ANALYSIS OF TRANSIT SERVICE IMPROVEMENTS IN THE CITY OF ZAGREB

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Original scientific paper

As a mass transit mode, public transport represents the backbone of sustainable urban mobility in highly-populated cities. In order to achieve modal shift from private car to public transport among city trips, transit service has to be attractive for passengers. In this manner, the operating speed, which highly depends on public transport priority, becomes an important indicator of public transport attractiveness. The tram priority research conducted in this paper is based on the available public transport data for the tram network of the City of Zagreb, such that two hypothetical tram priority scenarios were set. The results, in form of operating speed increase and savings in passenger spaces, show the possibilities for improvements while the operating capacity remains the same; all this is impacting the passenger travel time and costs for the operator as well as the local community of the City of Zagreb.

Keywords: City of Zagreb; public transport priority; sustainable urban mobility; tram network; transit service

Analiza poboljšanja prijevozne usluge na mreži tramvajskih linija Grada Zagreba

Izvorni znanstveni članak

Javni gradski prijevoz kao modalitet masovnog prijevoza putnika predstavlja okosnicu održive urbane mobilnosti u većim gradovima. Radi postizanja modalne preraspodjele gradskih putovanja sa osobnog automobila na javni gradski prijevoz, prijevozna usluga mora biti što atraktivnija putnicima. Operativna brzina kao bitan pokazatelj atraktivnosti javnog gradskog prijevoza ovisi većim dijelom o prioritetu javnog gradskog prijevoza. Istraživanja u ovom radu su provedena na temelju dostupnih podataka o prijevoznom procesu u mreži tramvajskih linija Grada Zagreba, te su postavljena dva hipotetska scenarija prioriteta. Rezultati u obliku povećanja operativne brzine i ušteda kapaciteta na mreži pokazuju kolike su mogućnosti za poboljšanje uz zadržavanje konstantnog operativnog kapaciteta s posljedicom smanjenja vremena putovanja kod putnika i uštedama kod prijevoznika kao i lokalne zajednice Grada Zagreba.

Ključne riječi: Grad Zagreb; mreža tramvajskih linija; održiva urbana mobilnost; prijevozna usluga; prioritet javnog gradskog prijevoza

1   Introduction

The ever-increasing global urbanisation process in the past decades has resulted in high private car usage, which led to traffic congestion in the majority of cities worldwide. The build-only approach could not solve this issue, so public transport has become the backbone of sustainable urban mobility because of its advantages over the private car in terms of efficiency. The efficiency is related to less space consumption, less energy consumption and less impact on the environment. However, in order to make the mobility of the urban areas sustainable, it is necessary to make public transport more attractive by encouraging passengers to shift from private cars, i.e. to change the current modal split of city trips in favour of public transport.

According to the existing literature, the definition of public transport priority often refers to giving public transport vehicles a clear pass at intersections, without stopping at traffic lights. However, the authors define public transport priority in broader terms – public transport priority is a set of measures aimed to approximate the current vehicle running times to optimum values. In other terms, the goal of introducing public transport priority is to eliminate any kind of disturbances on the network so that any change in vehicle speed would be a consequence of network geometry, dwelling at stops, or the vehicles only. Therefore, by the definition, public transport priority can only be a part of the dynamic aspect, excluding vehicle dwellings at stops or dwellings at termini, i.e. considering only running times at links.

According to the definition by the authors, there are three types of priority:
- priority by segregation refers to physical separation of public transport lanes from other traffic moving in

parallel – it is usually done by introducing barriers between the lanes or by any kind of road infrastructure preventing other vehicles to enter
- priority by legislation is derived from the existing legislation as a set of rules for other vehicles in road portions shared with the public transport to comply with – contrary to priority by segregation, priority by legislation can be subject to traffic violations
- signal priority refers to the minimization of the waiting time at intersections when a public transport vehicle approaches the intersection.

