UTILIZATION OF GPS IN PT PERFORMANCE EVALUATION

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ABSTRACT. *The focus of this paper is to demonstrate how Global Positioning System (GPS) can be utilized in order to conduct comprehensive data collection process and analysis of public transport (PT) performances. During CIVITAS ELAN project, GPS receivers were installed in trams in order to evaluate the impact of different project measures. We show how detailed analysis of obtained GPS data enabled us to conduct the evaluation of PT network performances on micro and macro level. The data was also used to define PT priority schemes which were implemented at 3 signalized intersections as a part of the project. Although valuable data was obtained, the paper also points out several disadvantages of this data collection methodology, which can be useful for future research endeavours.*

KEY WORDS: *Public transport performances, Data collection, Evaluation*

1 INTRODUCTION

In the variety of public services offered to the citizens of major cities, public transport (PT) service is certainly one of the main ones. In the European context, the PT is often referred as 'the backbone of the cities'. However, nowadays there are several challenges which PT operators are facing. The main two are: a) the operators are continuously struggling with the need to reduce operational costs and b) they have to keep up with the increasing passenger' requirements in terms of the quality of delivered service. It is clear that these two challenges are somewhat in collision with each other. On one side there are passengers who demand fast and reliable service which has to be provided in the state-of-the art PT vehicles, while on the other side PT operators are often dealing with the reduction of public funding, increasing energy prices and competition on the transportation market.

From 2008 to 2013 City of Zagreb implemented the CIVITAS ELAN project - large scale collaborative project which is a part of CIVITAS Initiative, (Anon., n.d.). One of the main project objectives was to optimize PT service by implementing various measures which, in turn, raised the quality of PT service for the end users. Specifically, new PT vehicles were introduced in operation (buses and trams) with better operational characteristics, intermodal conditions were improved as well as safety and security conditions, and PT priority system for trams was installed. These measures had to ensure that PT stayed one of the main transport modes in the city and that PT service becomes fast and reliable.

From the traffic engineering point of view the last abovementioned project activity (introduction of PT priority system) was especially interesting, because it imposed the need for detailed data analysis of traffic and PT network. The project measures were implemented in a predefined demonstration area within the city (approx. 10 km^2 around the city centre area). This corridor covered only one part of the total length of specific tram lines. This meant that improvements, achieved with the PT priority system, would occur only on specific network segments, while there would be no changes in other parts of the PT network. Moreover, due to technical issues which arose, the project team decided to implement the priority system on 3 intersections. It was, therefore, necessary to investigate tram network performances per specific segment of a line, in order to enable us to draw evaluation conclusions per specific intersection if necessary. In turn, this required very detailed set of data which describe the performances of PT network.

The first question which arose was *what where the common indicators of tram network performances?* By reviewing the literature on this matter, we found that

PT performances are often expressed by a mix of quantitative and qualitative indicators. This lack of standardisation was indicated long ago by Pullen who argued for improved definition and clarification (Pullen, 1991). Owing to this fact, the quantitative indicators are sometimes only represented by the monetised values of network delay, operation time etc., which means that PT network performances are expressed from the perspective of economists and that kind of analyses do not necessarily give an insight into full impact of different measures (e.g. this is the case in Currie et al., 2005, Currie et al., 2007 or Vedagiri and Arasan, 2009).

In (Harrison et al., 1998) authors defined "hard" quality indicators as those which are more quantifiable (e.g. access time) and "soft" quality indicators as "non-journey time attributes" such as information provision, staff attitude and satisfaction. Prioni and Hensher grouped bus performance indicators into six quality dimensions, also deploying the concept of "hard" and "soft" indicators (Prioni and Hensher, 2000). In (Egmond et al., 2003) four levels of PT performances are defined: external, strategic, tactical and operational. Different levels are focusing on population attributes, population density, political interest and regulations, organisational and financial framework analysis, accessibility of different PT modes, intermodality, marketing and information. Some authors devote higher importance to the user perspective of PT performance and argue that "hardcore" performances are good indicator for service provider, but "true" performance can only be evaluated with customer satisfaction survey (e.g. Thompson and Schofield, 2007).

