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Investigation of tram movement indicators in general structure of traffic flow

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Abstract: In the work, the average operating speed of the tram is investigated on the sections with the high density of the road network. Such peculiarities are inherent to the cities where its configuration has developed historically, and trams move in the general structure of traffic flow which is predetermined by the absence of traffic capacity reserves in the old, as a rule, central part of the city. It frequently causes the reduction of the whole traffic flow speed of movement, in particular on the intersections and within public transport stops. Determination of the mutual impact of automobile movement and trams is topical because, on the one hand, trams, taking into account their dynamic and technological movement peculiarities, worsen traffic flow indicators and on the other hand, vast traffic intensity cause downtime of the trams rolling stock in the queues before the intersection that decrease passenger transportation quality. In general, it was managed to determine the amount of change of the average tram operating speed for different methods of traffic flow control for different time of day.

Keywords: traffic flow, traffic intensity, traffic composition, urban public transport, speed of movement, tram priority

1. Introduction

Combining of movement of automobile transport and trams on a common roadway cause significant reduction of speed of the last in comparison with their technic-operational characteristics and taking into account worn-out state and track facilities, the effectiveness of passenger transportation by them on such sections is quite low. For the old historical cities, the solving of this problem is the topical task because the development of electric transport network provides opportunity also to reduce environmental pollution of city air pool and, simultaneously, provide massiveness of passenger transportation.

With the aim to avoid the negative phenomena during the designing of road network elements where trams move in general structure of traffic flow and to improve the level of service on their junction sections (intersections), special attention is paid to: minimization of delays in tram movement, increase of safety and improvement of access to tram stops; minimization of delay for the other vehicles in mixed traffic [1–4]. Quite often the attention is paid to the reduction of signal delay and the diversity of priority traffic signal control [5]. Besides, to avoid problems with delays in traffic flow movement, in which trams move, such approaches are using as investigation of existing places of crowding of vehicles; determination of optimal configuration of tram network; investigation and analysis of

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forecasted delay of traffic light signals in transport systems with tram movement; analysis of maneuvers and conflict science on traffic lanes where trams move, optimization of tram stops location; optimization of traffic light control phases on controlled intersections and pedestrian crosswalks [1, 6–9]. As only base transport model which describes movement of trams in traffic flow is determined, it is necessary to have clear vision about the possible frequency of their appearance and distribution of other types of vehicles on the lanes of passing and oncoming traffic [10].

General delay before traffic lights on the routes of tram movement is connected with two separate phenomena. Firstly, traffic light delays are simple delays that appear because of big amount of vehicles which use the same lane as tram and connected with intersection capacity [1, 5, 11–13]. Secondly, delays can appear due to temporary crowding on tram lanes the other urban public transport (buses) that can have joint stops for boarding and alighting passengers [11–15]. From the results of research, increase of tram speed and reduction in delay on controlled intersections is maximum restriction of manoeuvres on lanes with their movement.

Priority traffic light control can take one of two forms – passive or active [7, 14, 16–18]. Passive traffic light control – is development of such control systems, where the direction (street or road) that serves tram movement always is given more green time in comparison with other conflicting directions. Such actions cause increase in movement of the whole traffic flow that move in given direction [16, 19]. During the active control or regulation in real time regime the phase of traffic light on direction that serves trams changes during its approaching to the stop-line.

Control systems in regime of real time that change traffic light signal depending from traffic intensity have high level of effectiveness on those directions where traffic flows have significant level of unevenness [20, 21]. The essence of the work of such systems is based on the mechanisms of determination of vehicle (in our case tram), i.e. its identification by detector during approaching to intersection. If the detector detected it during permissive (green) time than such time continues, if the time was restrictive (red) than traffic light makes a switch from red to green earlier than it is provided by control regime.

Important element for provision the reliability of traffic light system control with adaptive control systems is constant collection of initial information about traffic flow condition and based on this issuance of the final decision (control algorithm) [22, 23].

