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AN ESTIMATION OF OPERATING SPEED INCREASE BY TRAM SIGNAL PRIORITY

ABSTRACT

Due to the excessive private car usage, the City of Zagreb is faced with motorization rate increase in the past few decades, constantly reducing the operating speed in tram network to its lowest values at the present, rendering public transport unattractive. Besides the partial integration within the road network and therefore interactions with motor vehicles, an additional reason for such values is very poor signal priority for trams at intersections. The previous research on tram signal priority has predicted significant operating speed increase for the network if the technology was implemented only partially, so this paper presents a simple methodology based on vehicle running times for estimating time savings and operating speed increase. The results in the paper estimate if signal priority could increase the operating speed to satisfactory levels by European standards, for shifting users from private cars, and making transport system in the city more sustainable in terms of finances, space and environment.

KEY WORDS

City of Zagreb; operating speed; signal priority; time savings; tram network;

1. INTRODUCTION

The City of Zagreb is the capital and the largest city of the Republic of Croatia, with population of an estimated 0.8 million [1], and a population density of 1,200 residents per square metre. The metropolitan area has the population of 1.1 million. The City itself is located on the southern slopes of Medvednica mountain, divided by the Sava river, with rough terrain only in the northern peripheral parts of the City. It consists of 17 municipalities, divided into 70 neighbourhoods.

The road traffic in the City is characterized by local streets, higher priority streets, and city avenues. Most of city avenues stretch from east to west, making the current state of traffic subject to the capacity of roads connecting northern and southern parts. Since motorisation rate is 430 vehicles per 1000 inhabitants, and passengers are used to their private cars, traffic congestion is usual in the morning and the afternoon peak periods on main road corridors.

The mobility in the City of Zagreb is highly related on purchasing power, comfort provided by the private cars, and a poor transport policy by the city administration. Due to the financial crisis starting in 2008, one third of people use private cars, one third use public transport, and the remaining third is divided into pedestrians and cyclists, with a continuous increase of bicycle traffic in the past several years. Although public transport has become financially more acceptable than private car, it still does not represent an acceptable choice for passengers.

Public transport in the City is organized mostly by trams and buses. Passengers ride on 140 bus lines and 15 tram lines, with approximately 740,000 daily trips, and the public transport vehicles record very high passenger densities in morning and afternoon peak periods. Public transport network is stretched throughout the City, covering every significant part of the City, resulting in 10-minute walks in the city centre and 15-minute to 20-minute walks in the periphery. Dynamic performance of public transport operated by trams is the weak link, with approximately 12 km h^{-1} operating speed unsatisfactory for passengers.

