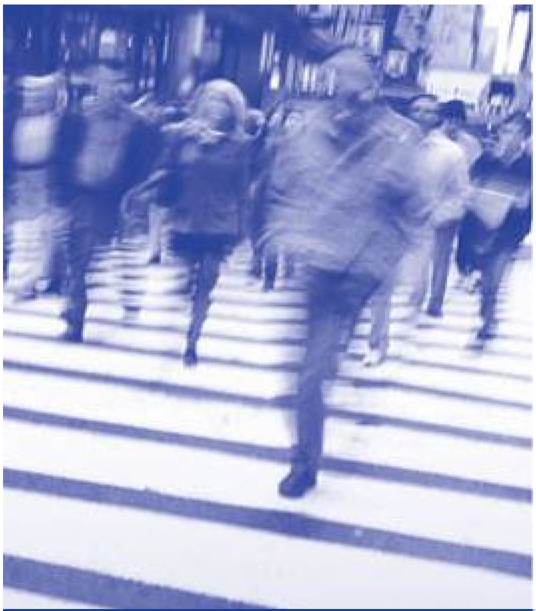

CIVITAS
Cleaner and better transport in cities

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Implementation status report on PT priority

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		x	vehicle identification		WP3 Demand management		WP9 Project coordination
		x	traveler information		WP4 Influencing travel behaviour		WP10 Project management
					WP5 Safety, security & health		WP11 Research and Technological Development
					WP6 Innovative mobility services		WP12 Impact and process evaluation
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CONTENT

ABSTRACT

Measure 8.2-ZAG “Public transport priority and traveler information” has as the main objective the improvement of mobility for all vehicles in the CIVITAS-ELAN corridor by giving priority at intersections to public transport. In this measure Savska cesta, one of the longest streets in the City of Zagreb, is selected as the test corridor. The simulation model was made by PTV VISSIM software because, among others advantages, it enables micro simulation of the area of interest by simple construction and editing of traffic network, modeling of vehicles with different characteristics, the psychophysical modeling of driver behavior (Wiedemann model), the stochastic definition of traffic parameters (speed, acceleration, power, dwell time, etc.), traffic signals modeling and effective outputting of results for further evaluation and interpretation. One of the important parameters of the model is traffic volume on the corridor. During peak hours (between 4 PM and 5 PM) 60 students were engaged to count traffic at all intersections along the corridor. In addition, pedestrians and cyclists were counted too, but only at intersections where they have important influence on the throughput capacity. In model developing process, it is necessary to define the routes of vehicles, and for this particular model we used static routes where distribution by direction of vehicles at intersections is pre-defined.

Real-time passenger information (RTPI) displays have been introduced at tram and bus stops/stations in the City of Zagreb. This represents a significant step forward in the pre-travel information services for public transport passengers. The conducted survey about passengers’ satisfaction with RTPI had the purpose of getting an overview of current passenger information perception and dealt with the prospective use of public transport if real-time information was more reliable and available.

Due to the specific behavior of traffic flow on each intersection, different approaches to implementation of traffic light priority algorithms have been considered. Among the available methods to solve the priority problem, e.g. operations on infrastructure, improvements of public transportation system or administrative measures, the adaptive management of signalized crossings by giving priority assignment to public transport vehicles is demonstrated.

1. INTRODUCTION

One of the key transport issues in the City of Zagreb is connecting north and south and vice versa due to insufficient transport capacity. Savska cesta is the key transport corridor connecting the narrowest City centre with the outskirts on the south and the city roundabout. Apart from heavy traffic, the corridor was chosen as the test CIVITAS-ELAN corridor because of the stated features.

1.1. Corridor description

Savska street was chosen as a test CIVITAS-ELAN corridor for measure 8.2. The corridor is a 3.2 kilometers long street, and it connects the historic City centre (on the north) with multidirectional intersection on the southern part of the corridor (**figure 1**). Traffic along the corridor is managed in both directions, with personal and public transport vehicles traveling in one level. Exceptions are small parts of the street where there are reserved lines for public transport. Public transport is managed by Zagreb Electrical Tramway (ZET) with eight tram lines operating on the corridor. On the corridor for the purposes of CIVITAS-ELAN project tramway mode is the dominant one, and bus service (used only in night hours and on special occasions) occasions is not considered in the project [5].

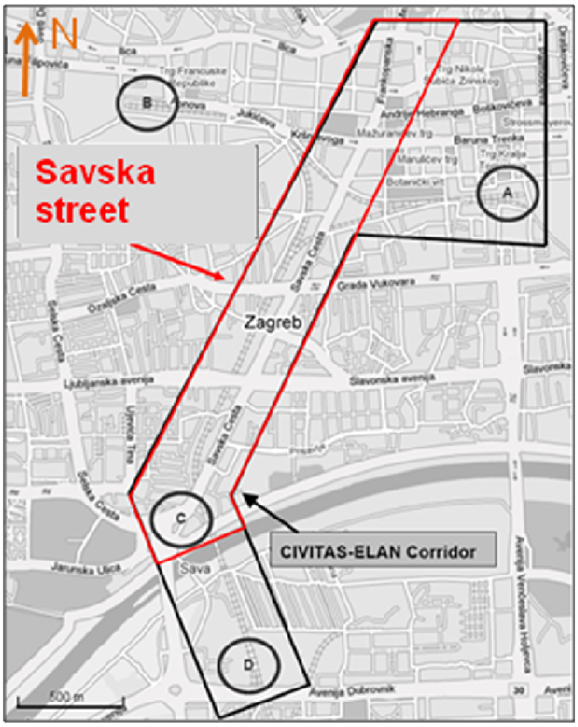

Figure 1: Savska cesta – selected CIVITAS-ELAN test corridor

Along the corridor there are 12 intersections, all of them equipped with horizontal and vertical traffic signalization and fixed signal control. Savska cesta is one of the most loaded streets in the City of Zagreb, which is most obvious during the morning and afternoon rush hours. Even though reserved tram lines exists, personal vehicle drivers do not respect them entirely, which causes significant increase in tram travel times and dwell times on stops before intersections. As a solution, telematic system of giving priority to tram vehicles at intersections is derived.

1.2. Measure objectives

1.2.1. Public transport priority

The main objective of CIVITAS-ELAN measure 8.2. is improvement of mobility for all vehicles in the test corridor by introducing priority techniques for public transport vehicles along the corridor. Transit priority improvements are defined as a range of techniques designed to speed up public transport vehicles and improve transport systems efficiency. Transit signal priority can also be defined as an operational method that improves movement of public transport vehicles through signalized intersections by adjusting the signal control logic. Transit signal priority improvements advance public services by providing faster and more reliable service – operating more service with same resources and by attracting more passengers. Also, by reducing conflicts with private traffic, transit priority improvements can reduce accidents and personal vehicle drivers' stress. Basically, transit priority improvements can be categorized in four main categories [9]:

1. ***roadway improvements/traffic regulations*** – includes minor changes to roadways, relocation of public transport stops, and minor changes in traffic regulations
2. ***public transport system operations*** – optimization of operation of public transport designed to reduce delays (for example: low-floor vehicles, improvement of payment methods, definition and implementation of public transport control centers – all already introduced in Zagreb public transport)
3. ***separate right of ways*** – carefully chosen sections of roadway designated specially for public transport vehicles, allowing them to bypass traffic congestions– already introduced in Savska street
4. ***traffic signal priority*** – optimization of traffic signals by providing green lights to public transport vehicles when they approach signalized intersections.

Implementation of public transport priority techniques can be difficult task to do because providing priority can mean taking capacity from other users on the road. Some difficulties include:

- low technical competence and lack of expertise on priority methods
- lack of support by different city traffic and transport infrastructure related departments
- weak coordination between city agencies and departments
- pressures and misunderstanding by personal vehicle users
- poor public understanding of the benefits [1].