Such control is especially effective on arterial sections of the road network that serve intensive traffic flows with significant heterogeneity. Also, it is necessary to note that neither passive nor active control forms cannot be used on those sections of city streets and roads where coordinated control of traffic flow movement is functioning, because adaptive change of algorithm on one of intersections cause the destruction of principle of unhindered movement of traffic flow during the passing by it the other intersections that are connected in such system [13, 16, 24].

Under any circumstances if the increase the speed of intersection passage, where most often appear traffic flow delays, can be reached, then it can be argued that increase of effectiveness of transport system functioning is happen [25, 26].

2. Materials and Methods

One of the main factors which were measured in this research is the real-time of tram movement on the routes and its change due to created (planned) schedules.

For the investigation of existing movement conditions such methods were used:

- field research during the determination of traffic flow indicators and tram movement characteristics using surveillance cameras (carried out on the base of Center of traffic movement control of Lviv municipal enterprise “Lvivavtodor”);
- documentary research during analysis of reporting and statistical data received with the help of program software MicroGIS (carried out on the base of Center of traffic movement control of Lviv municipal enterprise “Lvivavtodor” and Lviv municipal enterprise “Lvivelectrotrans”);
- simulation of intersection passage with the help of program software PTV VISSIM for the analysis of existing state on the routes and creation the simulation model of road situation for the different time periods, when the change of traffic intensity takes place.

For determination of the effectiveness of pointed algorithms, application the investigation of tram movement indicators on the routes of the transport network of Lviv city is carried out. For this purpose, two types are chosen where:

- passage of controlled intersections is happening in result of traffic light cycle operation with the fixed time program control;
- passage of controlled intersection is happening in result of traffic light cycle operation with the fixed time program control with the use of tram search algorithms in traffic flow.

Field research on determination of effectiveness of traffic flow intensity were carried out during working days of the week (Monday, Wednesday and Friday) on the streets where tram routes are mapped with the aim of determining the change of this indicator during the day and also traffic flow composition (share of public transport, in particular trams).

During the documentary research, which was carried out simultaneously with the field research, the time of passage by trams the sections of the chosen route is determined which is received from statistical data that came to the Center of traffic movement control from GPS-receiver, and also the deviation from established schedules on every control point is determined

Traffic simulation was that into program software VISSIM the primary indicators of traffic intensity, traffic composition and speed of movement were entered that were determined during the field research with the aim of receiving the indicator of delay on route sections in the current state. Also, the situation of determining the change of possible time losses during the change of these primary indicators was simulated. Separate scientific approaches to the traffic flow simulation in the composition of which are trams are reviewed in the work [27]. Besides, using the methods of traffic simulation it can be possible to achieve high precision of delay minimization results in traffic flows.

3. Results

Let's carry out short analysis of the tram routes network in Lviv city (Table 1).

Table 1. Characteristics of tram routes network in Lviv city.

№ of the route	Initial stop	Final stop	Type of route	Length, m	Number of routes	Time in movement, min
1	Railway station	Saksahanskogo St.	Circular	7896	19	49
2	Konovaltsia St.	Pohulianka St.	Linear	14266	32	65
3	Soborna Sq.	Aquapark	Linear	11019	21	45
4	Promyslova St.	Arts Academy	Linear	9752	23	49
5	Aquapark	Promyslova St.	Linear	16151	35	76
6	Railway station	Mykolaichuka St.	Linear	11469	32	60
7	Tatarbunarska St.	Pohulianka St.	Linear	15054	30	68
8	Soborna Sq.	Vernadskoho St.	Linear	13981	57	29
9	Railway station	Center	Circular	8541	18	49
10	Railway station	Pohulianka St.	Linear	10343	29	64
11	Railway station	Center	Circular	10413	21	62

Routes №2 and №8 were taken into consideration. They differ by the mode of arrangement of tram tracks relative to the roadway, the number of trams on the route, time of work. Tram route №2 in general (approximately 80%) is laid out in such way that the trams move in general composition of traffic flow, at the same time on the tram route №8 nearly 70% from its length tramcars move separately from the rest of the flow. Such two routes were chosen with the aim of comparison travel time between the stops due to the established schedules, choose the main indicators which impact on speed regime, analysis of received indicators of the average speed etc.