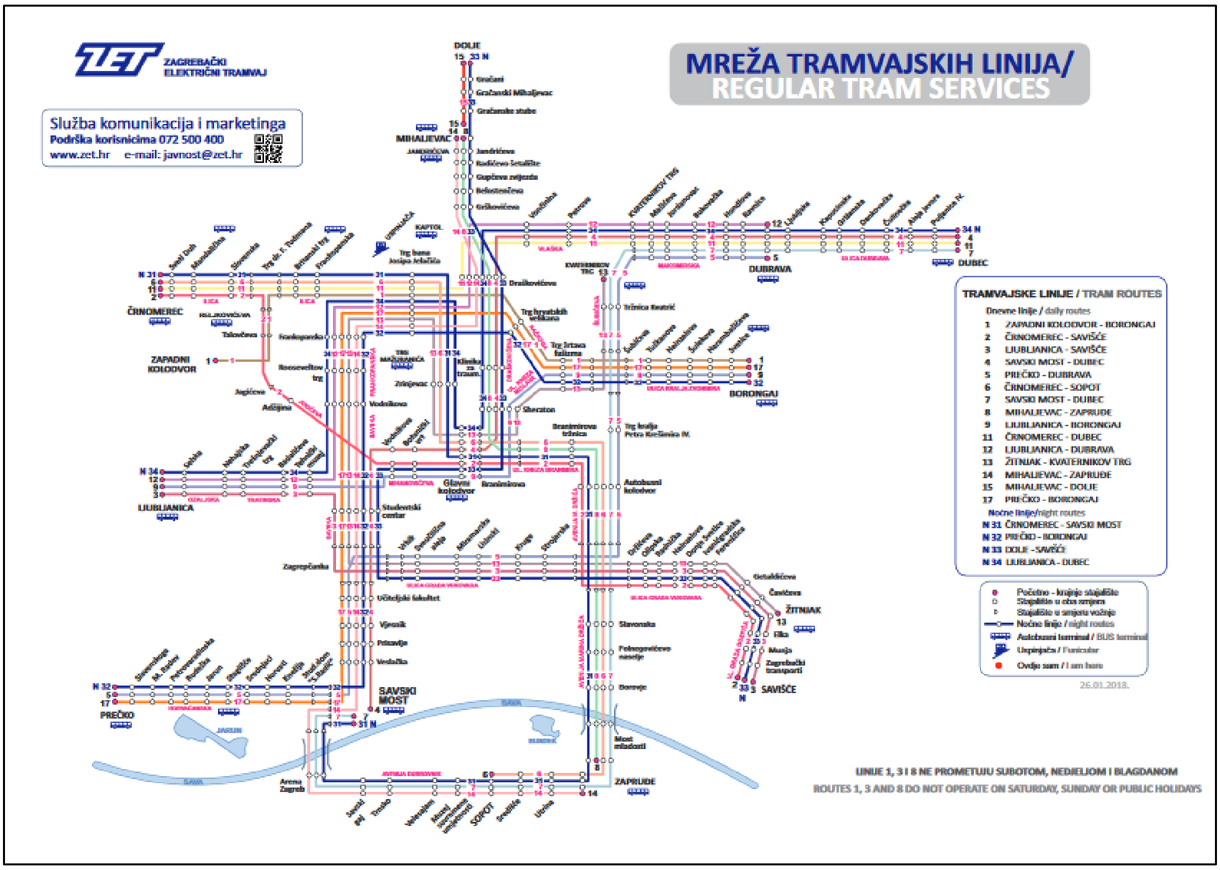

Figure 1 – Zagreb tram network
Source: [2]

Tram network in Zagreb (Figure 1) is a part of the urban road network, on which:

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

The operating speed of tram network in the City of Zagreb is has been steadily reduced from 15.4 km h^{-1} (in 1999) to 13.0 km h^{-1} (in 2009), which is approximately 16 %. This decline is the result of the increasing usage of urban road network by private cars. In this decade, the speed is usually between 12.0 and 12.5 km h^{-1}. Besides the private cars freely using the white lanes, an additional problem is yellow lane contravention, and there is not any kind of yellow lane enforcement present in peak periods. The increasing usage of urban road network by private cars is also the reason for shorter green light percentages for trams at intersections, making benefits for trams considerable only in tram lanes stretch on main city avenues.

Because it plays a significant part in quality of service, public transport priority is a subject of much research. In recent times, different kinds of solutions related to signal priority have been developed to increase performance of public transport network, and they are mostly based in implementing communications technologies and intelligent transport systems. Once implemented, the technologies usually result with considerable improvements if compared to no priority at all. Wahlstedt (2011) studied bus signal priority in Stockholm by implementing simulation-based method for analysing partial dynamic signal timings and fully-adaptive signal control systems with the Swedish PRIBUSS method. Public transport priority results in shorter travel times for buses up to 20 % depending on the method, and longer travel times for crossing traffic and traffic following the prioritized buses in one direction [3]. 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 % [4].

