketbook 2016. European Commission, Luxembourg (2016)
8. U.S. Department of Transportation: Passenger Travel. Facts and figures 2016. Bureau of Transportation Statistics, Washington (2016)
9. Macioszek, E., Lach, D.: Analysis of the results of general traffic measurements in the west pomeranian voivodeship from 2005 to 2015. Sci. J. Silesian University Technol. Ser. Transp. **97**, 93–104 (2017)
10. Macioszek, E., Lach, D.: Analysis of traffic conditions at the Brzezinska and Nowochrzanowska intersection in Myslowice (Silesian Province, Poland). Sci. J. Silesian Univ. Technol. Ser. Transp. **98**, 81–88 (2018)
11. Chmielewski, J., Iwanowicz, D.: Intelligent transportation systems in Bydgoszcz. Arch. Transport Syst. Telematics **6**(2), 11–15 (2013)
12. Szczuraszek, T., Iwanowicz, D.: The impact of the analysis period on the estimation accuracy of queue lengths at intersection inlets with traffic lights. In: Macioszek, E., Sierpiński, G. (eds.) Recent Advances in Traffic Engineering for Transport Networks and Systems. LNNS, vol. 21, pp. 181–192. Springer, Cham (2018)
13. Institute of Transportation Engineers: Traffic Engineering Handbook, 7th edn. Wiley, Hoboken (2016)
14. Ministry of Finance in Poland: Annex No. 6B to the Ordinance of the Minister of Transport, Construction and Maritime Economy of December 20, 2018, amending the regulation on the exclusion of the application of certain provisions of the Act - Aviation Law to certain types of aircraft and the specification of conditions and requirements for the use of these ships. Ministry of Finance in Poland, Warsaw (2018)
15. Archives and database of Dron Bydgoszcz: FlyFoto.Pro, z lotu ptaka, z lądu, spod wody. Experimental research. Archives and database of Dron Bydgoszcz, Bydgoszcz (2016)

16. YouTube. https://youtu.be/7VQ1jCA9s7c and https://youtu.be/lVpvyycqytY
17. Archives and database of the Department of Road Engineering and Transport, Faculty of Civil and Environmental Engineering and Architecture, the University of Science and Technology in Bydgoszcz: Research of formation process and the volatility of queue lengths on intersection inlets with traffic lights 2015–2018. Department of Road Engineering and Transport, Bydgoszcz (2018)

Author Index

E. Macioszek et al. (Eds.): TSTP 2019, LNITI, p. 199, 2020.
https://doi.org/10.1007/978-3-030-39109-6