As a possible solution, it is suggested to introduce a telematic system of giving priority to tram vehicles on intersections in order to achieve:

- increase of average speed in peak hours,
- shortening of tram journey times and increase in service quality levels,
- increase in number of PT users, and
- noise and pollution reduction [2].

1.2.2. Traveler information

A major step in increasing PT service quality level was the introduction of real-time passenger information system consisted of public transport control center and displays mounted on tram stops. In order to determine their satisfaction with the new service, a survey was conducted among PT users. A significant step forward in improving the quality of service and increasing the competitiveness of public transport is made by introducing pre-trip information for passengers through displays at stops.

In the past few years, significant progress has been made in pre-trip passenger information and slightly smaller in on-trip information. The most significant progress in pre-trip information is the introduction of a dynamic passenger information system on stops.

Current options of pre-trip information are:

- Internet
- Call Centre
- Real-Time Passenger Information (RTPI) displays on stops
- Paper-based timetables
- TV/Radio

The most significant improvement in pre-trip information is the introduction of RTPI displays at bus and tram stops which inform users about the arrival time of each tram or bus line. Currently, there are 128 displays in the city of Zagreb, out of which 52 are at the bus and 76 at the tram stops (**figure 2**). On the CIVITAS-ELAN corridor 128 LED displays were installed by ZET after signing of the project consortium agreement and before the official start of the project.

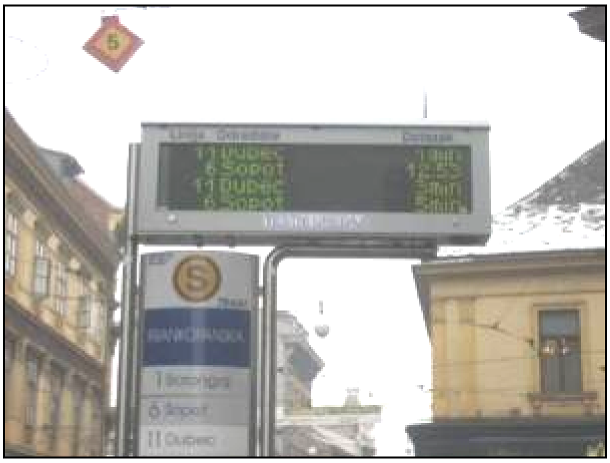

Figure 2: Dynamic passenger information panel

The system functions on the basis of the previously entered timetable, odometer (measuring the distance between stops) and the GPS system as a positioning control system. If a time difference occurs while driving, the vehicle reports its position through the TETRA communication system. Technical features of the system do not provide the possibility of showing information about long delays and disturbances on the line, and the possibility of an auditory user notification by the public transport control center through the display is not performed [5].

2. DESCRIPTION OF CORRIDOR'S TRAFFIC INFRASTRUCTURE AND CONDITIONS

2.1. Traffic Control Infrastructure

On the corridor there are 11 different signal controllers and one pedestrian signal controller (**figure 3**).

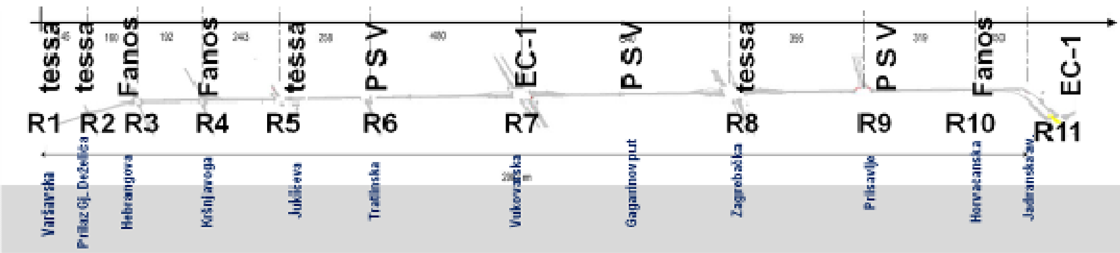

Figure 3: Signal controller types on the corridor

Controller coordination doesn't exist along the whole corridor, but there are five coordinated segments as visible on **figure 4.**

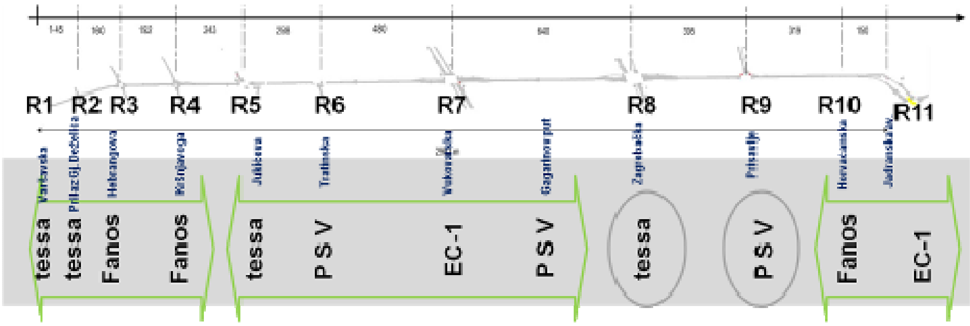

Figure 4: Signal controller cooridnation on the corridor

Figure 4 shows interruption of coordination between signal controller segments:

- R4/R5
- PP/R8
- R8/R9
- R9/R10.

Coordination issues and aged signal controller devices (as listed below) cause great difficulties in priority techniques implementation for the whole corridor. For that reason, feasible implementation is acceptable only on intersections R1 through R4.

2.1.1. Traffic signal controller – *JCFBA 300 (Tessa)*

Traffic signal device JCBFA 300 is device aimed for traffic management on only one intersection. This type of device is also first local microprocessor device implemented in the city of Zagreb. Central processing system is based on 16-bit microprocessor INTEL 8086 (5 MHz). Communication unit is asynchronous with two serial channels. Transfer speed is 300-4800 Bd. This device can be configured up to 24 signal groups, and up to 36 detectors. Software structure is divided to programmable unit and data unit. Programmable unit is constant, and data unit is generated depending on signal controller function.
Zone supervising switchboard for this type of signal controller is JCC 150, after which command signal plans are modified. It is possible to connect up to 8 devices in coordination without supervising switchboard. In local operating mode, managing algorithm can be traffic dependent.

2.1.2. Traffic signal controller – *FAN-2000*

Signal controller FAN-2000 developed by FANOS, is integral part of distributed signaling system FAN-NET. Devices are interconnected via communication modules. In fixed functioning, this controller enables programming of up to 32 signal plans. Local device has the traffic dependent management possibility, and up to 32 detectors can be connected. Number of maximum independent signal groups is 32. For additional functions, controller FAN-2000 is equipped with 10 parallel inputs and outputs. Also, device can be equipped with separate control unit, which enables manual operating, automatic operating mode, and malfunction diagnostics.

2.1.3. Traffic signal controller – *TCD 1007 (PSV)*

Local signal controller TCD 1007 is relay-type device from GKS 768 controlling system, and supervising device PRC 1012. Device TCD 1007 is equipped with seven signal plans dependent to supervising device command. Additional (auxiliary) signal plan is executed if there is no upper level command. It could be equipped with up to 16 signal groups (plus 8 reserved for pedestrians). Detectors for vehicle notification can be included, with three detection logics. Communication between detectors is half-duplex.