There is also research with estimations on operating speed increase for tram network in the City of Zagreb. The analysis of yellow lane priority on a single tram line in Zagreb tram network was conducted by Brčić, Slavulj & Šojat (2012). By using optimization tools, the result was operating speed increase of 8 % and savings of one transport unit, which is 7 % of the total number of transport units on the line [5]. Based on the research results from [5], Brčić, Slavulj & Šojat (2014) conducted another research where they estimated that yellow lane enforcement, if implemented, would result in 3.6 % operational speed increase in the network and estimated operating speed increase by 30 % with every type of priority combined [6]. The research on public transport priority based on two scenarios was conducted by Šojat, Brčić and Slavulj (2017). The operating speed increase was 7 % in case of minimum delays, and 41 % in case of the absolute tram priority [7]. The mentioned research for the City of Zagreb suggests that there is a considerable space for improving the operating speed based on signal priority only.

Within the Civitas project family implemented in Europe, 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 [8]. 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 [9]. In addition, a pilot-project was carried out which involved yellow lane enforcement by traffic police at the same corridor. Significant time savings of 25 % throughout the corridor were achieved [10]. However, besides the mentioned two pilot project, there has not been a single comprehensive project implemented in the City which would introduce long-term priority solutions for the network.

Considering signal priority for trams, this paper presents a methodology for estimating the operating speed increase if tram signal priority was implemented in the City of Zagreb based on the collected data in trams during the afternoon peak periods, and the results, compared with the results of previous research, should serve to more accurately describe the extent of improving the service for passengers.

2. METHODOLOGY AND RESULTS

The data used for this paper was collected in Zagreb tram network in the afternoon peak periods. Since the representative data can be obtained only in morning and afternoon peak periods, and the students of the Faculty of Transport and Traffic Sciences in Zagreb were the ones collecting the data, the afternoon peak period was chosen because it was more suitable for most students than the morning peak period, considering their schedules (this type of task demands significant resources in time and people). The measurement period, October and November 2016, is representative for tram network in Zagreb. The data was provided by GPS data loggers, measuring speed and position in one-second intervals. The students holding data loggers were standing in vehicles near the driver cabin. The measured routes showed no major errors in collected routes due to lost GPS signals (by vehicle roof or the high-voltage wires). The gathered data was then processed by using *Google Earth*, *CanWay*, *Microsoft Excel*, and *QGIS*.

The data sample encompassed every tram line on the network except the line 15 (which is much shorter than the rest, and completely segregated from the network). Therefore, on corridors with more lines, the sample was satisfactory (more than five samples were collected), and on corridors with fewer lines or only one tram line operating, the sample was scarce (between three and five samples were collected).

Between the stops, there is usually more than one factor affecting the driving speed, so determining the driving speed improvements based on signal priority becomes complex. So, to draw conclusion regarding signal priority only, we considered only stop spacings with signalized intersections as the sole operators on them (Figure 2) – in these spacings, there are no obstacles for trams (such as pedestrians at crossings, vehicles in the same lane or possible yellow lane contraventions) except the signalized intersections blocking the vehicles on completely segregated tram lanes (green lanes). For tram network, these spacings are totally 42,3 km out of 107,9 km (39 %). For the rest of the network (where such measurement could not be made), we presumed that the 39 % of network would be enough to represent the entire network, i.e. the operating speed change for this part of the network would be mandatory for the entire network without the major deviations in reality (although this cannot be proven).