An important aspect of public transport priority is the measurement of its efficiency. Firstly, the optimum running times are usually obtained a priori, considering the network geometry, vehicle specifications, and the legislation. Secondarily, the actual running times at links are usually obtained by recording running times due to the complexity of transport process. The comparison of actual running times and the theoretical ones gives the ratio of the actual speed on the link and the optimal speed, which is a measure of priority effectiveness, named the priority percentage. This can be done for each link, particular portions of the network (e.g. stop spacings), or the entire network.

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 operating speed increase between 15 % and 25 % [1]. Within the Civitas project family, many measures related to public transport have been implemented. Such 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 operating speed increase, travel time reduction and eventually, passenger satisfaction and the modal shift [2].

The analysis of tram priority in form of hypothetical yellow lane enforcement was conducted by Brčić, Slavulj and Šojat (2012). The real-time data was collected by the GPS logging units placed in trams on a single line in the network with the highest yellow lane percentage (tram line 4 with 64 % of yellow lanes – lanes segregated by legislation). The goal was to combine the data obtained for the morning peak period and off-peak period in order to create a scenario in which yellow lane enforcement was introduced in morning peak period. A nonlinear model was developed for the optimization purposes, with the minimisation of the number of transport units as the objective function, such that the constraints were derived from limitations in the network. The optimisation process resulted in operating speed increase of 8 %, and 7 % savings in passenger spaces, which was equivalent to one vehicle on the line [3].

The analysis of tram priority in the form of yellow lane enforcement for the entire tram network was conducted by Brčić, Slavulj and Šojat (2014). For the purpose of data collection for the entire network, the input data was obtained from Brčić, Slavulj and Šojat (2012), and the simple linear model was applied to extrapolate the amount of savings to the entire tram network if the yellow lane enforcement was introduced. The assumption of the model was the highest yellow lane percentage on tram line and the fact that the line 4 operates throughout the key sections of the city. The analysis resulted in the operating speed increase of 3,6 %, and the passenger space savings of 3,5 % [4].

Based on the operating speed data in the City of Zagreb, this paper aims to research possible improvements in operating speed if two hypothetical priority scenarios were implemented. Also, it is wanted to find whether the operating speed values can be returned to the ones in 1999, or if they can be made higher, all in order to increase the attractiveness of tram network and to achieve the modal shift of city trips in favour of public transport.

2   Analysis of the current state

The public transport network in the City of Zagreb consists entirely of public surface transport, operated by trams and buses. Tram network consists of 120 km of tram lanes, and the network is positioned mainly in the inner city area [5]. By the mode of segregation, tram lanes are divided into:
-    green lanes (53 %) – completely segregated tram lanes
-    yellow lanes (21 %) – lanes exclusively for public transport and taxi vehicles based on the legislation
-    white lanes (26 %) – lanes completely shared with the mixed traffic.

An example of a road portion with yellow and white lanes is shown in Fig. 1.

Operating speed on tram network in the City of Zagreb has been constantly decreasing from 15,4 km/h in 1999 to 13,0 km/h in 2009 (Fig. 2). The most recent data shows the ongoing trend of operating speed decline by an average 0,2 km/h per year –the operating speed was 12,4 km/h in 2014, which is the decrease of 19 % if compared to the value in 1999. The constant operating speed decrease is a result of the increased private car usage, especially in peak hours. The most significant consequences of the increased private car usage are:
-    yellow lane contravention in peak hours, because the yellow lane enforcement has not been established in the City of Zagreb
-    traffic violations involving pedestrians and vehicles at intersections, and car parking next to tram lanes
-    shorter green times for trams at intersections.

An additional reason for operating speed decrease is poor track maintenance. Due to the lack of funding needed for proper maintenance, adoption of lower speed limits was a measure for ensuring safe tram operations, resulting in even higher operating speed decrease, especially after 2006.

Figure 1 An example of tram lanes integrated into road network – transition from yellow lane (farther) to white lane (closer)

In the City of Zagreb, two projects related to tram priority were implemented. The first was the Civitas-Elan project, with the measure "Giving priority to public transport". Partial signal priority was implemented at three intersections in Savska Street, resulting in 5 % time savings for the entire corridor [6]. The second one was a pilot-project which involved yellow lane enforcement by the traffic police at the same corridor. Significant time savings of 25 % throughout the corridor were achieved [7].

