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Road and Rail Infrastructure III

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THE IMPACT OF PUBLIC TRANSPORT PERFORMANCE IMPROVEMENTS ON SUSTAINABLE URBAN MOBILITY – AN EXAMPLE OF THE CITY OF ZAGREB

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Abstract

The global urbanisation process in the world is considering urban mobility as its top priority. Therefore, the public transport becomes more significant because of its spatial, energetic, economic and environmental advantages over other modes of transport and thus becomes the framework of sustainable mobility in most cities. Furthermore, the strengthening of public transportation in urban areas produces additional requirements in terms of its efficiency and operability. This is especially related to public surface transport (trams and buses) which is not segregated from other traffic, so the public transport process is constantly interfering with other vehicles sharing the same urban network. Consequently, this influence of other vehicles leads to commercial speed reductions in public transport and thus the attractiveness of public transport becomes significantly lower. The previous research on this subject has concluded that the yellow lane enforcement (as part of public transport priority by legislation) can lead to better transport process (travel times, network occupancy, and reliability) and other positive effects (energy savings, impact on the environment, reduction of external costs) at the entire urban network. This paper presents an analysis of priority by legislation for the entire tram network in the City of Zagreb – the main attention is dedicated to yellow lane contravention in the peak hour. The analysis of the research conducted in this paper, related to operational features and shared space characteristics, provided conclusions regarding the significance of interferences and possible improvements in both efficiency and effectiveness of tram network in the City of Zagreb.

Keywords: tram traffic, tram priority, network speed, City of Zagreb

1 Introduction

The basic principle of sustainable urban mobility is the modal shift of city trips in favour of public transport. Therefore, the public transport has to operate at peak efficiency in order to attract as many as passengers possible. There are two basic parameters of public transport efficiency: dwelling time at stops and running time along station spacings. Both parameters have impact on the operating speed at individual public transit lines and the network commercial speed associated with quality of service. Desirable running times can be achieved by applying public transport priority, in form of:

- priority by segregation;
- priority by legislation;
- signal priority.

1.1 The background of the research

Public transport priority is a subject of much research because it plays a significant part in quality of service. In recent times, different kinds of solutions related to priority have been developed in order to increase performance of public transport network. Pyrgidis & Chatziparaskeva (2012) studied signal priority of tram network in Athens and found that it is possible to expect increases in commercial speed between 15 % and 25 % [2]. Within the Civitas project family, many measures related to public transport have been implemented. Such of the measures are: new traffic lights and bus priority in Malmö, bus priority in Prague, public transport priority in Ljubljana, Rotterdam, Kraków and Suceava, bus rapid transit corridors in Toulouse, Lille and San Sebastián, new traffic light regulation in Vitoria-Gasteiz, yellow lane surveillance in Perugia and high-mobility corridor in Genova. All the measures resulted in commercial speed increases, travel time reductions and eventually, passenger satisfaction linked to modal shift [3].

The Civitas-Elan project was carried out in Zagreb, with one of the measures named „Giving priority to public transport“. Signal priority was implemented at three intersections in Savska Street, resulting in 5 % time saving for the entire corridor [4]. In addition, a pilot-project was carried out which involved yellow lane enforcement by traffic police at the same corridor. Significant time saving of 25 % throughout the corridor was achieved [1].

The analysis of yellow lane priority on a single tram line (line number 4) was conducted by Brčić, Slavulj & Šojat (2012). The data was collected by GPS logging units placed in trams. A nonlinear model was developed for the optimisation purposes, with minimisation of the number of transport units as the objective function and constraints derived from network limitations. By using the Solver (MS Excel) and Nonlinear Programming (WinQSB) modules, the optimisation resulted in commercial speed increase of 8 % and savings of one transport unit, which is 7 % of the total number of transport units on the line [5].

1.2 Tram priority in the City of Zagreb

Tram network in Zagreb is a part of the urban road network, on which:

- 53 % is segregated completely (green lanes);
- 21 % is in separate road lanes (yellow lanes);
- 26 % is shared with other modes of transport (white lanes).