During the carrying out of these research one of the main tasks was to collect information about existing condition of transport network; investigate the influence of general traffic flow on tram movement on the routes №2 and №8; determine the quality of service provision which includes the evaluation of operation performance indicators on sections of pointed routes, execution of daily transportation plan and provision the precision in movement. Also, the important task is to investigate how the operation of algorithms of the automated system of traffic flow control impacts on indicators of effectiveness of transport system functioning from the principle of optimization for the criteria of delay minimization by the way of comparing these indicators for tram routes №2 and №8.

According to research results, carried out in program software MicroGIS, it is received "stadiums of movement" which allow carrying out tram movement indicators monitoring as on the separate route sections and on the whole its duration. Typical appearance of such "stadium of movement" for the route №2 is given on Figure 1. Using this data, it is determined the planned and actual arrival time to the stopping point with the determination of deviation in schedules; speed and time of movement between stops. Together with available information about traffic flow intensity in which moves the tram, the number of junction points (intersections), which it passes, and the way of traffic light system control (fixed-time or adaptive) on them, and also fixed size of passenger flow for the determined period, it can be determined factors which mainly impact on tram movement regimes.

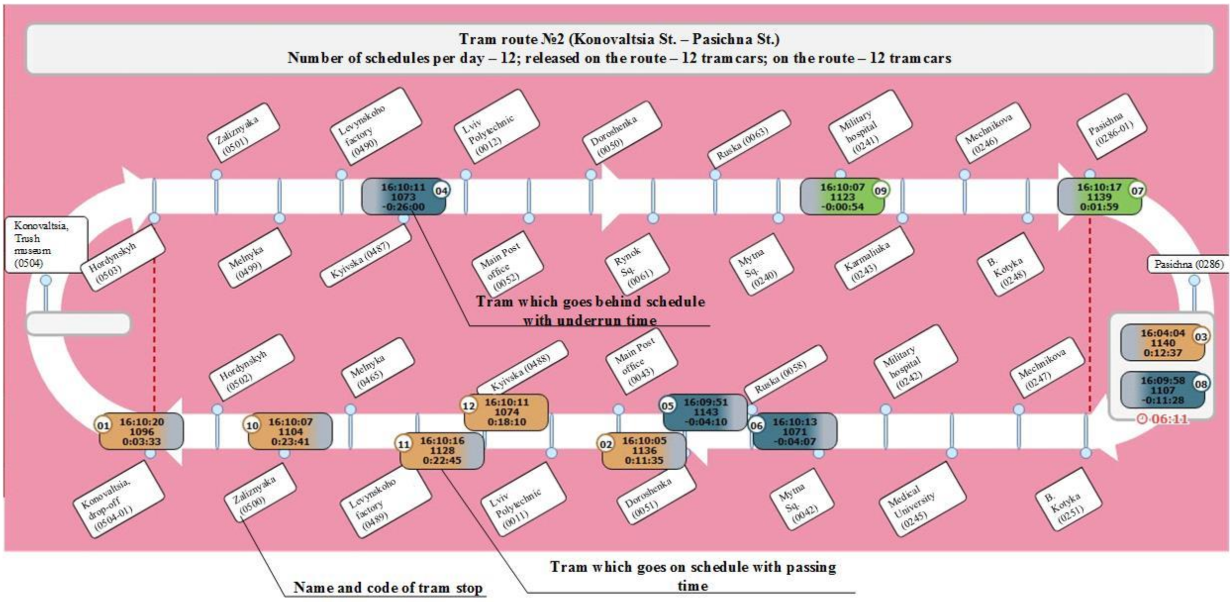

Figure 1. General view of interface in specialized program software "Ukrainian geoinformational systems", where monitoring of "stadiums of movement" is performed.