2.1.4. Traffic signal controller – *EC-1 (PEEK EUROCONTROLLER)*

EC-1 is local signal device managed by EC Trak system. This type of controller is conceived on standalone signal groups' logic. Device is equipped with 32-bit microprocessor Motorola 68302. Upgrade and easy maintenance is enabled by modular design oh hardware. Software architecture is also modular, and enables different control applications and algorithms for adaptive traffic control (local intersections control, traffic zone, etc.). This device supports up to 40 signal groups, 128 detectors.

2.2. Data collection

To simulate public transport priority techniques it was necessary to develop micro simulation model. Simulation tool used to develop the model was PTV VISSIM. In order to develop and calibrate existing state model, it was necessary to collect certain traffic data from the corridor. The key indicator of the simulation model refers to the traffic volume based on which all other evaluation parameters and measures are derived.

2.2.1. Traffic volume

To collect traffic data on the corridor, around 60 observers/students were involved in vehicle counting campaign. They counted traffic simultaneously at all corridor intersections in peak hours between 4 and 5 P.M. (**figure 5**).

Figure 5: Traffic counting on the corridor by students

During vehicle counting, the structure of traffic flow at each entrance to the corridor was also recorded and entered into the model.

At the observed corridor, the total of 26 types of traffic volume (i.e. private vehicles, public transport vehicles, etc.) at the entrance to the corridor was recorded, and accordingly, the same number of different traffic flow structures with respect to the types of vehicles.

Observers counted pedestrians and cyclists in places where there were no crossings with traffic lights for them since it can significantly affect the intersection throughput.

When creating the model, it was necessary to define the routing of vehicles at each intersection. In VISSIM simulation software, there are two types of vehicle routing:

- static routing - vehicle paths are statically defined in advance by the distribution of traffic flow in the possible directions of movement at intersections, and
- dynamic trip assignment – trip assignment is achieved based on the default origin-destination travel matrices (OD matrices).

Considering the counted traffic data and greater accuracy in calculations, static routing is applied in the model.

2.2.2. Acceleration and deceleration

Acceleration

For collecting other traffic data, especially caused by public transport, GPS receivers were installed in public transport vehicles. Maximum acceleration and deceleration are based on the technical characteristics of vehicles, while the desired acceleration and desired deceleration are calculated by processing GPS tracks. Acceleration is calculated from the formula:

$$\frac{\Delta v}{\Delta t} = \frac{v_{max} - v_0}{t_{v=max} - t_{v=0}} = a ,$$

for 10 journeys (in autumn season) in the time interval from 4-5 P.M. and towards the south direction. **Figure 6** shows that the maximum speed was achieved in the 10th measurement. The maximum achieved speeds in this section are presented in **table 1** in fields that are painted in purple. Acceleration calculated for each journey can be found in the last column of the same table. Thus, it can be seen that in the 10th measurement, the acceleration of 0.871 m/s^2 was calculated. In the first measurement, the calculated acceleration was 0.404 m/s^2.

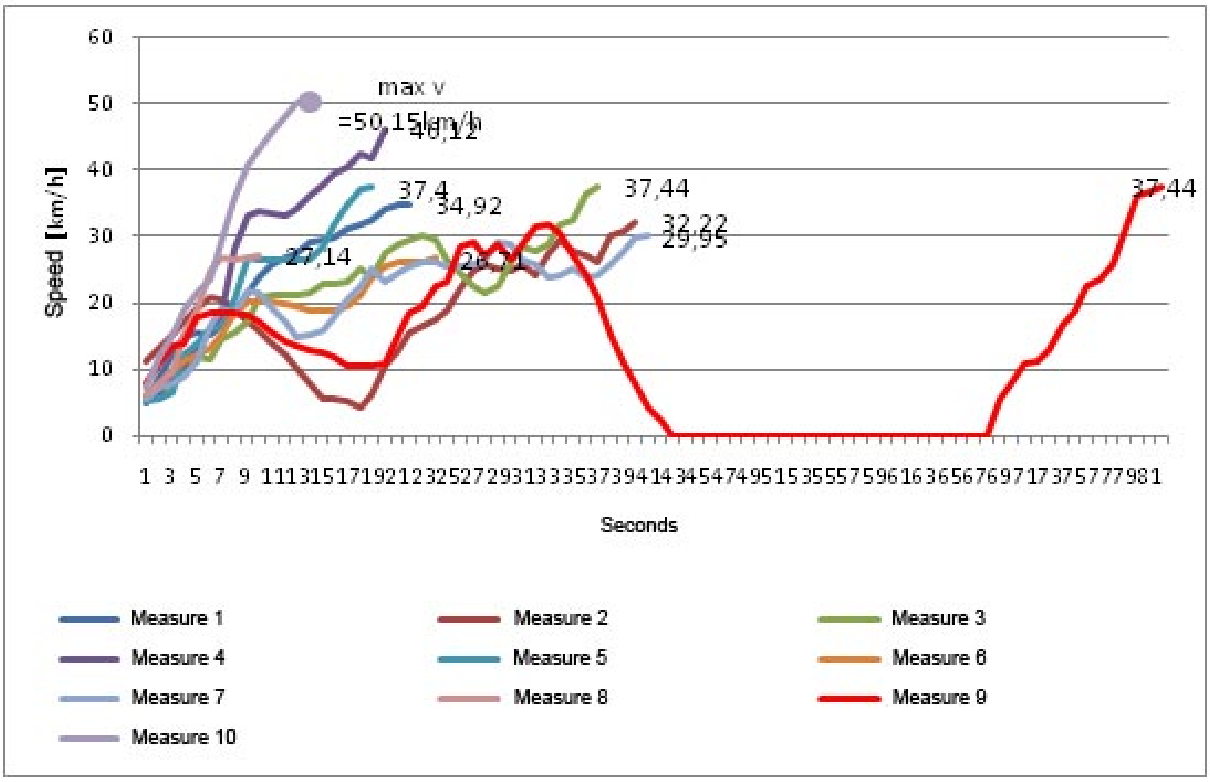

Figure 6: Maximum speed

Table 1: Maximum speed and acceleration

Meas-urement 1	Meas-urement 2	Meas-urement 3	Meas-urement 4	Meas-urement 5	Meas-urement 6	Meas-urement 7	Meas-urement 8	Meas-urement 9	Meas-urement 9	*accelera-tion*
29,02	13,97	21,64	36,18	26,57	18,68	15,05	25,45	13	50,15	**0,871**
32,4	5,51	23,9	41,83	37,4	23,69	25,2	23,33	10,55	40,46	**0,495**
34,2	5,26	27,58	46,12	35,64	25,45	23	22,54	10,73	33,8	**0,582**
34,92	6,3	29,63	44,24	33,26	26,24	25,34	23,54	18,43	21,67	**0,404**
34,52	12,96	29,56	43,06	30,85	26,71	26,03	23,69	22,39	13,75	**0,285**
22,36	29,45	37,44	22,36	20,34	24,8	24,12	22	20,77	0	**0,267**
14,04	30,17	36,29	15,3	21,28	21,64	30,02	18,04	4,07	0	**0,194**
0				0		6,19	6,55	37,44		**0,693**

Deceleration

Figure 7 shows tram journeys from its maximum speed until it stops (velocity = 0). The selected section was on the northern part of the corridor, from Frankopanska street to Trg maršala Tita because that is where a tram reaches maximum speed. Deceleration was calculated from the formula:

$$\frac{\Delta v}{\Delta t} = \frac{v_{max} - v_0}{t_{v=max} - t_{v=0}} = a \quad ,$$

Measurements were made for 10 journeys in the interval from 4-5 P.M. towards the south. The graph shows that the maximum speed was achieved in the 10th measurement. The moment when the analyzed tram stopped is shown in Table 2 in green-colored fields (v=0). Deaceleration calculated for individual journeys can be found in the eleventh column of the table. Thus, it can be seen that in the 10th measurement, the acceleration of 0.871 m/s^2 was calculated. In the first measurement, the calculated acceleration was 0.373 m/s^2. The third, the fifth and the seventh journey end in the same moment, thus the acceleration was calculated in the fields of the additional two columns. For the third journey, the acceleration is 0,433 m/s^2, for the fifth journey 0,247 m/s^2, and for the seventh journey 0,417 m/s^2.