Commercial speed of tram network in the City of Zagreb is has been declining from 15.4 km h^{-1} (in 1999) to 13.0 km h^{-1} (in 2009), which is approximately 16 % (Fig. 1). This decline is the result of the increasing usage of urban road network by private cars. Besides the private cars freely using the white lanes, an additional problem is created by yellow lane contravention, because there is not any kind of yellow lane enforcement present in peak hour. The increasing usage of urban road network by private cars is also the reason for shorter green light percentages for trams at intersections. All these factors negatively influence the commercial speed of tram network in the City of Zagreb.

In the scope of priority by legislation, this paper presents a case study of the City of Zagreb and in particular, investigates what kind of changes would happen on tram network if yellow lane contravention was eliminated. This is done for peak hour because the probability of yellow lane contravention is highest for that period.

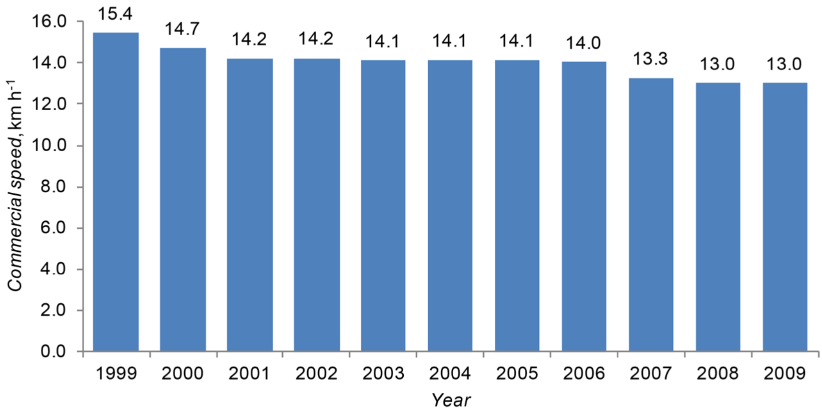

Figure 1 Commercial speed of tram network in the City of Zagreb [1]

2 Methodology

The input data was obtained from Zagreb Electric Tram, which is the public transport service provider in Zagreb [6]. For each transit line (l) the following data was available for the peak hour:

- capacity of transport units by type;
- number of transport units by type;
- operating speed ($V_{o,l}$);
- total line length ($L_{T,l}$);
- total length of yellow lanes ($L_{Y,l}$).

From the data above the following can be derived:

- addition of the capacities of transport units by type gives the line capacity (C_l);
- addition of line capacities gives the network capacity;
- addition of the number of transport units by type gives the number of transport units on a line (N_l).

The network commercial speed (V) is the average speed of the entire set of transport units on the network:

$$V = \frac{\Sigma_l V_{o,l} N_l}{\Sigma_l N_l} \tag{1}$$

The yellow lane percentage on a transit line (p_l) is the ratio of total length of yellow lanes and total line length:

$$p_l = \frac{L_{Y,l}}{L_{T,l}} \tag{2}$$

The operating capacity on a transit line (Q_l) can be derived from the fundamental equation of transport process in public transport network [7]:

$$Q_l = \frac{V_{o,l} C_l}{L_{T,l}} \tag{3}$$

The research methodology in this paper is based on the results in Brčić, Slavulj & Šojat (2012), in which the tram line 4, with the percentage p_4 produced increase in operational speed of i_4. A simple linear model will be used to estimate the increases in operational speed (i_l) for each other transit line by knowing their yellow lane percentages (p_l):

$$i_l = \frac{i_4}{p_4} p_l \tag{4}$$

The assumption that justifies the proposed model is the fact that the transit line 4 has the highest percentage of yellow lanes in the network and, in addition, the line operates throughout the key sections of the city. This makes the line number 4 a representative for yellow lane contravention, so authors presume that exactly this line would produce the most credible linear model. From the increase, new operational speeds for each transit line ($v_{o,l}$) can be derived:

$$v_{o,l} = (1 + i_l) V_{o,l} \tag{5}$$

Based on the model, two different scenarios are being considered by authors:
- Scenario 1 – if the number of transport units on each transit line remains unchanged, the new network commercial speed (v) as the indicator of quality of service for passengers is sought the same way as in the Eq. (1);
- Scenario 2 – if the operating capacity on each transit line remains unchanged, the new network capacity (c) as the indicator of savings for the operator is sought the same way as in the Eq. (3).