The data used for this paper was obtained from the scientific research project "The Development of Sustainable Urban Mobility Plans", conducted by the Faculty of Transport and Traffic Sciences, and supported by the University of Zagreb [8]. One of the goals of the project was to conduct tram priority research in the City of Zagreb. The project activities related to the priority were:
-    tram network design in a geo-referenced software to obtain link lengths

- data collection in the morning peak period with GPS loggers placed on each tram line
- data processing done by the GPS processing algorithm to obtain driving times for each link and dwelling times at stops.

There were two methods used for the determination of minimum possible driving times on links:
- the movement diagram method (based on pre-defined values for acceleration, speed, and braking) did not provide high-quality results because the standard movement curve could not be used for each link due to the lack of detail in the network data provided
- the fastest vehicle method (based on best measurements) provided results that were sufficient in quality because the sample for each link was large enough in order to select one vehicle that crosses the link with minimum possible driving time. Although the provided data obtained by the fastest vehicle method was sufficient in quality, the method itself is still questionable because of the problem with either running times too large (in case of synchronized traffic lights), or too small (when the vehicles move faster than allowed). This method has to be re-evaluated in the future or the vehicle movement diagram method has to be applied, supported by a higher level of detail.
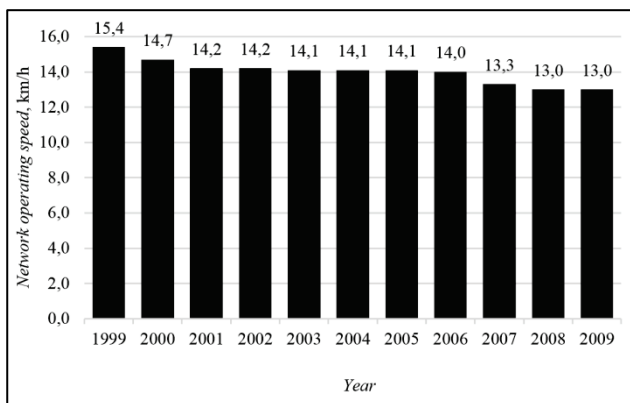

Figure 2 Operating speed in tram network of the City of Zagreb in the period 1999-2009 [5]

From the research data, the following was extracted:
- link lengths
- average running times (between stops)
- minimum running times (between stops)
- stop dwelling times.

The theoretical and practical values for running times on each link were then compared in a geo-referenced software in order to determine the priority percentage. The research of the priority percentage unveiled critical spots on the network related to priority and confirmed that critical spots occur due to the cumulative effect on links, which was usually a result of pedestrian flows at crossings and private cars using tram lanes (legal or illegal). Combined with high tram frequency (which is greater than 30 vehicles per hour in several sections, causing tram passages below one minute), the cumulative effect causes serious delays in those sections.

The research pointed out the importance of introducing priority by segregation and signal priority, and provided estimations of changes in operating speed for each tram line and the network.

3 Research methodology

Using the link lengths, average running times, minimum running times, and average dwelling times at stops, the following was determined for each line route in this paper:
- line route length in kilometres
- average travel time in minutes
- maximum travel time in minutes.

The input data were used to determine the following (such that termini were considered as endpoints of line routes):
- delay coefficient in percent and schedule adjustment time in minutes (from average travel time and maximum travel time)
- crew resting time in minutes (the authors derived it from current legislation in Croatia related to labour) as one eleventh of the average travel time
- vehicle rearrangement time in minutes (derived from terminus geometry, crew resting location, signalized intersections belonging to terminus, etc.)
- terminus time in minutes
- partial cycle time in minutes (as the sum of the average travel time and terminus time).