For the purpose of evaluating different impacts of PT priority system, we were focused exclusively on the operational performances of specific tram lines which traverse through the corridor. The vagueness of PT performance definitions encouraged us to define our own evaluation indicators which were then used for evaluation of the PT priority system in Zagreb. Defined indicators required detailed data sets so that evaluation of operational performances would be possible per specific segment of the line. For this purpose it was decided to use GPS tracking of trams over the period of two weeks before and two weeks after the implementation of the PT priority. Here, we bring the results of this analysis and point out several disadvantages of this data collection methodology.

The remainder of this paper is structured as follows: Section 2 describes our performance indicators used in evaluation, brief description of data collection methodology can be found in Section 3, Section 4 brings results and short discussion while Section 5 concludes.

2 DEFINITION OF PERFORMANCE INDICATORS

A single journey of a tram has two terminals (origin terminal A and destination terminal B) and a finite number of PT stops and signalised intersection in between (see Figure 1). The main impact of the PT priority system on the operational performance of trams is the reduction of intersection delay. This reduction should result in a decrease of travel times between adjacent PT stops and terminals of the same PT line, but sometimes this is not the case due to the various background impacts: mixed traffic conditions, number of PT users, number of PT vehicles in operation, time-gap between PT vehicles and partial implementation of PT priority system, (Matulin et al., 2010).

For instance, due to mixed traffic conditions, in the peak periods of the day, when transport demand is at its highest levels, queues of cars can be formed in front of signalised intersections, and block the tram tracks. The tram pathway can also be blocked by traffic accidents which results in further performance deterioration. In this case, positive impacts of giving priority to trams at signalised intersections can be easily cancelled out, because trams cannot reach the intersections. Sun et al. detected and described the complex interactions between PT vehicles and general traffic vehicles in such mixed traffic environments (Sun et al., 2008). In addition, possible increase of PT users could require more PT vehicles in order to satisfy the increased transport demand. More trams can increase the possibility of congestion. This means that the time-gap between two trams can become too small, so several trams may arrive at the same PT stop at the same time, which then negatively affects boarding and alighting times. In this case trams will spend more time at the PT stops, thus their round trip times and passenger travel times will increase as well, even though trams might get the priority at intersections.

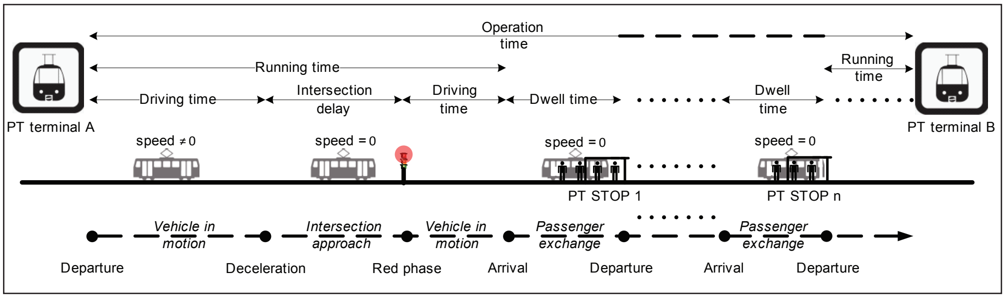

Figure 1 Operation time decomposition (Matulin et al., 2011)

Effects of the PT priority system could also be reduced if the system itself is partially implemented. This can happen in two cases:

1. If PT priority system is not implemented on all signalized intersections of the selected line/corridor (in this case PT vehicles could pass through one intersection and cause a blockage on the consecutive intersection).

2. If priority equipment is not installed in all PT vehicles which travel on the same line/corridor (in this case a vehicle which is not equipped with the priority equipment could disturb traffic flow of the PT vehicles which are equipped).

All of the above described background impacts affect the operational performance of trams. During the analysis of the possible benefits of a PT priority system, such impacts must not be ignored. In our case, when the PT priority system is implemented only on a part of the tram line, certain improvements which are achieved on a micro level (e.g. on specific intersection or between two adjacent PT stops) could remain undetected if operational performance of each line segment is not evaluated. Therefore, we decomposed tram operation time into smaller time segments and defined evaluation indicators (this is depicted in Figure 1 and described in Table 1).