3 Research results

The rolling stock of Zagreb Electric Tram is shown in Table 1 – there are currently seven different types of transport units by capacity.

Table 1 The rolling stock of Zagreb Electric Tram [6]

Designation	Name	Year	Capacity
/	/	/	sps veh^{-1}
201+T	TMK 201 with 591	1974	213
401	ČKD Tatra T4	1977	103
401+T	ČKD Tatra T4 with B4	1977	217
301	ČKD Tatra KT4	1985	150
2100	TMK 2100	1994	242
2200	NT 2200	2005	202
2300	NT 2300	2009	130

Table 2 shows the layout of each type of transport unit on each transit line, and also the total number of units on each line in transport units (veh) as well as the line capacity in spaces (sps). This gives the network capacity of 34,872 sps made by 179 veh operating in peak hour.

Table 2 Tram rolling stock matrix [6]

Line	201+T	401	401+T	301	2100	2200	2300	N_l	C_l
/	veh	veh	veh	veh	veh	veh	veh	veh	sps
1				5				5	750
2	3					11		14	2861
3				8				8	1200
4			4			10		14	2888
5					8	4		12	2744
6			4			12		16	3292
7			4			12		16	3292
8			5					5	1085
9				9			1	10	1480
11						18		18	3636
12						15		15	3030
13				9			1	10	1480
14			4			12		16	3292
15		2						2	206
17						18		18	3636

Table 3 shows the input parameters for each transit line in order to get yellow lane percentage in percents (%) and operating capacity in spaces per hour (sps h^{-1}). Using Eq. (1), the network commercial speed in 2012 becomes 12.4 km h^{-1}, which is an even higher decline of 20 % compared to 1999 (the decline of network commercial speed was 16 % in 2009 compared to 1999).

Table 3 Parameters of tram network prior to implementation of the linear model

Line	Name	$V_{o,l}$	$L_{T,l}$	$L_{Y,l}$	p_l	Q_l
/	/	km h^{-1}	m	m	%	sps h^{-1}
1	Zapadni kolodvor – Borongaj	11.5	12022	1501	12	714
2	Črnomerec – Savišće	12.4	21784	4686	22	1625
3	Ljubljanica – Savišće	12.7	20766	3022	15	735
4	Savski most – Dubec	11.7	25186	16014	64	1337
5	Prečko – Kvaternikov trg	11.2	25182	2989	12	1224
6	Črnomerec – Sopot	13.1	20820	3584	17	2070
7	Savski most – Dubrava	13.6	26108	6655	25	1716
8	Mihaljevac – Zapruđe	13.2	16768	1055	6	857
9	Ljubljanica – Borongaj	10.8	14754	4936	33	1084
11	Črnomerec – Dubec	12.9	23978	13421	56	1949
12	Ljubljanica – Dubrava	11.7	18682	10418	56	1893
13	Žitnjak – Kvaternikov trg	11.5	22736	3918	17	746
14	Mihaljevac – Zapruđe	14.1	25650	3688	14	1806
15	Mihaljevac – Dolje	14.8	5422	0	0	562
17	Prečko – Borongaj	11.8	25356	3900	15	1694

After the implementation of the simple linear model, the results for each transit line are shown in Table 4 as increases in operational speed (%), new operational speeds in kilometres per hour (km h^{-1}) and new capacities (sps). The constant in Eq. (4) is 0.127, which means that for every percent of yellow lanes on the line there will be about one eight of percent of increase in operational speed.