In addition to the line length in kilometres, the dynamics for each line was determined:
- cycle time in minutes
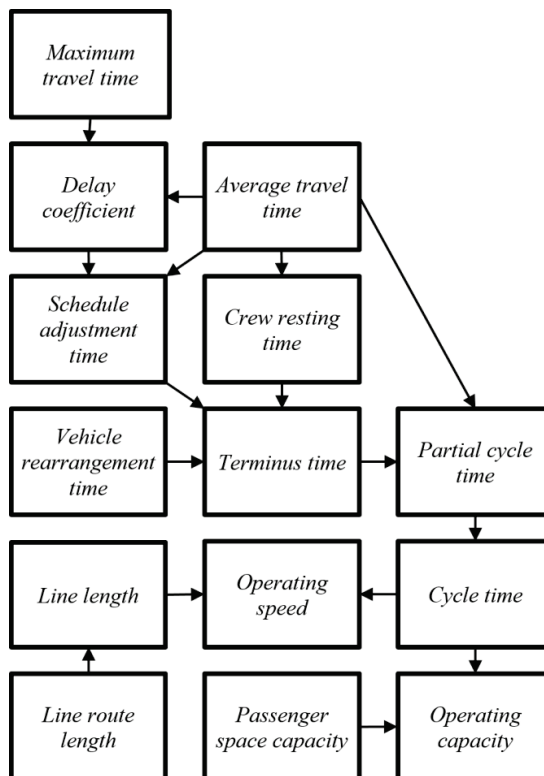- operating speed in kilometres per hour.

Figure 3 The quantity block-diagram based on input data for obtaining operating capacity

The statics for each line were determined from the capacity of each vehicle type, giving the number of passenger spaces as in [9], in thousands of seats for each line. Finally, the number of passenger spaces and operating speed were used to determine operating capacity in thousands of spaces per hour as the basic quantity for further calculations. The process for obtaining every quantity is shown in Fig. 3.

The methodology of the paper considers two different hypothetical priority scenarios based on the input data:
- in the line scenario, the average travel time for each line is defined as the minimum travel time among each vehicle operating on that line – the line scenario represents the case of minimum delays
- in the link scenario, the average travel time for each line is defined as the sum of minimum times for each link belonging to that line – the link scenario represents the case of absolute tram priority.

Changes in average travel time result in changes in:
- delay recovery time
- crew resting time
- terminus time
- partial cycle time
- cycle time
- operating speed.

The input data still provides:
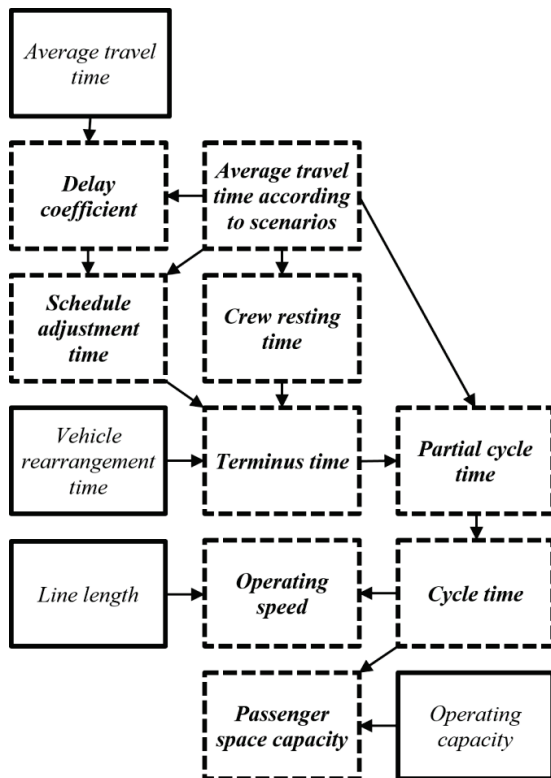- vehicle rearrangement time
- line route length and line length.