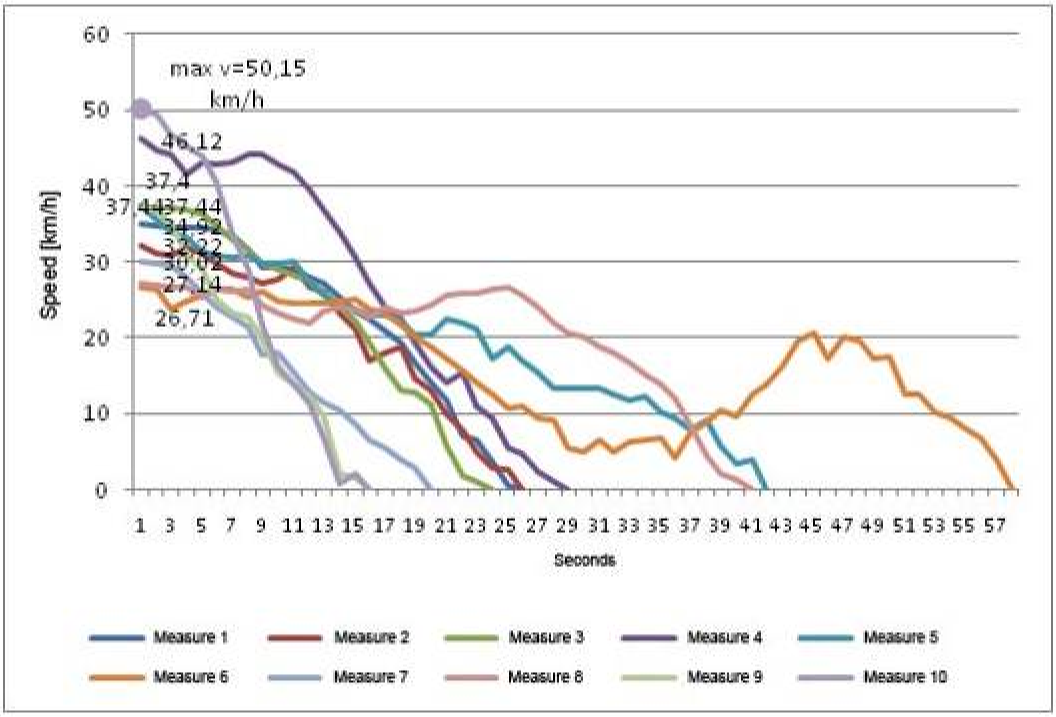

Figure 7: Achieving speed 0 km/h from maximum speed

Table 2: Deceleration

Measu-rement 1	Measu-rement 2	Measu-rement 3	Measu-rement 4	Measu-rement 5	Measu-rement 6	Measu-rement 7	Measu-rement 8	Measu-rement 9	Measu-rement 10	decele-ration	decele-ration	decele-ration
31,61	22,25	22,39	42,8	30,02	26,35	29,09	24,34	28,84	0	0,871		
0	31,18	28,22	1,04	13,43	12,46	22,72	4,57	0		0,373		
	29,88	27,36	0	13,21	10,66	21,46	1,98	0		0,442		
	28,01	24,3		12,56	9,5	18	0	0		0,184		
	18,9	0		0	7,6	0		0		0,433	0,247	0,417
	0				20,66			0		0,344		
					0			36,83		0,128		
								0		0,650		

2.2.3. Desired speed

The analysis of tram speed expressed in km/h for the tram lines (3, 4, 5, 9, 12, 13, 14 and 17) for a segment of their itinerary, which is located in the corridor, is shown in Table 3. The table shows the arithmetic mean speed calculated for all the recorded data (AM 0 included), i.e. including the situations when the tram stopped (speed 0), e.g. stopping for red traffic lights, tram in front which caused that the analyzed tram cannot enter into the tram station or because of cars at the tram line where cars and trams share the same operating area. Then the arithmetic mean speed was calculated so as to exclude the situations in which the tram had a speed of zero (AM 0 excluded), i.e. arithmetic mean was calculated only for cases when the tram was in motion. In the same way, the standard deviation of speed (SD 0 included and SD 0 excluded) were calculated. In the last row of Table 3, the maximum measured tram speed for a particular tram line is shown.

Table 3: Descriptive statistical parameters for tram speed by tram lines *(AM – arithmetic mean; SD – standard deviation; Max – maximum measurement results, inc – included, exc - excluded)*

	Tram lines						
	3	**4**	**5**	**9**	**12**	**13**	**14 i 17**
AM inc 0=	7,46	12,50	18,16	9,25	13,09	10,98	13,30
AM exc 0=	15,35	17,81	21,08	12,88	17,48	16,88	18,59
SD inc 0=	9,71	11,48	11,89	7,53	11,68	11,32	12,01
SD exc 0=	8,55	9,65	10,12	5,67	10,26	9,86	10,16
MAX_v=	43,49	46,12	45,47	30,64	50,15	50,15	50,15

It can be seen in **table 3** that the arithmetic mean for all tram lines is calculated so as to exclude stopping on the way (traffic lights, tram in front, cars on tracks) from over 2.9 to 7.89 km/h. Differences in the change (2.9 km/h with tram lines 5 and over 5 km/h with tram lines 3, 4, 13, 14 and 17) indicate the existence of different corridor parts where there are longer delays. The biggest difference between the arithmetic mean calculated in those two manners was obtained for the tram line 3 (7.89 km/h), which has a short delay in the corridor but passes through a part of the corridor where there are large tram delays due to red traffic lights (middle of the corridor, i.e. Savska street and Vukovarska street intersection) and due to the presence of cars on tram tracks.

The highest average speed is achieved by the tram line 5 since in that part of the corridor there are no critical points. Deviation from the arithmetic mean (standard deviation) is also reduced as expected in case of calculating the standard deviation in order to exclude the measured values where the speed is 0. Maximum speed is also different for individual tram lines because of the conditions in the field where such speeds can be achieved (infrastructure quality and the distance between stops/traffic lights). Maximum measured speed values are 50.15 km/h and were achieved on the section (Frankopanska street tram stop - Trg maršala Tita tram stop). That section also represents a part with the largest variations in trams running time.

The graph in **figure 8** shows tram speeds on the section Frankopanska street stop-Trg maršala Tita tram stop. Full circles mark the endings of an individual recorded journey from which it can be seen that the running time on this section varies from 48 seconds (4th measurement) to 210 seconds (1st measurement). The reason for long delays in this section is the Trg maršala Tita tram stop, which coincides with an intersection with traffic lights, which causes long delays at the tram station and makes it impossible for the next tram to enter the tram stop. Furthermore, it can be seen from the GPS traces that in this section the tram stopped for the red phase at the traffic light (there are two intersections with traffic lights in this section) only in two cases (9th and 10th measurement) [5].