Table 1 Indicator description (Matulin et al., 2011)

Level	Indicator	Description
Macro	Operation time	The time that elapses from the departure of a PT vehicle from a terminal to the arrival at the other terminal on the line.
	Operating speed	The average journey speed of PT vehicles between an origin and a destination terminal, including any delay arisen in the course of the journey.
Micro	Dwell time	The time which a vehicle spends on PT stop due to passenger exchange. The time needed for opening and closing the doors is also a part of dwell time.
	Intersection delay	The time that elapses from the arrival of a PT vehicle at an intersection approach to its passing through the intersection.
	Speed per segment	Vehicle speed for predefined segments of the line (a segment represents a part of PT line between two adjacent PT stops).
	Running time	The time that elapses from the departure of a PT vehicle from a stop to the arrival of a PT vehicle at the adjacent stop.
	Driving time	The time that a vehicle spends in motion.

Since we conducted the measurements in predefined demonstration area of the project (corridor), by the operation time we consider the time that elapses from the entering of a PT vehicle into the corridor to the exit from the corridor.

3 DATA COLLECTION

In order to collect the data about the operation time and its segments we decided to use GPS tracking of trams. Four GPS receivers were installed in four trams travelling on the same line. Measurements were conducted twice: before and after implementation of the PT priority system. Recordings took place in two week period (Monday to Sunday), each day from 6 a.m. to 10 p.m. Every GPS receiver recorded the vehicle position and actual speed each second. GPS data was extracted from the devices and imported in an Excel table for the analysis. Setting up the recording interval to one second provided us with the high resolution of the measurement which was important for the performance evaluation by defined indicators. Nevertheless, apart from good measurement resolution which was highly beneficial to us, this method also created some issues which had to be resolved in the process of data analysis.

The issues were manifested as a mismatch between geographical locations of the control points (PT stops or signalized intersections) and actual tram position recorded by GPS receiver as indicated on Figure 2a and Figure 2b (triangles on the GPS track represent tram in motion and rectangles represent that tram is stopped). GPS vehicle tracking method gives very accurate results for the tram operation time and average commercial speed. Nevertheless, when the tram speed is around 0 km/h, due to the GPS signal reflection, GPS tracks can be in offset to about 30-40 meters. Without map matching (Figure 2b.) it is impossible to determine actual vehicle position in a specific moment of time, which is important for calculation of different operation time segments.

In case when two trams arrive on the same stop in the same time, as it is depicted in Figure 3a, with the GPS vehicle tracking method it is not possible to determine the exact reason why tram B stopped. In this specific situation, geographical location of the PT stop and the position of tram B, when the speed v is 0 km/h, do not overlap. Knowing the GPS signal reflection problems, during the data processing it is hard to determine whether the tram B has reached the PT stop and started to alight/board passengers or another vehicle (tram or even individual vehicle) was occupying the PT stop at the time.

Furthermore, when the PT stop is located directly in front of signalized intersection and the “red” period is activated (Figure 3b), intersection delay and dwell time measurements are incomplete. This results in inaccurate calculation of driving time and speed per segment. While processing the GPS data it can be easily detected when the tram speed was 0 km/h, but in this case the difference between dwell time and intersection delay cannot be recognized.

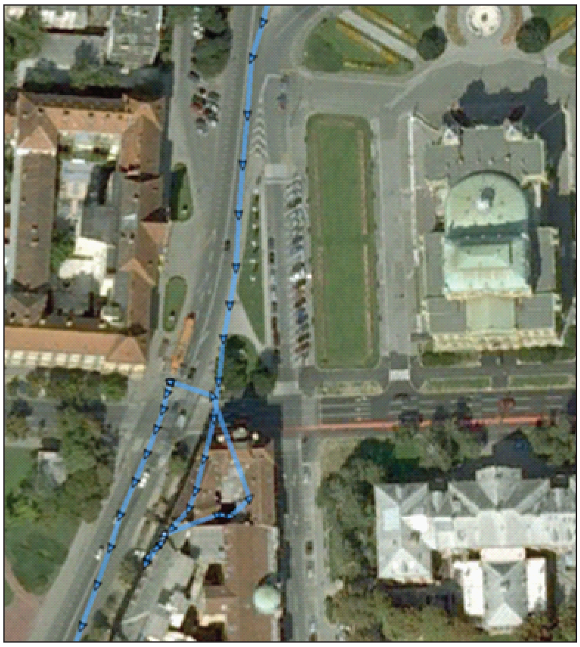

Figure 2a Recorded GPS track, (Jelušić et al., 2010)