Figure 4 The quantity block-diagram based on scenarios for obtaining the number of passenger spaces

The delay coefficient (δ) was reduced in both scenarios such that a linear interpolation was made with it based on the change in average travel time (T_O):

$$\delta' = \frac{T'_o\, \delta}{T_o}. \qquad (1)$$

The change in operating speed directly affects the fundamental equation of transport supply in public transport [10]:

$$Q = \frac{CV_C}{L}, \qquad (2)$$

where Q is operating capacity, C is the number of passenger spaces, V_C is cycle speed, and L is line length. As a consequence of operating speed increase, authors consider decrease in number of passenger spaces for each line, such that the operating capacity remains unchanged, as shown in Fig. 4. Dashed blocks show the quantities that changed when the two scenarios were set, and the solid blocks represent the quantities that remained unchanged.

Finally, the operating speed in the entire network (V_N) is defined as the product of sums considering the number of passenger spaces; the number of passenger spaces on the network (C_N) is defined by simply adding the number of passenger spaces for each line:

$$V_N = \frac{\sum_L V_L C_L}{\sum_L C_L}, \qquad (3)$$

$$C_N = \sum_L C_L, \qquad (4)$$

The values in Eq. (3) and (4) are used to show what kind of changes on the network would happen if the case of absolute priority or the case of minimum delays were achieved in tram network.

4   Research results

After the implementation of the procedure described in Fig. 3, operating capacity was calculated for each line (Fig. 5), and it was then used as mandatory for the implementation of scenarios. The diagram in Fig. 5 shows that lines 06 and 11 have to provide the highest operating capacity ensured by high number of passenger spaces as they operate throughout the key areas of the city and by that, they attract many passenger trips. Although the line 15, with two vehicles operating on 5 km line length, has the minimum number of passenger spaces on the network, it provides relatively high operating capacity because it is the only representative on the network in terms of priority performance near absolute values. The operating capacity shown in Fig. 5 for each line is achieved with total number of 34 900 spaces moving with an average of 12,2 km/h.

The results after the subjection of the average travel time to changes in both scenarios according to the scheme in Fig. 4 resulted in average travel time decrease of 7 % in the line scenario, and 28 % in the link scenario, which makes the decrease in link scenario 4,1 times greater than the one in the line scenario. The highest decrease in travel

time occurs on lines 04, 09 and 12 – lines that have in common the highest vehicle frequency, the highest proportion of white and yellow lanes, and the highest share of critical spots on the network where the cumulative effect occurs. Line 15 has the smallest values of travel time decrease because the priority on that line is near absolute values (the line is completely segregated and does not have signalized intersection on any of its routes). Besides the line 15, lines with the smallest travel time decreases are the ones which have the highest green lane percentage in the network.
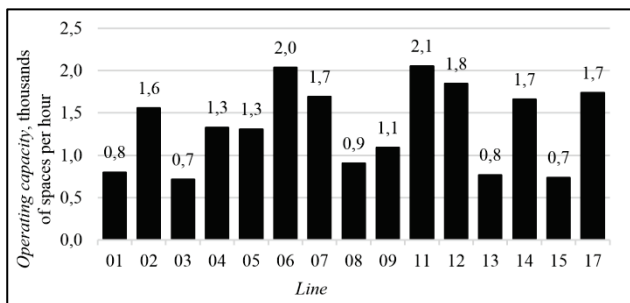

Figure 5 Operating capacity for tram lines based on the input data

After combining the travel times and terminus times for each line route, the operating speed increase is shown in Fig. 6, and the savings in passenger spaces is shown in Fig. 7. The changes are similar to the ones in travel times, with the lines 04, 09 and 12 as the lines with the most significant improvements. The average operating speed increase is 8 % in line scenario, and 39 % in link scenario, which makes the increase in link scenario 5,2 times greater. The average saving in the number of passenger spaces is 7 % in line scenario, and 27 % in link scenario (4,0 times greater).