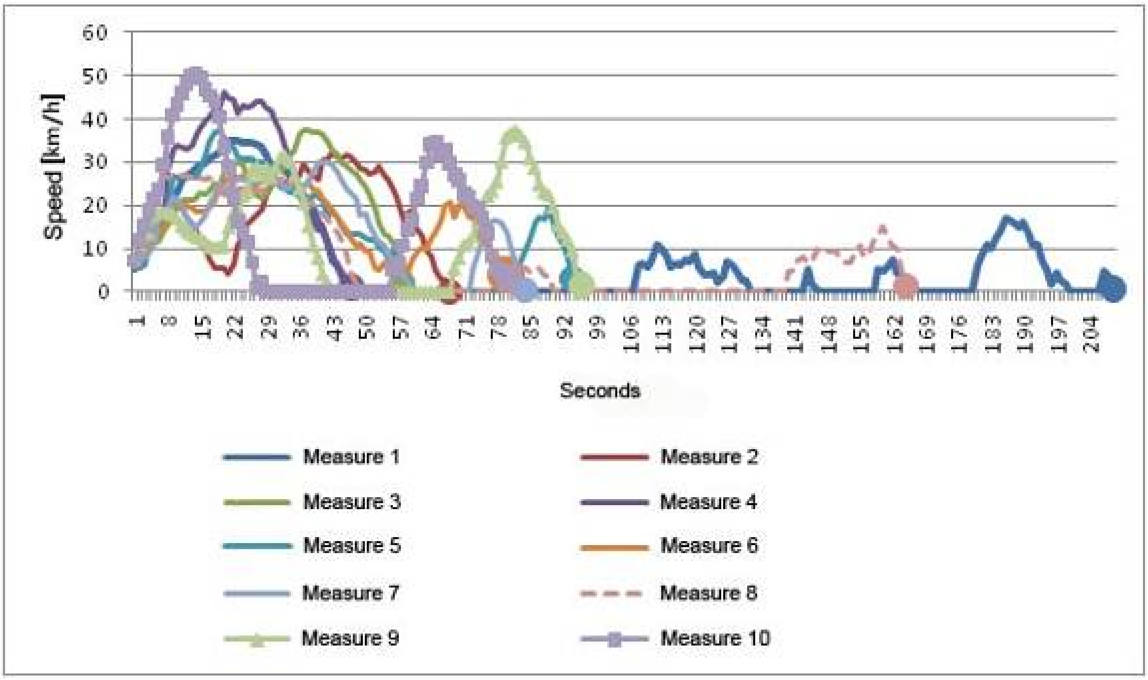

Figure 8: Tram speed in the section Frankopanska street tram stop - Trg maršala Tita tram stop

3. IMPLEMENTATION STATUS

3.1. Traveler information

The most significant improvement in pre-trip information on the corridor is the introduction of RTPI displays at tram stops. All tram stops on the corridor are covered with displays, i.e. 2 LED displays are mounted on both sides of each tram stop.

Total satisfaction of users with the public transport services in Zagreb was examined (survey was conducted among 131 users of urban public transport of different ages). Given the high level of motorization and the current no-competitiveness of public transport in regard to personal vehicles, it is interesting to observe how the introduction of reliable and more accessible pre-trip and on-trip information affects potential users to decide to travel by public transport rather than car. The data according to which almost 63% of the examinees would use public transportation more frequently if the pre-trip and on-trip information was more reliable and more accessible, suggests that the demand for public transport services can be increased.

Almost 60% of examinees use pre-trip information through displays at stops and with the increase in the reliability of information on them that percentage will surely increase also. The obtained results are not localized and can point to a general conclusion for other cities that have not yet introduced RTPI displays at stops, i.e. good and reliable pre-trip passenger information affects the increase in the demand for public transport services [5].

3.2. Possible technical solutions for public transport priority

3.2.1. Simulation model results

For algorithm development and effect on signal controllers, the add-on module for VISSIM simulation tool called VisVAP (*Vehicle Actuated Programming*) was used. VisVAP enables object-oriented programming and making of programming logic via a flowchart. The layout of the flowchart and its components is defined according to the German standard RiLSA 1992.

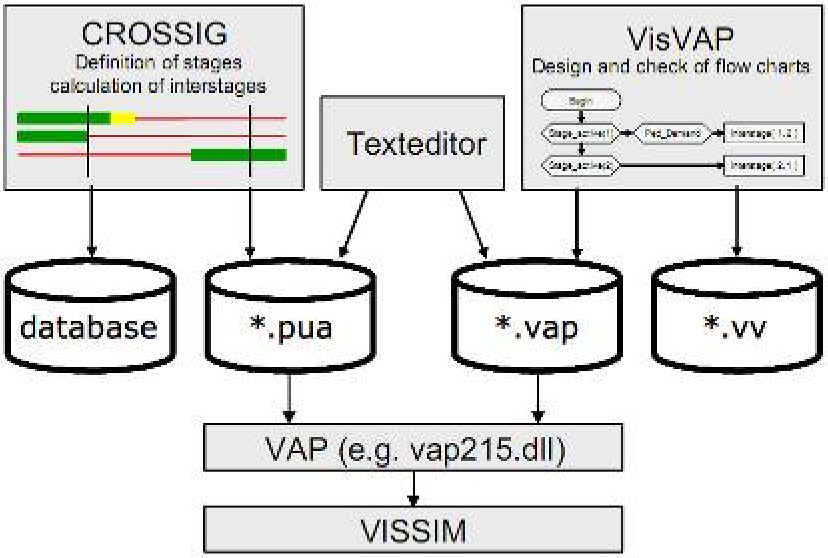

Figure 9: Graphic display of VisVAP modul work mode [12]

According to **Figure 9**, it is evident that first it is necessary to make an ASCII database with the extension ***.pua** which contains information on the number of signal groups, intergreen matrices, definition of signal plan, etc. The next step is the creation of an algorithm in VisVAP module after which ASCII with the extension ***. vap** is generated and placed into the VISSIM simulation tool replacing the settled signal plan of a certain intersection. The connection between ***.vap** program control and VISSIM are detectors (**Figure 10**) placed on the simulation model and the duration of the signal cycle, according to which the behavior of the signal plan at a specific intersection (**Figure 11**) is further conditioned.