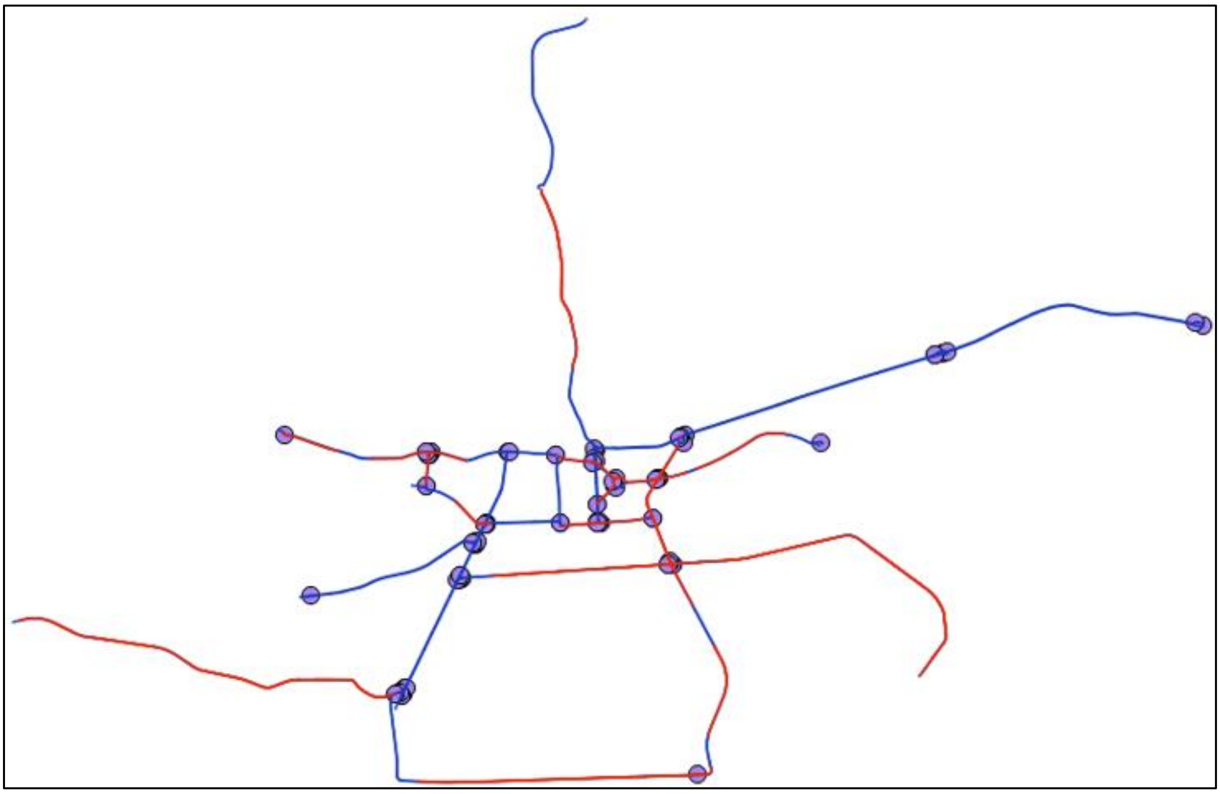

Figure 2 – Parts of tram network where the measurements could be made (in red)
Source: by authors

For measuring the possible improvements from signal priority, average driving time and minimum driving time were extracted to calculate average and maximum driving speed from times and spacing lengths. For each spacing, there were two possible measures for determining minimum times:

- Movement speed method (a priori): the minimum time Δt_{MIN} is a result of several input variables - maximum speed on the spacing v (usually limited by traffic regulations), l is length of the spacing, a is vehicle acceleration, and b is vehicle deceleration (each value positive):

$$\Delta t_{MIN} = \frac{v}{2a} - \frac{v}{2b} + \frac{l}{v} \tag{1}$$

- Fastest vehicle method (a posteriori): the minimum time Δt_{MIN} is determined by the fastest vehicle in the sample of times t_n – the coefficient k is used for corrections if necessary:

$$\Delta t_{MIN} = k * \min_n t_n \tag{2}$$

From these two measures, the measure (2) was chosen because the results were more precise – the former measure often resulted with unrealistic results due to the complex network geometry or the problems with drivers exceeding speed limits (legislation problems). Based on the times, the priority was calculated based on average V_{AVG} and maximum possible speed V_{MAX}:

$$p_n = \frac{V_{AVG}}{V_{MAX}} \tag{3}$$

To get the average priority p for the network, for each spacing separate priority p_n was multiplied by the spacing length l_n, then summed and divided by the total length (the priority on spacing was weighted onto the network):

$$p = \frac{\sum_n p_n \, l_n}{\sum_n l_n} \tag{4}$$

Based on the (4), for the value p we got 77 % - therefore, the operating speed in the network, due to the the signalized intersections, is 23 % less than it could be, and if we consider the current operating speed of 12.6 km h^{-1}, there is a possibility to increase that speed on the network up to 15.5 km h^{-1}.