Such specialized program software is designed for improvement of visual monitoring of trams movement on the route where by the green color are marked trams that move due to established schedule, by the brown color – move with slight deviation from the schedule with pointing the time of such deviation; by the blue color – move with significant deviation (time of deviation also points). If to the color of those trams that late relative to the established schedule grey background is added, then this means that tram moves in a special regime. The special regime can be used in cases when city events are held, traffic accidents occur, repair works are being carried out on the lines etc.

Important practical value of program software MicroGIS is in the fact that the final specified results of monitoring are displayed on ultimate consumers (citizens, tourists etc.) on the means of cellular communication.

Results of monitoring were recorded into research protocol that looks like Table 2.

Table 2. Protocol for recording the monitoring results of tram movement indexes on the route.

№ of record	Name of stopping point (its number in database of ASCTM)	Distance between stopping points, m	Time of movement between stopping points, min	Speed between stopping points, km/h	Arrival time on stopping points		Deviation	
					planned	real	passing	underrun
1								
2								
…								
n								
Average value of index								

Observation for realization the transportation by urban public transport (UPT) (in our case it is tram) and its control performs the Department of operational response. According to received information it is carried out its processing and making a decision due to the situation which is on the route. The key tasks of the Department are service of traffic light objects in Lviv city which are on balance of the enterprise and monitoring the UPT and formation of daily work reports.

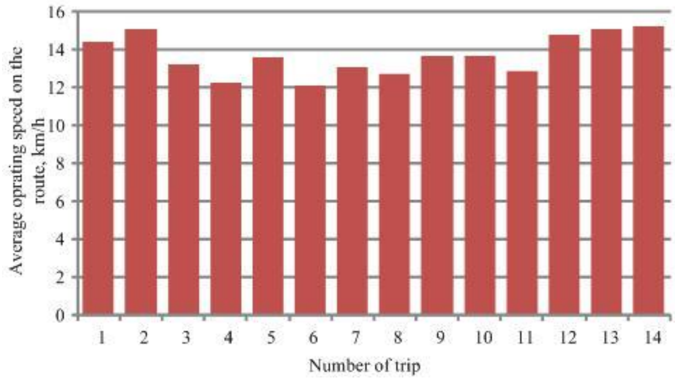

Figure 2. Change of the average operating speed of movement during the day on tram route №2.

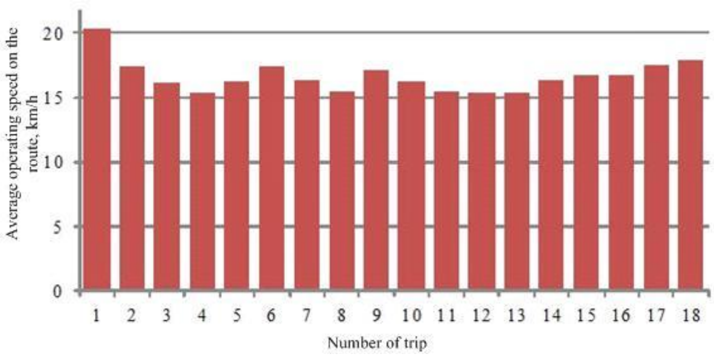

Figure 3. Change of the average operating speed of movement during the day on tram route №8.

Having processed the data of measurement the average operating speed of movement on the chosen tram routes during the workday, it is received such their distribution for every trip of routes №2 (Figure 2) and №3 (Figure 3).

On the tram route №2 the average operating speed during the day is about 12 km/h. The highest its value in the trip is observed in the morning period from 06:30 to 08:20 and in the evening period 20:10 to 22:27 that is nearly 15 km/h. General speed fluctuations during the work of the route ± 3–4 km/h.