For the same operating capacity, the theoretical results (based on research) for the entire network are the following:

- network operating speed increases to 13,0 km/h (by 7 %) in the line scenario, and to 17,2 km/h (by 41 %) in the link scenario
- the number of passenger spaces in the network is saved down to 32 500 spaces (by 7 %) in the line scenario, and down to 24 700 spaces (by 29 %) in the link   scenario.
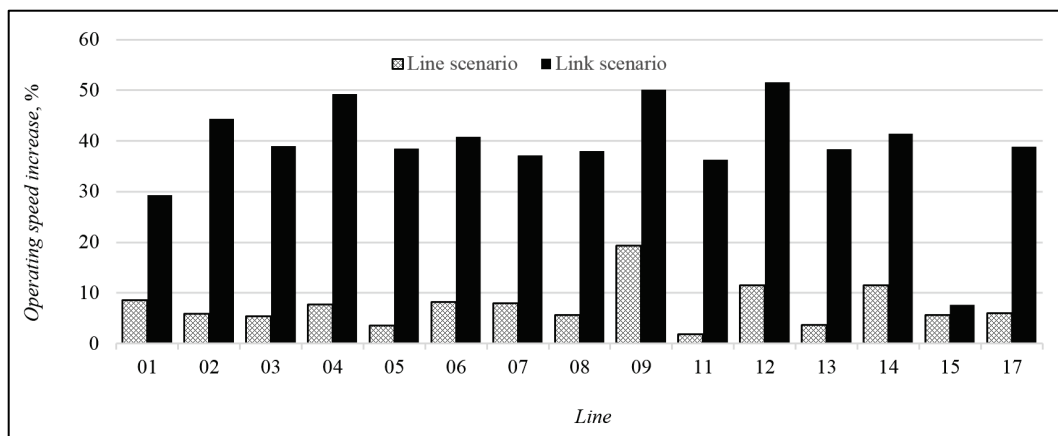

Figure 6 Operating speed increase in line and link scenarios for each line
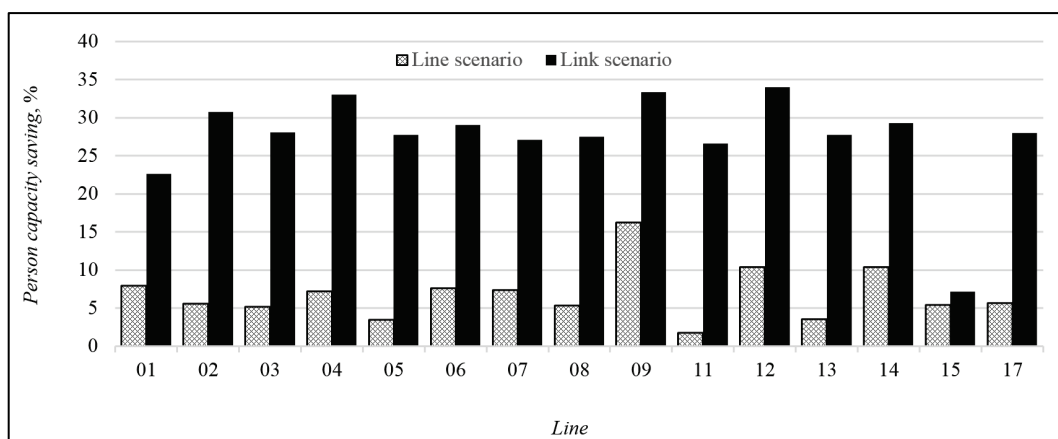

Figure 7 Savings in the number of passenger spaces in line and link scenarios for each line

The savings in the number of passenger spaces can be shown in form of investment cost savings in TMK 2200 vehicles (the most recent tram type with 202 spaces per vehicle by the standard of 4 standees per m^2). Considering the price of one TMK 2200 vehicle of 1.87 million EUR, and the total of 112 vehicles (63 %) operating on the network, the results are the following:

- in the line scenario, the 2400 passenger space saving is equivalent to 12 vehicles or 22 million EUR
- in the link scenario, the 10 100 passenger space saving is equivalent to 50 vehicles or 94 million EUR.

5 Discussion

The results of the research conducted in the paper show that operating speed and the number of passenger spaces on the network can considerably change if solely line scenario was considered. The 0,8 km/h change is considerable for passengers in reducing their on-line travel time, because it would return the operating speed values to the ones in 2007. The saving of 2400 passenger spaces is also considerable for the operator, because 6 lines on the network operate with less vehicles equivalent.