Table 4 Parameters of tram network after the linear model

Line	Name	i_l	$v_{o,l}$	c_l
/	/	%	km h^{-1}	sps
1	Zapadni kolodvor – Borongaj	1.6	11.6	738
2	Črnomerec – Savišće	2.7	12.7	2785
3	Ljubljanica – Savišće	1.8	13.0	1178
4	Savski most – Dubec	8.1	12.6	2672
5	Prečko – Kvaternikov trg	1.5	11.4	2703
6	Črnomerec – Sopot	2.2	13.4	3222
7	Savski most – Dubrava	3.2	14.1	3189
8	Mihaljevac – Zapruđe	0.8	13.3	1076
9	Ljubljanica – Borongaj	4.2	11.3	1420
11	Črnomerec – Dubec	7.1	13.8	3395
12	Ljubljanica – Dubrava	7.1	12.5	2830
13	Žitnjak – Kvaternikov trg	2.2	11.7	1448
14	Mihaljevac – Zapruđe	1.8	14.3	3233
15	Mihaljevac – Dolje	0.0	14.8	206
17	Prečko – Borongaj	2.0	12.0	3566

The final results for each scenario are the following:

- In scenario 1, the network commercial speed for the same number of transport units rose to 12.8 km h^{-1}, which is an increase of 3.6 %;
- In scenario 2, the network capacity for the same operating capacity dropped to 33,662 sps, which is a decline of 1,210 sps, or 3.5 %.

The savings in network capacity can be imagined as the removal of 6.0 veh of 2200, 5.0 veh of 2100, or the entire transit line number 3.

4 Discussion

In the scope of the two scenarios presented in this paper, the linear model has its drawbacks. Firstly, the probability of yellow lane contravention is extremely complex because it depends on various factors. Such factors are traffic flows next to yellow lanes, pedestrians at crossings, etc. In addition, yellow lane contravention shows different patterns in different parts of tram network because it is subject to the cumulative effect. Therefore, the linear model used to describe yellow lane contravention on other transit lanes can only serve as an approximation. In reality, it is necessary to develop an empirical model which would provide the data for each part of the network separately.

Another drawback is the assumption that it is possible to establish relationship between yellow lane contravention and operating speed while in reality that relationship is only indirect. The yellow lane contravention has impact solely on the running times (it has no influence on dwelling times at stops whatsoever). The justification in this case is the lack of detail in the available data. The data should contain running times for the entire tram network, and even more precise, running times for every section by type of segregation as in the methodology presented in Brčić, Slavulj & Šojat (2012).

The transportation process used in this paper is also simplified, so it is very roughly presented when considering terminal times (linearity assumed) or critical volume-to-capacity ratios of transport units (100 % assumed). Those elements play a very important part in the optimisation model, so they have to be taken into account.

From the passenger perspective, the 3.6 % increase in network commercial speed is not very significant, but if yellow lane contravention was eliminated, the quality of service would sharply increase because large oscillations of travel times would also be eliminated, so passengers would not have to input time surplus for the worst case scenario trip, and by this their travel time could be expected to become smaller anyway. Even small increases of network commercial speed can significantly reduce external costs of travel.
Although the savings in network capacity are 3.5 %, they can also be significant because the removal of transport units results in considerate reductions of personnel costs, vehicle operating costs, vehicle maintenance costs, network congestion and the probability of disruptions in power grid even for a small number of units.

5 Conclusions and suggestions

The research conducted in this paper showed that possible elimination of yellow lane contravention (which can be achieved by yellow lane enforcement) brings significant improvements in tram network, interpreted as network commercial speed increase (3.6 %) or network capacity decrease (3.5 %). The benefits are cost reductions and better quality of service. Based on previous experiences and the ones obtained in this paper, if every kind of priority was combined together, authors estimate that network commercial speed in the City of Zagreb could increase up to 30%.
Transport process in this paper was simplified to adapt to the input data. However, the mutual interaction of elements and constraints from the optimisation process itself require thinking of the optimisation process as a nonlinear problem, which has to be solved by appropriate software tools. For such a problem, the input data has to have sufficient quality and the amount of detail.
To ensure better quality of the input data, a geo-referenced network with all the necessary features and with the possibility to change in time is recommended. Also, the tram priority can sometimes leave the negative impact on the road network, so the only way to estimate the consequences is the usage of simulation tools. Only in such manner tram network can be successfully maintained from the traffic technology perspective.
In the near future, it is necessary to fully examine the dynamic efficiency of tram network in the City of Zagreb (to include all possible elements influencing network commercial speed). Such a study would reveal the weak points on the network (points with the lowest capacity), and appropriate corrections done on those points would result in better network commercial speed and consequently, better quality of service for passengers.

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