Average operating speed during the day on the tram route №8 is about 16 km/h and its maximum value is observed from 06:08 to 06:40 and is about 20 km/h. The lowest average operating speed in 15 km/h is recorded in the period of the morning and evening peak hours. General fluctuations of the average operating speed during the work of the route ± 4–5 km/h.

Based on this, it can be said that the general increase in the average operating speed of tram providing the construction of tramway separately from the roadway gives the increase of its value in 4-5 km/h even in the case when all intersections, through which lays the route, are in one level. Such a conclusion takes into account the fact that the passenger flow on both routes has not been measured but the time of tram at the stop was nearly the same.

Also, it was managed to carry out the monitoring of the average operating speed of movement depending from the length of the section (distance between the stops) on both investigated routes, results of which are given on Figure 4 and 5.

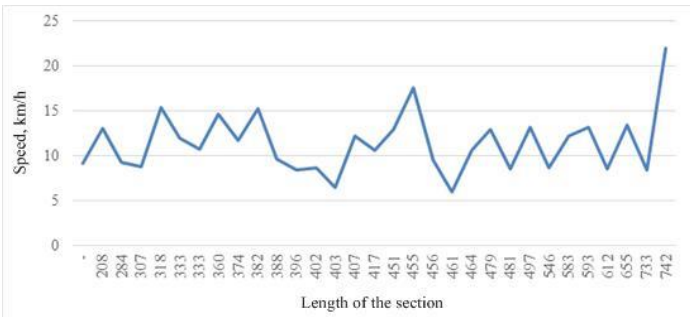

Figure 4. Change of the average operating speed from the length of the section on tram route №2.

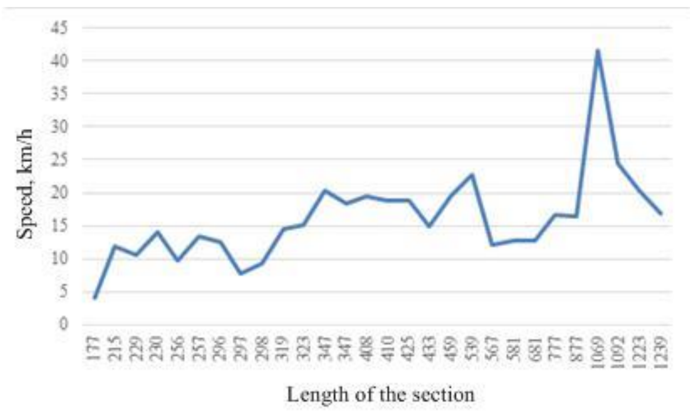

Figure 5. Change of the average operating speed from the length of the section on tram route №8.

From the given figures it can be made a conclusion that providing trams movement in general structure of traffic flow (Figure 4) its average operating speed almost has not some typical tendency of change than in the case when trams move separately by allocated tramway (Figure 5). These graphs represent the amount of mutual influence of tram and traffic flow.

4. Discussion

During the documentary research, the data was received about the average operating speed of trams on tram route №2 before implementation the system of automated control of movement (adaptive control on controlled intersections with the provision of tram movement priority) and compare them with analogical values of its indicator in conditions of operation such system. Distributions of these speeds are given on Figure 6.