In the link scenario, the 17,2 km/h showed the theoretical limits of operating speed in tram network. Since the average European operating speed standard in tram network is approximately 16,0 km/h, higher investments in each type of priority would result in reaching the operating speed standard of 16,0 km/h, which is the desired high performance in terms of priority. In addition, the saving of 10 100 spaces is equivalent to almost three lines with the highest number of passenger spaces (lines 06, 11 and 17 combined together hold 10 600 spaces of the total number of passenger spaces).

The benefits of even minor implementations are considerable, because:
- from passenger perspective, the operating speed increase on the network results in better quality of service due to less time spent in transport process which directly impacts the public transport attractiveness
- from transit operator perspective, savings in the number of passenger spaces on the network in form of withdrawing transport units result in considerable reductions of personnel costs, vehicle operating costs, vehicle maintenance costs and network congestion costs
- from local community perspective, external costs and impact on the environment become less.

Scenarios in the paper were simplified in order to adjust the process to the resolution of the available input data. However, relations between network elements and the influence of other road network users such as private cars and pedestrians require higher amount of detail for consideration in order to provide more accurate results. The scenarios lack an analysis of link capacity and vehicle frequency, because critical spots in the network usually involve high vehicle frequency.

Additional problem related to hypothetical scenarios presented in the paper is related to the delay coefficient taken from the provided data which was then applied to both scenarios with linear interpolations based on the average travel time. In reality, delays are also influenced by changes in priority and in this manner, they cannot be predicted by simple linear interpolations. Better delay coefficient estimations require the usage of modelling and simulation tools.

The premise in the scenarios was the saving in the required number of passenger spaces as a consequence of operating speed increase. However, as the operating speed increases, the public transport attractiveness becomes higher, and it is expected that the adequate transport supply would have to be provided for the additional transport demand. Therefore, the decrease in the number of passenger spaces in reality would be less.

The activities on termini in this paper were simplified, such that they do not include the analysis of the available spaces or differences between the smallest and the largest travel times. Such level of detail has to be considered for better results.

The two scenarios described would have difficulties to implement in the reality. Based on the experience of the authors on the subject, the line scenario would give results similar to the ones if the yellow lane enforcement was implemented on the entire network; however, this would require major investments in the optical surveillance technology, currently being used in the City of Zagreb for monitoring car parks or intersections. In addition to this technology, the link scenario would require signal priority implemented on every intersection and pedestrian crossing, which is based on the vehicle detection technology, while the current white tram lanes would have to be replaced with either yellow lanes or green lanes, which requires huge infrastructure investments, and major traffic flow reorganising.

6 Conclusion

The results from the two scenarios implemented in this paper showed considerable improvements in line scenario (7 % better operating speed, 7 % saving in the number of passenger spaces, 22 million EUR investment cost savings), similar to the yellow lane enforcement. The availability of the surveillance technology (for prevention and correction actions) is the main argument for establishing yellow lane enforcement supported by the results from the line scenario.

In the link scenario, a representative of absolute tram priority, the operating speed is 41 % better, with 29 % saving in passenger spaces and 94 million EUR of investment cost savings – this represents the possible theoretical space for improvement in reality. The current state of the network suggests that the implementation of any kind of measure from the absolute priority scenario would be significant, especially if the measures were implemented solely on critical spots on the network.

In the City of Zagreb, public transport attractiveness is possible to be improved significantly by increasing the quality of service. In the current network state, operating speed increase related to the quality of service could bring significant passenger travel time decrease, and this can be made by introducing or improving public transport priority in the network. However, one must not forget that the operating speed improvements and, especially, service reliability improvements are also related to the quality of infrastructure.

In the scope of further activities, it is recommended to fully research the dynamic efficiency of tram network in the City of Zagreb based on public transport priority by using modern software tools for creating simulations and making models. Such activities would provide better predictions of operating speed change and interventions in passenger spaces required to increase it with less investments.

7   References

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