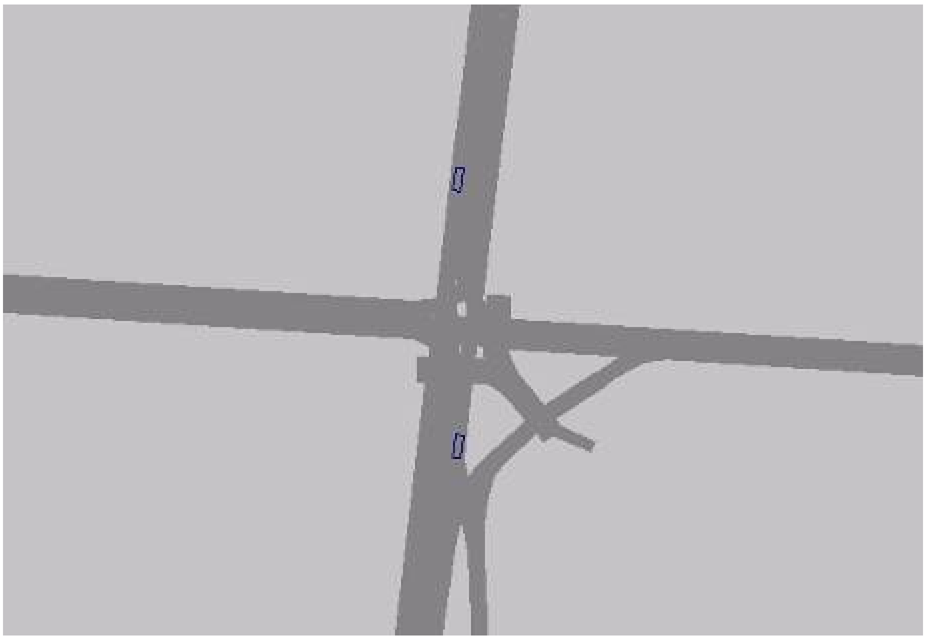

Figure 10: Detector placement in VISSIM simulation model

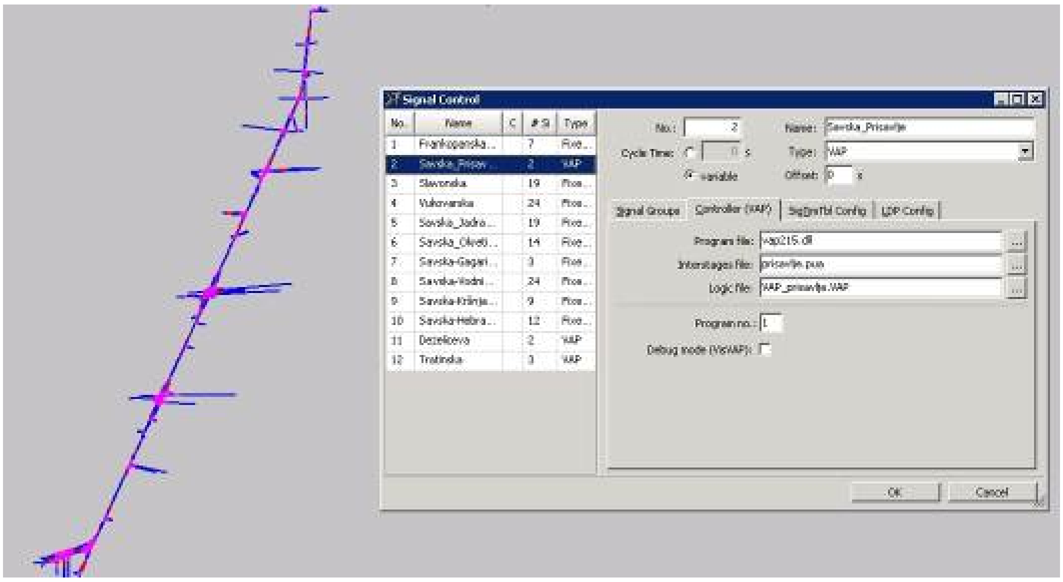

Figure 11: Definition of management algorithm for individual intersections in VISSIM

Before the algorithm implementation, it was necessary to consider all the possible scenarios at selected intersections in order to correctly develop priority allocation algorithm that takes all those scenarios into consideration. Below are given scenarios and the algorithm development for the selected intersections within the corridor.

After development of priority algorithms, and their implementation in simulation model, it is possible to conclude that some priority techniques can be implemented in selected corridor, but only on some intersections. Specificity of the corridor excludes possibility to implement priority techniques on all intersections along the corridor (high traffic loads on lateral links, existence of perpendicular "green waves", intersections with great number of signal groups, etc.).

Other priority techniques that include roadway improvements/traffic regulations (minor changes to roadways, relocation of public transport stops, and minor changes in traffic regulations) were also comprised in simulation model.

Simulation results were narrowed only on tram lines 14 and 17 which are the only lines which operate thorough entire corridor. Before priority techniques implementation average travel time was 1297.4 seconds, and after implementation of techniques average travel time was reduced to 1084.3 seconds. Complete analysis of travel times before and after introduction of priority in the model was shown in WD1 document.

Regarding implementation of public transport priority on the corridor, there are some difficulties. Some signal controllers on intersections along the corridor are outdated, and there is no possibility to reprogram them. **Table 4** shows types of signal controllers along the corridor with dates of first installation.

Table 4: Types of signal controllers along the corridor

	lane 1		lane 2	date of first implem.	device type	manufacturer
R1	Frankopanska	-	Varšavska	23.7.1990.	JCFBA 300	TESLA
R2	Frankopanska	-	Dežehćev Prilaz	1.3.1989.	JCFBA 300	TESLA
R3	Savska	-	Hebrangova	12.5.1987.	IVD 1203	fANOS
R4	Savska	-	Kršnjavoga	19.4.1987.	TCD 1007	FANOS
R5	Savska	-	Vodnikova	21.5.1991.	JCFBA 300	TESLA
R6	Savska	-	Tratinska	21.5.1991.	TCD 1007	TESLA
R7	Savska	-	Ulica Grada Vukovara	21.5.1991.	EC-1	PEEK
PP	Savska	-	Pedagoška Ak. - PP	21.5.1991.	TCD 1007	TESLA
R8	Savska.	-	Zagrebačka/Ljubljanska	1.11.1989.	JCFBA 300	TESLA
R9	Savska	-	Prisavlje	12.6.1977.	TCD 1007	TESLA
R10	Savska	-	Selska	21.2.1992.	TCD 1007	FANOS
R11	Jadranski most	-	Selska	21.2.1992.	TCD 1007	PEEK

3.2.2. Detection and identification of public transport vehicles

There are reserved lanes (yellow line) for public transport vehicles on the corridor. Therefore, any of the existing detection technologies would be usable for recognizing the public transport vehicles. Existing detection technologies are presented in **table 5** Detectors are divided as intrusive and non-intrusive. Intrusive detectors are embedded in pavement, while the non-intrusive detectors are mounted on consoles or posts above or by the lane.

Table 5: Detector technology types

Intrusive detector technology	**Non-intrusive detector technology**
Inductive loop	Passive infrared
Magnetic	Active infrared
Magnetometer	Ultrasonic
Piezoelectric	Acoustic array
	CW (Continous Wave) Microwawe radar
	FMCW (Frequency Modulated Continous Wave) Microwave radar
	VIP (Video Image Processor) *Emulated inductive loop*

Commercial products [11] are mostly used for detection of non-rail vehicles. Therefore, classic inductive loops and piezoelectric detectors cannot be used for that purpose. Magnetic detector and CW

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radar are also not appropriate because they cannot detect stopped vehicles or the ones that are moving very slowly. Sound detectors in an urban environment don't show high performances.

Active infrared detectors have been developed for special purposes and tend to be very expensive. However, the main reason for our inability to use the afore-mentioned technologies lies in undisciplined drivers. In fact, many drivers violate traffic regulations by using the reserved lane (individual vehicles, transport vehicles, etc.). **Figure 12** displays the results of a 15 minute measurement of the number of such violations. The measurement was conducted by video sensors and software package from the firm PROALAM. In the monitored 15 minute interval, as many as 65 vehicles used the reserved lane.

Figure 12: Number of traffic violations – usage of the reserved lanes

Some commercial detectors can perform additional signal analysis, thus being able to classify the vehicles by their length. However, classification ensured by these detectors is not satisfactory. Unmistakable classification of a tram vehicle is possible by using inductive detectors installed directly by the rail. An example of such detector is the detector produced by the ALTPRO Company. The advantages of their detector are its precision and endurance. The original purpose of their detector is detection of train wheels. Since tram and train rails differ, detector installation is possible with some rail modifications, or it is necessary to develop a new design of such detectors. **Figure 13.a** shows wheel sensor ZK24, and **figure 13.b** shows its inner equipment (electronics) [13].

Figure 13: a. Wheel sensor ZK24

Figure 13: b. Inner equipment

It is also necessary to develop interface circuits for connection with traffic light controllers, which can only be performed with the consent and cooperation of the manufacturers and maintaining firms of controllers. The limitation of this technology is that it cannot provide information on the number of vehicle operating line, which is important for an advanced public transport vehicles priority on intersections.