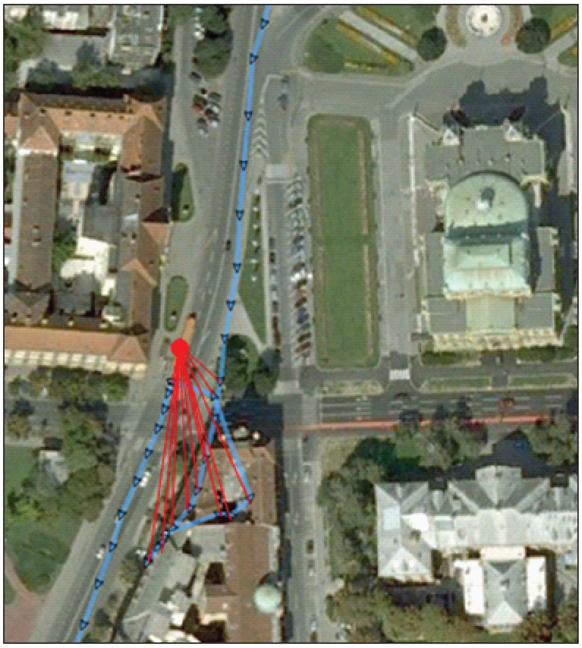

Figure 2b Recorded GPS track and actual PT vehicle position, (Jelušić et al., 2010)

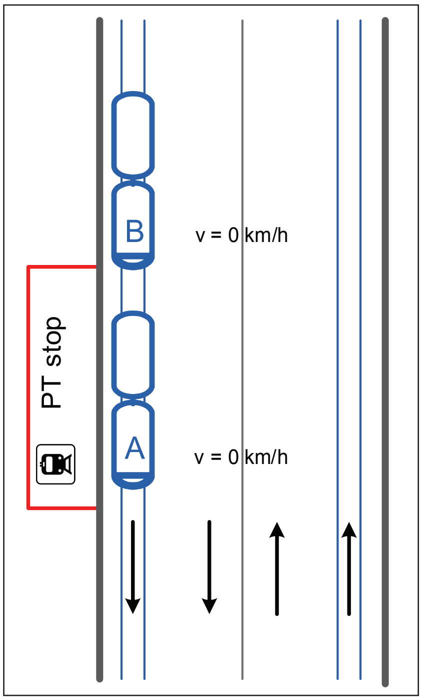

Figure 3a Arrival of two trams on the same PT stop, (Jelušić et al., 2010)

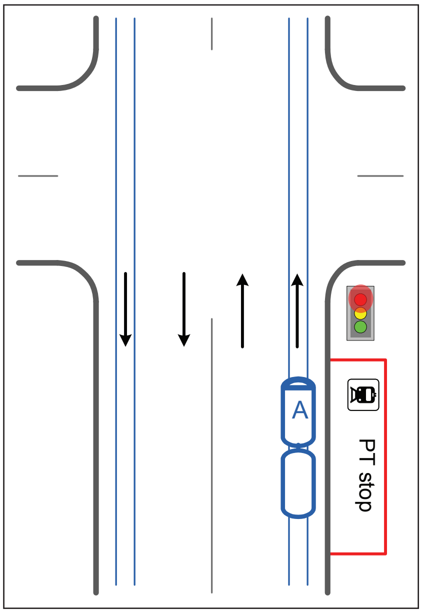

Figure 3b Specific geographical locations of PT stop, (Jelušić et al., 2010)

4 IMPACT OF PT PRIORITY SYSTEM

In Table 2 we present the results of the data analysis, i.e. the performance of the tram network in the demonstration corridor before and after the implementation of the PT priority system (only for one direction of travel). The gray coloured rows represent the location where PT priority equipment is installed.

Operation time is calculated by adding up tram running time and dwell time. Operating speed is then derived by dividing the corridor length (2,855 m) and operation time. Average running time and average driving time is presented between two consecutive PT stops; average dwell time is presented for each PT stop, while average intersection delay is presented for each intersection in the corridor.