3. DISCUSSION

The results indicate that the possible space for improving operating speed in tram network is possible similar to the predictions in [5], [6] and [7] – since the speed can be improved up to 23 %, signal priority stands out as the most prominent method if the implementation costs are considered, in contrast to lane segregation (the costs are significantly higher, and there is still need to introduce signal priority in some cases) or yellow lane enforcement (the effect is smaller – 3.6 % operating speed increase [6], although important for timetables).

The sample explained in the previous section contained enough samples on high-frequency corridors in the network; however, on corridors where fewer lines operate the number of samples was less (since the measurement was conducted for tram lines). On those corridors, measurements should be higher for more accurate results.

In the previous section, two possible methods for obtaining minimum driving times at spacings were mentioned, and the latter one was used, because it produced more accurate results than the former one. However, there are problems with the fastest vehicle method as well, that can be divided into two possible cases:

- The times are too low, or speeds too high – this is mostly the case when the fastest vehicle runs faster than the speed limit by traffic regulations – in these cases, a coefficient should be used for time compensation, or the sample (if big enough) should be observed to a percentile (e.g. the fastest vehicle not included);
- The times are too fast, or speeds too low – this is mostly the case when the signals between public transport stops are coordinated, and regardless of vehicle performance, minimum driving times will always be the same, while they could be smaller.

Therefore, to reach the most precise results, the times should be obtained by the first method, accompanied by a comprehensive network analysis, considering geometry, traffic regulations, and vehicle performance.

Another methodology for estimating operating speed increase by signal priority (not covered by this research) is the one that considers vehicle frequency – since the vehicles are the units for measuring operating speed, besides the length of the spacing, this methodology should also consider vehicle frequencies on network corridors to estimate operating speed improvements. However, this methodology should consider the entire network since vehicle frequencies vary among corridors with different priority operators.

Another factor that should be considered when estimating signal priority is the complexity of intersections – if at intersection trams operate only in one direction (and the opposite direction), and the intersection is not highly complex regarding other traffic (number of phases, phase length, pedestrians), implementing signal priority for trams would result in considerable time savings. However, if the intersection is complex (trams coming from multiple directions, more phases, or phases that require coordination with other intersections), implementing tram priority could have a very low impact. Since the number of complex intersections makes a considerable percentage, the 23 % operating speed increase would be smaller, since introducing signal priority on different intersections would result in different effects.

4. CONCLUSION

The research in this paper has confirmed the estimation from previous research – if signal priority was implemented on tram network in the City of Zagreb, the operating speed could increase up to 23 % - from the existing 12.6 km h^{-1} to 15.5 km h^{-1}. This is only the increase due to signal priority, so if yellow lane enforcement and lane segregation were considered as well, the network could easily have vehicles operating above 16.0 km h^{-1}, which is the value recommended by the European standards, regardless of low spacing and high vehicles to network length ratio.

If tram priority was considered in the City of Zagreb, there are large possibilities for improving the operating speed. If compared to tram lane segregation and yellow lane enforcement, signal priority has the best potential for improvement because the investments are minimal, and the effects are considerably high. The decision on improving tram priority must be made on the decision-making level with a sound traffic policy. The higher operating speed should be an imperative if public transport is to be made more attractive for passengers, thus making them shift from private cars, resulting in better mobility in peak periods for every citizen.

The further step in analysing tram and bus priority in the City of Zagreb would be a comprehensive analysis to show the intersections with the highest effectiveness if the signal priority was implemented, as well as the intersections where such measure could result in slight or no improvements at all. The intersections should be mapped, and simulation tools used to precisely estimate if implementing signal priority is time-effective or cost-effective.

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