Vehicle identification

Identification of public transport vehicles implies recognition of the vehicle's number (number of operating line). This enables implementation of more advanced methods of public transport priority. At intersections, the controllers get the information of the number of operating line and, depending on the detour direction, it can activate the request for phase prolongation or the request for activation of the appropriate phase. Identification sensor systems can be implemented in different modes:

- VIP (Video Image Processing)
- GPS device with communication devices
- RFID (Radio Frequency Identification) technology
- Microwave sensor for identification (special designed microwave link)
- Special designed inductive loop (special designed communication system)

VIP – Video Image Processing

VIP system for vehicle identification by plate recognition should consist of a camera, a video image processor, appropriate algorithms for patterns recognition, communication devices and interface circuits for connection with signal controller. There are also few disadvantages associated with the usage of camera, the first being the camera's field of view. Each camera on the corridor should be carefully mounted to "catch" the number on the vehicle's plate. Bad weather conditions and light changes could cause errors in plate numbers recognition [12]. Furthermore, an expected problem is accurate determination of tram position, which causes a demanding system calibration. There are no such products for public transport priority on the market.

GPS device with communication devices

Vehicle identification system with GPS devices require appropriate wireless communication devices, one in the vehicle and one in signal controller cabinet. When the vehicle is on the detection point (predefined detection point), transceiver should send an identification message to the controller. The advantage of such system is definition of a flexible detection point. The present disadvantage is GPS inaccuracy in urban environment due to signal reflection. **Figure 14** presents recorded positions of moving GPS devices (with Chipset *SiRF Star III*) in the corridor segment. Errors in positions determination are up to 60 meters, so without accuracy improvement by usage of odograph and appropriate algorithms, GPS device is not usable.

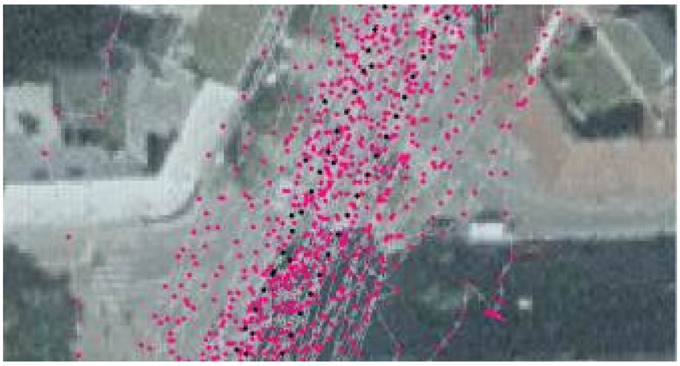

Figure 14: Recorded position of GPS devices in corridor segment

RFID technology

One of the possibilities of vehicle identification is usage of RFID technology. There are industrial RFID products which could be used in public transport vehicle identification. An example of such product is "IPICO INC" IP-X Read-Write UHF RFID Tag (**figure 15.a**) [14]. Tag can be mounted directly to metal surfaces, which are on any part of the tram. Its advantage is long read range up to 6 meters. Tag reader can be placed in the pavement between rails or by the lane. It also has possibilities of reading fast moving tags, up to 250 km/h, so it doesn't pose restrictions for tram traffic. Another way of using the device is to put the tag on the pavement. Passage of a vehicle with the tag reader would activate wireless transfer of data to the controller. In that case there is no need for communication and supply cables. The tags are relatively cheap, small and robust. The tag reader IP-X UHF High Performance EVI Reader (**figure 15.b**) works on frequencies between 860 and 960 MHz. Data outputs are Ethernet or RS 485. In order to complete the system in the function of priority, it is necessary to accomplish communication with signal controller and develop interface circuits. Our opinion is that this technology should be especially considered for public transport priority implementation [16].

Figure 15: a. Industrial RFID Tag

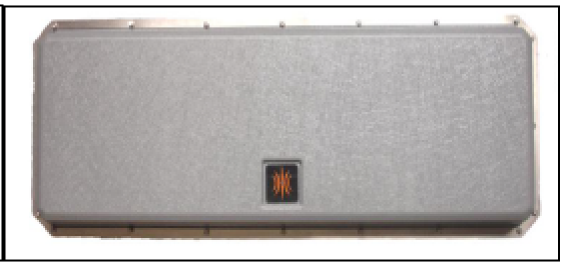

Figure 15: b. Reader by IPICO

Microwave sensor for identification

Microwave sensor for identification of tram vehicles has been originally designed for controlling tram rail crossovers. It is produced by the MARETON Company from Zagreb. The identification system consists of a pair of microwave transceivers (**figure 16**). One is mounted on tram vehicle and connected to the vehicle's information bus controller. Through the information bus controller the transceiver gets data on garage number, time tables, direction and current status of the vehicle. When establishing communication with the other transceiver placed in the pavement, the vehicle's transceiver transfers current data to pavement transceiver [16]. The transceiver consists of transceivers module and motherboard. The module is produced in ZIGBEE technology (ISM 2,4 GHz), that is XBEE-DIGI, with ceramic non-directional antenna. Motherboard is equipped with:

- microprocessor,
- communication port RS232,
- communication interface for IBIS,
- five digital outputs and
- five digital inputs
- two relay outputs.

The transceivers have a range up to 120 meters in open space, with the transfer speed of 38.4 kbit/s. The declared voltage of the device is 24 VDC, consumption of 20 mA in standby mode and 60 mA in active mode. The device's dimensions are 120x120x60 mm, it weights 350 g, which means it doesn't require a lot of space for embedding. It can also be mounted on posts by the lane.

An eventual problem of this technology is change in radio wave propagation condition, eventual obstacles such as other trams or vehicles, which cause the detection point to move. It is necessary to identify the possibility of detection point being in the tolerable range. This can be solved by using transceivers with directional antennas. In that case, the pavement transceiver should be placed close to the detection point. Transceivers communicate when their antenna's radiation patterns lap. Communication with the controller would be realized through installation of cables or wirelessly with an additional pair of transceivers. It is necessary to design interface circuits in order to connect to the controller. In case of cable communication standard RS-485 should be used.

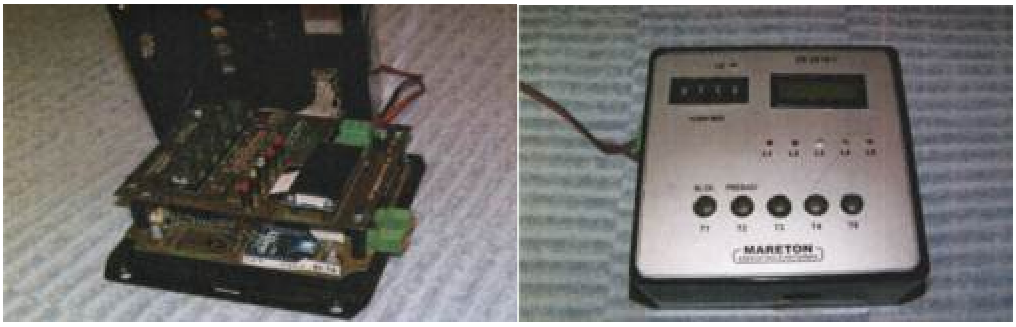

Figure 16: Prototype of microwave sensor for identification MARETON

Special designed inductive loops
Product VECOM by PEEK Company is a system for identification of public transport vehicles. It is the only available system dedicated for public transport priority on Croatian market. It consists of:

- “inductive loop” VECOM-C Loop cable,
- VECOM-C LDP (Loop Distribution Panel),
- VECOM-C Transceiver and VECOM C-Unit.

Transceiver is mounted on the vehicle, while inductive loop is embedded in pavement between rails. C-Unit is housed in controller cabinet. Voltage supply is 220 VAC or 24 VDC.