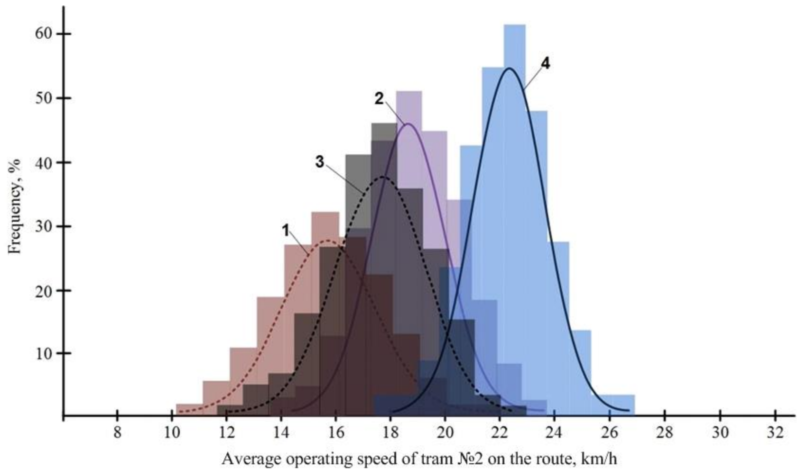

Figure 6. Distribution of average operating speed on tram route: 1 – operation of route in peak period before ASCTM implementation; 2 – operation of route in off-peak period before ASCTM implementation; 3 – operation of route in peak period after ASCTM implementation; 4 – operation of route in off-peak period after ASCTM implementation.

Research results certify that difference in average operating speed for peak and off-peak periods is 17–26%. Taking into account the fact that before implementation ASCTM and after such a difference is almost the same, we can receive the impact of change of traffic volume on tram operation index. Besides, general effect from implementation ASCTM gives growth of average operating speed on the route approximately on 13% for peak and approximately on 22% for off-peak periods. Based on this, conclusion can be made that during observance the certain constant interval in movement on the route implementation of ASCTM provides opportunity to release some amount of motive power of trams, and general effect for streets on which goes the route is increase of capacity because for such their (streets) parameters (1x1 lane) vehicles follow behind tramcar.

During the simulation 4 sections on city streets with 1x1 lanes were chosen, on which tram route №2 goes, with the possibility to pass the tram from the right side, that is tramways are laid on the axis of the street. Percentage of UPT in the flow on pointed sections was on section 1 – 7%; on section 2 – 5%; on 3 – 6%; on 4 – 5%. Trams share in traffic flow composition was about 2%. All other vehicles are automobiles. On all sections in specialized program software PTV VISSIM simulation of change the average connection speed for all vehicles was carried out for the condition that the share of UPT increased in comparison to existing on 5, 10, 15, 20 and 25%. Results of simulation are given on Figure 7.

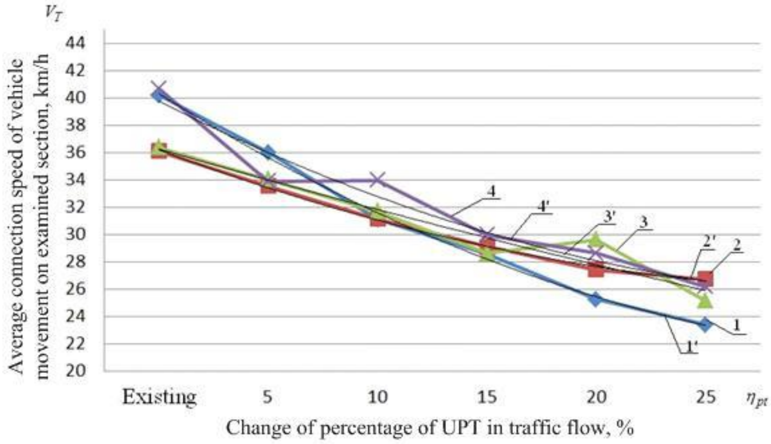

Figure 7. Change of the average connection speed of vehicle movement on investigated sections depending from increase of UPT share in traffic flow composition.

On given figure, under numbers 1, 2, 3, 4 simulation results, which were get in software environment VISSIM for examined sections, are marked, and 1', 2', 3', 4' are trend lines of these results change.

5. Conclusions

For the results of the investigation it is determined changes in time losses of tram movement on different sections of the road network, expressed by the change of the average operating speed and delay in traffic flows. Separated tram movement by the allocation of separated tramway gives the growth of the average operating speed on 4-5 km/h. Application of adaptive control on controlled intersections which operates by the principle of giving the priority in the movement to the tram increases the average operating speed on 3-4 km/h in comparison to fixed-time program control in conditions of its movement in the general structure of traffic flow.