Table 2 Results

Indicator	Before implementation		After implementation		Difference: After – Before	
Operation time [hh:mm:ss]	Average: 00:14:58		Average: 00:14:00		- 58 seconds, i.e. - 6.46%	
Operating speed	Average: 11.45 km/h		Average: 12.24 km/h		+ 0.79 km/h, i.e. + 6.9%	
Running time [hh:mm:ss]	PT stop_sequence number	Average running time between two stops	PT stop_sequence number	Average running time between two stops	PT stop_sequence number	Difference
	veslačka_1		veslačka_1		veslačka_1	
		0:01:05		0:00:59		- 6 seconds
	prisavlje_2		prisavlje_2		prisavlje_2	
		0:01:24		0:01:38		+ 14 seconds
	vjesnik_3		vjesnik_3		vjesnik_3	
		0:01:08		0:00:52		- 16 seconds
	učit_akademija_4		učit_akademija_4		učit_akademija_4	
		0:02:32		0:02:17		- 15 seconds
	zagrebčanka_5		zagrebčanka_5		zagrebčanka_5	
		0:00:56		0:00:57		+ 1 second
	stud_centar_6		stud_centar_6		stud_centar_6	
		0:01:29		0:01:27		- 2 seconds
	vodnikova_7		vodnikova_7		vodnikova_7	
		0:01:15		0:01:11		- 4 seconds
	trg_marš_tita_8		trg_marš_tita_8		trg_marš_tita_8	
	(PT priority)	0:01:49	*(PT priority)*	0:01:26	*(PT priority)*	- 23 seconds
	frankopanska_9		frankopanska_9		frankopanska_9	
	Cumulative:	**0:11:38**	**Cumulative:**	**0:10:47**	**Cumulative:**	**- 51 seconds - 7.3%**
	Average-average:	**0:01:27**	**Average-average:**	**0:01:21**	**Average-average:**	**- 6 seconds - 6.89%**

Indicator	Before implementation		After implementation		Difference: After – Before	
Driving time [hh:mm:ss]	PT stop_sequence number	Average driving time between two stops	PT stop_sequence number	Average driving time between two stops	PT stop_sequence number	Difference
	veslačka_1		veslačka_1		veslačka_1	
		0:00:54		0:00:59		+ 5 seconds
	prisavlje_2		prisavlje_2		prisavlje_2	
		0:01:03		0:01:13		+ 10 seconds
	vjesnik_3		vjesnik_3		vjesnik_3	
		0:01:06		0:00:52		- 14 seconds
	učit_akademija_4		učit_akademija_4		učit_akademija_4	
		0:01:25		0:01:12		- 13 seconds
	zagrebčanka_5		zagrebčanka_5		zagrebčanka_5	
		0:00:55		0:00:57		+ 2 seconds
	stud_centar_6		stud_centar_6		stud_centar_6	
		0:00:45		0:00:53		+ 8 seconds
	vodnikova_7		vodnikova_7		vodnikova_7	
		0:01:00		0:01:06		+ 6 seconds
	trg_marš_tita_8		trg_marš_tita_8		trg_marš_tita_8	
	(PT priority)	0:00:26	*(PT priority)*	0:00:22	*(PT priority)*	- 4 seconds
	frankopanska_9		frankopanska_9		frankopanska_9	
	Cumulative:	**0:07:34**	**Cumulative:**	**0:07:34**	**Cumulative:**	**0** **0%**
	Average-average:	**0:00:57**	**Average-average:**	**0:00:57**	**Average-average:**	**0** **0%**
Intersection delay [hh:mm:ss]	Name of the intersection	Average inter-section delay	Name of the intersection	Average inter-section delay	Name of the intersection	Difference
	Veslačka	0:00:01	Veslačka	0:00:00	Veslačka	- 1 second
	Prisavlje	0:00:11	Prisavlje	0:00:05	Prisavlje	- 6 seconds
	Slavonska	0:00:21	Slavonska	0:00:25	Slavonska	+ 4 seconds
	Gagarinov	0:00:02	Gagarinov	0:00:00	Gagarinov	- 2 seconds
	Vukovarska	0:01:07	Vukovarska	0:01:05	Vukovarska	- 2 seconds
	Koturaška	0:00:01	Koturaška	0:00:00	Koturaška	- 1 second
	Tratinska	0:00:33	Tratinska	0:00:28	Tratinska	- 5 seconds
	Vodnikova	0:00:11	Vodnikova	0:00:06	Vodnikova	- 5 seconds
	Kršnjavoga	0:00:14	Kršnjavoga	0:00:05	Kršnjavoga	- 9 seconds
	Perkovčeva	0:00:01	Perkovčeva	0:00:00	Perkovčeva	- 1 second
	Hebrangova	0:00:43	Hebrangova	0:00:49	Hebrangova	+ 6 seconds
	Deželićeva	0:00:25	Deželićeva	0:00:04	Deželićeva	- 21 seconds
	Varšavska	0:00:11	Varšavska	0:00:11	Varšavska	No change
	Cumulative:	**0:04:01**	**Cumulative:**	**0:03:18**	**Cumulative:**	**- 43 seconds** **- 17.84%**
	Average-average:	**0:00:19**	**Average-average:**	**0:00:15**	**Average-average:**	**- 4 seconds** **- 21.04%**