VECOM system provides data exchange between vehicles equipped with the VECOM C- Transceiver and roadside equipment. Approximately 200 different vehicle codes can be decoded. Communication is supported by standards RS232 (service channel), RS422 and RS485. Cable length is up to 800 meters. Wireless communication is also possible.
Main advantage of VECOM product is identification of the vehicle on exactly defined point and compatibility with controller EC-1. Disadvantages are a need for construction work on road infrastructure (loop installation and cable installation) and very high costs of implementation (product and installation) [17].

Classification of public transport vehicles based on detection of vehicles in the reserved lanes is not applicable because of a large number of traffic violations by other vehicles, which use reserved lanes. Unambiguous classification of public transport vehicles is possible by using the inductive detector ALTPRO, but it requires interventions on the rails or new design of products, and it does not provide information of the line number [15].
Vehicle identification is possible by the microwave sensor MARETON and the VECOM system PEEK. The microwave sensor is still in a developmental phase and it still requires some improvements and design of interface circuits. The VECOM system satisfies the requirements of identification and compatibility, but its cost is high.

3.2.3. Implementation status conclusions

Cost of services and equipment offered are too high for the pilot project because it does not include technical solution all along the corridor, but only for three intersections, and for one tram individually. Costs are high due to the fact that existing signal equipment and technical solutions are obsolete and require further development and installation of additional equipment. To examine contemporary signaling solutions all along the corridor, it is necessary, unless to add additional sensors for trams, to set signaling devices that are compatible, i.e. that can be preprogrammed from supervisory centre. Costs that should be approved in particular are associated with the cabling for the coordination or implementation of advanced wireless connectivity technology. Rough estimate is that the replacement of all signaling devices and their connection to the supervisory centre is necessary and that so elaborated technical solution needs 30.000€ per intersection and additional 20.000€ for connectivity. Also, in the time of project development, City authorities invited tenders for automatic traffic control study, so implementation of pilot priority techniques on few specific intersections will be postponed.

4. DISSEMINATION

Introduction of priority possibilities, simulation results, and possible implementations of priority techniques were conducted via various media channels. Also, public presentations of simulation results (and priority techniques in general) where organized and were targeted to public interested in benefits of such public transportation system improvements. From preliminary research number of scientific papers were produced, one student was awarded with Rector Award, and one doctoral thesis application was conducted, too.

Figure 17: Announcement poster for public presentation of public priority

12. january 2011.	**Presentiation within ODRAZ initiative "Wednesdays in tramway"**
Presentation of measure 8.2. evaluation results, public transport priority overall to general public and stakeholders involved in development of transport policy of city of Zagreb. Discussion with citizens about public transport priority benefits, their expectations from "enhanced" public transport system.	

13. january 2011.	**Presentation for Internet portal www.online-zagreb.hr**
Video presentation about CIVITAS-ELAN project (measure 8.2.) on Internet portal http://www.online-zagreb.hr. Simulation results presentation and explanation on future implementation possibilities and benefits for public transport system of City of Zagreb, and for City's transport system overall. **Link:** http://www.online-zagreb.hr/moj_zagreb/zagreb-hr/video-tramvajima-s-prioritetom-do-brzeg-javnog-prijevoza/	

15. january 2011.	**Report in TV show "Eko Zona"**
Report on public transport priority and CIVTAS-ELAN project development in the TV show "Eko Zona" on national television HRT, First programme. Introduction of public transport priority to general public, benefits of priority, initial evaluation results, etc.	

Produced scientific papers:

- Mrvelj, Š., Matulin, M., Jelušić, N.: Public Transport Priority System: Impact on Quality of Service, Proceedings of the 21st International Central European Conference on Information and Intelligent Systems, Varaždin 2010., 22-24 September, pp. 457-462; (ISSN 1847-2001)

- Jurišić, D., Jelušić, N., Matulin, M.: Measurement of Public Transport Perfomance Indicators by PDA Computer system, Proceedings of the 19th International Symposium on Electronics in Traffic, Ljubljana, 2011., 28 March 2011, paper ID R6, (ISBN 9978-961-6187—49-7)

- Mrvelj, Š., Matulin, M., Jelušić: Two-Level Evaluation of Public Transport System Performances. Approved paper for Promet – Traffic & Transportation, Scientific Journal on Traffic and Transportation Research (2011.)

- Rector reward in academic year 2009/2010; student Darko Jurišić, Measurement of public transport performance indicators by PDA computer system; (Mentor Niko Jelušić)

5. FINAL CONCLUSIONS

To extend the proposed priority solutions all along the corridor, it is mainly necessary to add additional announcement sensors to trams and to set signaling devices that are compatible, i.e. that can be pre-programmed from supervisory centre. Cost of services and equipment offered are too high for the pilot project because it does not include technical solution all along the corridor, but only for three intersections, and for one tram individually. Vehicle identification is possible by the microwave sensor MARETON and the VECOM system PEEK. The microwave sensor is still in a developmental phase and it still requires some improvements and design of interface circuits.

Costs are associated with the cabling for the coordination or implementation of advanced wireless connectivity technology. Rough estimate is that the replacement of all signaling devices and their connection to the supervisory centre is necessary and that so elaborated technical solution needs 30.000 EUR per intersection and additional 20.000 EUR for connectivity.

6. REFERENCES

1. Nash, A., B.; Sylvia, R.: Implementation of Zürich's Transit Priority Program, MTI Report 01-13, San Jose State University, 2001.
2. Evans, H.; Skiles, G.: Improving Public Transit Through Bus Preemtion of Traffic Signals, Traffic Quarterly, vol. 24., No. 4., 1970., pp. 531-543.
3. Ekeila, W.: Dynamic Transit Signal Priority – Master of Applied Science, University of Sharjah, 2002.
4. Ekeila, W., Sayed, T., El Esawey, M.: Development and comparison of dynamic transit signal priority strategies, Efficient Transportation and Pavement Systems – Al Qadi et all, London 2009.
5. CIVITAS-ELAN documents: Working document no.1 – Developing Programs for Traffic Light Triggering, Measure 8.2-ZAG Public transport priority and traveller information, Faculty of Traffic and Transport Sciences, University of Zagreb, 2010.
6. Nash, B., A., Sylvia, R.: Implementation of Zurich's Transit Priority Program, Mineta Transportation Institute, San Jose State Univerrsity, 2001.
7. Sane, J., K.: Traffic Signal Priority – A Justified Favoring of Public Transport, ENTIRE Documents, 1999. (http://www.hel2.fi/ksv/entire/repPriorityJustification.htm)
8. Sane, K., Salonen, M.: SYVARI – A New Idea for Using Public Transport Priority at Coordinated Traffic Signals, Proceedings of 16th World Congress on ITS, Stockholm, 2009.
9. Ngan, V., W., K.: A Comprehensive Strategy for Transit Signal Priority, Master of Applied Science, The University of British Columbia, 2000.
10. Vujic, M.: Public Transport Systems Adaptive Cooperative Control, Doctoral Qualification Examination, Faculty of Transport and Traffic Sciences, Zagreb, 2010.
11. Mimbela, L.E., Klein, L.A. et al.: A Summary of Vehicle Detection and Surveillance Technologies used in Intelligent Transportation Systems, The Vehicle Detector Clearinghouse Project, FHWA ITS Program Office et al., 2003.
12. PTV Vision, VisVAP User Manual, 2005.
13. Klein, L.A.: Sensor Technologies and Data Requirements for ITS, Artech House, Boston, London, 2001.
14. Mikrovalni senzor za identifikaciju tramvajskih vozila, Mareton, Zagreb, 2010.
15. http://www.altpro.com/cro/Preuzimanje/Katalozi, Katalog tvrtke “ALTPRO”, 2010.
16. http://www.ipico.com/, Product data sheet, 2010
17. http://www.peektraffic.se/download/VECOM_Compact_brochure_EN.pdf, 2010.