On the other hand, increase of UPT share (including trams) by 25% causes sharp decrease of the average connection speed for all vehicles in the flow by 30-40%.

Such research can be the reasoning for redevelopment the routes of UPT, giving it the priority with the aim of increase the effectiveness of transport system functioning in historical cities.

References

1. Scheffler, R.; Strehler, M. Optimizing traffic signal settings for public transport priority, *Proc. of the 17th Workshop on Algorithmic Approaches for Transportation Modelling, Optimization, and Systems (ATMOS 2017), (September 7-8), Vienna, Austria,* 2017, 9:1-9:15. https://doi.org/10.4230/OASIcs.ATMOS.2017.9
2. Li, Y.-H.; Chen, K.-M.; Ma, J.; Li, Y.; Wang, Y.-P. Optimization of tram operation network based on considering traffic demand characteristics. Jiaotong Yunshu Gongcheng Xuebao. *Journal of Traffic and Transportation Engineering* 2017*, 17(6)*, 64-75.
3. Liu, S.; Zheng, Y.; Zheng, S.; Fu, Y.; Quan, M. Research on priority organization mode of modern tram, Proc. of the 17th COTA International Conference of "Transportation Professionals", (July 7-9), Shanghai, China, 2018, pp. 1949-1959. https://doi.org/10.1061/9780784480915.206
4. Pomykala, A. Effectiveness of urban transport modes. *MATEC Web of Conferences* 2018, 180 p., art. no. 03003, 7. https://doi.org/10.1051/matecconf/201818003003.
5. Wu, J.Q.; Yu, Y.; Lin, X.Y. Dynamic Priority Algorithm for Modern Tram Based On MADM. Proc. of the 2017 2nd IEEE International Conference on "Intelligent Transportation Engineering", ICITE 2017, (September 1-3), Singapore, 2017, pp. 89-93. https://doi.org/10.1109/ICITE.2017.8056887
6. Li, Y., Cai, Q., Xu, Y., Shi, W., Chen, Y. Design of real-time actuated control system for modern tram at arterial intersections based on logic rules. *Advances in Mechanical Engineering* 2018, *10*(12), 1–13. https://doi.org/10.1177/1687814018815423.