Indicator	Before implementation		After implementation		Difference: After – Before	
Dwell time [hh:mm:ss]	PT stop_sequence number	Average dwell time	PT stop_sequence number	Average dwell time	PT stop_sequence number	Difference
	veslačka_1	0:00:18	veslačka_1	0:00:16	veslačka_1	- 2 seconds
	prisavlje_2	0:00:19	prisavlje_2	0:00:15	prisavlje_2	- 4 seconds
	vjesnik_3	0:00:13	vjesnik_3	0:00:14	vjesnik_3	+ 1 second
	učit_akademija_4	0:00:14	učit_akademija_4	0:00:17	učit_akademija_4	+ 3 seconds
	zagrebčanka_5	0:00:14	zagrebčanka_5	0:00:18	zagrebčanka_5	+ 4 seconds
	stud_centar_6	0:00:44	stud_centar_6	0:00:28	stud_centar_6	- 16 seconds
	vodnikova_7	0:00:16	vodnikova_7	0:00:20	vodnikova_7	+ 4 seconds
	trg_marš_tita_8	0:00:44	trg_marš_tita_8	0:00:45	trg_marš_tita_8	+ 1 second
	frankopanska_9	0:00:18	frankopanska_9	0:00:20	frankopanska_9	+ 2 seconds
	Cumulative:	**0:03:20**	**Cumulative:**	**0:03:13**	**Cumulative:**	**- 7 seconds - 3.5%**
	Average-average:	**0:00:22**	**Average-average:**	**0:00:21**	**Average-average:**	**- 1 seconds - 4.55%**

As it can be seen from the table, GPS vehicle tracking provided us with enough data to be able to conduct very detailed evaluation of network performances. It made evaluation possible on a micro level, i.e. evaluation per specific intersection, and on the macro level, i.e. for the whole corridor.

The data shows that average tram operation time was decreased by 58 seconds or 6.46%, while operating speed is increased by 6.9%. The largest share of these 58 seconds comes from the reduction of intersection delay on Deželićeva intersection (indicated by the gray rows). The average delay on that intersection alone is reduced by 21 seconds. Cumulative intersection delay in the corridor was reduced by 43 seconds or 17.84%. Furthermore, cumulative running time was also decreased by 51 seconds or 7.3% which was expected due to the reductions of intersection delay. However, it must be noted that cumulative dwell time was reduced by 7 seconds which also contributed to these improvements.

On a micro level we can see that average running time on the part of the line where the priority is introduced shows that between PT stops trg_marš_tita_8 and frankopanska_9 it was reduced by significant 23 seconds. Of course this is due to the already mentioned reduction of intersection delay at Deželićeva intersection by 21 seconds.

5 CONCLUSION

The introduction of PT priority system imposed different research requirements in all phases of its implementation and evaluation. In this paper we were focused only on the last phase, i.e. evaluation, for which we defined several evaluation indicators. Due to specific implementation conditions and restraints (various background impacts and partial implementation of the system) it was recognized that only full data sets will suffice if we want to be able to conduct detailed performance evaluation of the tram network. The ability to record tram speed and position each second was very much appreciated, thus GPS vehicle tracking method was selected.

As it can be seen from the presented results, this data collection method made evaluation possible on a micro level, i.e. evaluation per specific intersection, and on the macro level, i.e. for the whole corridor. This ability was crucial for the project evaluation and we believe that this can be highly beneficial for future investigations of PT network performances.

Nevertheless, we were also able to identify few drawbacks of this methodology. Two main ones were: a) mismatch between geographical locations of the control points (PT stops and intersections) and actual tram position recorded by GPS receiver which requires additional attention in the data analysis process, and b) inability to distinguish dwell time and intersection delay if the PT stop is located directly in front of signalized intersection.

Based on these findings we can conclude that GPS vehicle tracking method provides enough data for very detailed evaluation, however, it is wise to supplement it with other methods (e.g. on-sight measuring, video image analysis etc.) in order to avoid abovementioned drawbacks.

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