7. De Keyser, O.; Hillewaere, M.; Audenaert, P.; Maenhout, B. Optimising the public transport priority at road intersections. *IET Intelligent Transport Systems* 2018, *12*(8), 986-994. https://doi.org/10.1049/iet-its.2018.5133
8. Shi, J.; Sun, Y.; Schonfeld, P.; Qi, J. Joint optimization of tram timetables and signal timing adjustments at intersections. *Transportation Research Part C: Emerging Technologies* 2017, *83*, 104-119. https://doi.org/10.1016/j.trc.2017.07.014
9. Zhu, H.; Hang, C.; Yang, X.A bandwidth maximization model for coordinated tramcar signal priority control alone arterials, Proc. of the 4th International Conference on "Transportation Information and Safety", ICTIS 2017, (August 8-10), Banff, Alberta, Canada, 2017, pp. 631-634. https://doi.org/10.1109/ICTIS.2017.8047832
10. Nguyen-Phuoc, D.Q.; Currie, G.; De Gruyter, C.; Young, W. Net impacts of streetcar operations on traffic congestion in Melbourne. Transportation Research Record 2017, Australia, 2648, 1-9. https://doi.org/10.3141/2648-01.
11. Ji, Y.; Tang, Y.; Wang, W.; Du, Y. Tram-Oriented Traffic Signal Timing Resynchronization. *Journal of Advanced Transportation* 2018. art. no. 8796250, 13. https://doi.org/10.1155/2018/8796250
12. Fang, S.; Ma, J.; Wang, Y. Research on comparison of tram with BRT. *Lecture Notes in Electrical Engineering* 2017, *419*, 165-174. https://doi.org/10.1007/978-981-10-3551-7_12.
13. Teply, S.; Allingham, D.I; Richardson, D.B.; Stephenson, B.W. Canadian Capacity Guide for Signalized Intersections*.* Third Edition. Institute of Transportation Engineers, District 7. Toronto, 2008. 230 p.
14. Ou, D.; Yan, H.; Li, H.; Li, W. Optimization of Conflicting Tram Signal Priority Requests Based on Spatiotemporal Interlocking Logic Using Microscopic Simulation. *International Journal of Software Engineering and Knowledge Engineering* 2018*, 28* (4), 507-522. https://doi.org/10.1142/S0218194018400089
15. Yang, M.; Ding, J.; Wang, W.; Ma, Y.-Y. A coordinated signal priority strategy for modern trams on arterial streets by predicting the tram dwell time. *KSCE Journal of Civil Engineering* 2018*, 22*(2), 823-836. https://doi.org/10.1007/s12205-017-1187-4
16. Bai, Y.; Li, J.; Li, T.; Yang, L.; Lyu, C. Traffic Signal Coordination for Tramlines with Passive Priority Strategy. *Mathematical Problems in Engineering 2018*, 2018. art. no. 6062878, 14. https://doi.org/10.1155/2018/6062878
17. Chen, X.; Chao, C.; Li, D.; Dong, C. Capacity reliability of signalized intersections with mixed traffic conditions. Tsinghua science and technology 2009, 14(3), 333-340. https://doi.org/10.1016/S1007-0214(09)70049-5
18. Currie, G.; Duy, Q.; Young, W. Modelling the Direct Impact of Tram Operations on Traffic, Proc. of the 23th ITS World Congress, (October 10-14), Melbourne, Australia, 2016, pp. 1-12.
19. Fornalchyk, Ye.; Mohyla, I.; Hilevych, V. The saturation flow volume as a function of the intersection passing speed. *Transport problems 2013, 8(3),* 43-51.
20. Slavych, V.P. Metody i modeli systemy avtomatyzovanogo upravlinnja transportnymy potokamy mista*. PhD thesis*, HNTU, Kherson, 2009, 193 p.
21. Zhou, Y.-F.;Wang, Y.; Wei, W.; Hong, Z.-X.; Guo, X.-J. An Arterial Signal Coordination Optimization Model for Trams Considering Timetable Constraints. Jiaotong Yunshu Xitong Gongcheng Yu Xinxi, *Journal of Transportation Systems Engineering and Information Technology* 2018*, 18(2),* 73-79. https://doi.org/10.16097/j.cnki.1009-6744.2018.02.012
22. Stotsko, Z.; Fornalchyk, Ye.; Mohyla, I. Simulation of signalized intersection functioning with fuzzy control algorithm. *Transport problems* 2013*, 8(1)*, 5-16.
23. Pappis, C.; Mamdani, E. A fuzzy logic controller for a traffic junction. *IEEE transactions on systems, man and cybernetic*s 1977, *1*(10), 707-717.
24. Chen, Z.; Wang, H. Arterial green-wave band design with tram priority, Proc. of the 17th COTA International Conference of "Transportation Professionals", (July 7-9), Shanghai, China, 2018, pp. 2761-2772. https://doi.org/10.1061/9780784480915.290
25. Guerrieri, M. Tramways in Urban Areas: An Overview on Safety at Road Intersections. Urban Rail Transit, 2018, 4(4), 223–233. https://doi.org/10.1007/s40864-018-0093-5.
26. Gong, Q.; Sun, L.; Huang, Y.; Qiao, J., Liu, C. Study on the safety evaluation of modern tram at intersection based on traffic conflict, Proc. of the 17th COTA International Conference of "Transportation Professionals", (July 7-9), Shanghai, China, 2018, pp. 4483-4492. https://doi.org/10.1061/9780784480915.464.