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FOREWORD

The volume in front of you is the second proceedings of the scientific papers presented in a form of technical reports. The presented work is a result of the *Program for stimulation of research and innovation at the Faculty of Transport and Traffic Sciences*, which is a crucial part of a strategic framework with an aim to improve quality of research activities and increase productivity in the field of traffic and transportation engineering.

The main purpose of the *Program* was to encourage the developmental and innovative character of scientific activity at the Faculty of Transport and Traffic Sciences in a way of forming research groups of individuals with the same interest. By networking at the Faculty's level, with active participation and involvement of doctoral and post-doctoral students, and with completely independent funding by the Faculty, scientific research should be directed towards international project applications. This was also a requirement for research groups to continue funding after the first year. Additionally, the *Program* was designed to allow a large degree of freedom for researchers, as well as confidence and independence in their work. After three years and four completed cycles, some of the researchers justified this trust.

Certain and measurable shifts have been made in terms of systematization and channeling of scientific research at the Faculty of Transport and Traffic Sciences. It is a matter of perspective whether they are made in right direction or not. As the author of the Program, it seems to me that critical number of people capable to make a difference is still lacking. Present *modus operandi* forces academic stuff to perform mostly as administrators, spending quite significant amount of their valuable time (when they are not teaching) to feed complex bureaucracy apparatus and to participate in discussions on large number of a technical issues – which are often highly irrelevant. It seems that the majority adopted this mode of operation, and that is a matter of concern. I can safely state that this is a reason why creativity is at the low end. For this reason, after three years of the *Program* activities, the success curve was asymptotically close to its mean value. In such circumstances, it may be time to slow down and to focus the work of individuals who think and act outside the box in some other direction.

Nevertheless, 2018 PROM-PRO Workshop offers respectable scientific work presented here in the form of technical reports. It is the result of two-year research and team effort. In alphabetical order by the name of the lead researcher, technical reports deal with topics relevant in Faculty's domain of scientific research.

In paper *Adapting the Railway System in the Integrated Passenger Transport (ARSIPT)* by B. Abramović, et al. the aim was to determine the mechanisms of adaptation in an integrated railway passenger transport in the legal, organizational, technological, technical and economic terms. The conclusion is that the railway is the backbone for organizing integrated passenger public system services.

The research of different markers which allow anonymous identification of vehicles was presented in the second paper called *Vehicle Detection from Video in Bad Weather Conditions* (authors M. Muštra, et al.). During the period of project funding, the team managed to write and actively participate in writing of five different project proposals with different funding schemes, mostly financed by the EU, one of which has already been accepted. The total amount of funds applied for is around 21 million HRK.

By combining strategies aimed to reduce private car usage and strategies for increasing the attractiveness among other modes of transport (public transport, non-motorized transport), the improvements of transport system in general can be achieved. The third paper called *Planning Sustainable Urban Mobility Using Transport Demand Management* (authors M.

Slavulj, et al.) deals with this phenomenon. The future work will be focused on developing sustainable urban mobility plans with particular interesting measures involving public transport and mobility management for large institutions.

General purpose of the project *The Use of Unmanned Aerial Vehicles in the Traffic Incident Management* (authors P. Škorput, et al.) was the expansion of the Faculty of Traffic and Transportation Sciences research work in the field of unmanned aerial vehicles in ITS, namely traffic control systems and incident situations management. The focus of the research was to find ways to extend existing ITS applications to innovative functionalities and to propose a more efficient way of managing incidents in traffic by using unmanned aerial vehicles.

Modern methods for the reduction of the exhaust emission are focused on advanced traffic control to decrease travel times and the number of stop-and-go actions. In research presented in report called *The Impact of Advanced Urban Traffic Control on Energy Efficiency* (authors M. Vujić, et al.) the application of adaptive traffic control on signalized intersections was considered and a simulation model of demonstration corridor in the city of Zagreb was made. The most important result was a simulation model of real corridor in the city of Zagreb (Zagrebacka Avenue) and the calibration of the model with real traffic situation.

Generally, the results from all presented projects can be divided into five categories: involvement of students, cooperation with industry and academia, submitted project applications, obtained additional projects and funds, and published papers. Overall results fulfilled the purpose of the *Program for stimulation of research and innovation* at the Faculty of Transport and Traffic Sciences.

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ADAPTING THE RAILWAY SYSTEM IN THE INTEGRATED PASSENGER TRANSPORT (ARSIPT)

ABSTRACT

The purpose of the research is to determine the mechanisms of adaptation in an integrated railway passenger transport in the legal, organizational, technological, technical and economic terms. Railways are the traditional mass carrier. Therefore, railways in an integrated public transport service are the core carrier of traffic load in such a complex system. For passengers, railways have many advantages like: (1) speed, (2) capacity, and (3) comfort. But also planning railway services must obey the rules of good design and common sense. In our research we have defined necessary steps on organizational level for railway undertakings to be a functional part of the integrated passengers public transport system. Furthermore, we have defined functional connection between urban and rural area on organizational level in the integrated passenger public transport system.

KEYWORDS:

Railway transport; integrated passenger transport, tariff system; quality

1. INTRODUCTION

Mobility, as one of the basic needs of a population, is a prerequisite for the development of a region in which the population migrates. A quality connection between the rural and urban areas is a key factor in preventing major exodus into urban centers. Due to its capacity, cost-effectiveness, spatial rationality and ecological acceptability, the public transportation serves as framework for mobility. On the other hand, the lack of quality public transport services is why nowadays the passenger car migrations hold a significant share in the distribution of transport modes in urban, as well as in rural areas.

The main indicators in the public transport services include: (1) accessibility, (2) journey time, (3) departure frequency, (4) cost, and (5) safety. The commuters migrations demand an adequate traffic infrastructure, public transport availability and a satisfactory transport option [16].

Regional traffic connection is a matter of key national importance due to the economic and social development. Functional regions are the ones with a high level of traffic interaction.

A detailed analysis based on the existing data, with emphasis on defining the demand in larger distances and on regional, suburban and urban level, is imperative for a functioning region. Commuting within a certain region in fact reflects the general development of that area. The daily commuting in our area for the most part refers to traveling to and from work or school. Passenger transport relates to the use of passenger and public transport vehicles as integral part of transport supply and demand of daily commuting. In public passenger transport system, one of the principal aims of transport services is its quality. The most common features of the quality of service include (1) comfort, (2) ease of use, (3) accessibility, (4) cost-efficiency, (5) punctuality, (6) regularity and (7) speed [4].

The mobility issues were particularly emphasised in uncontrolled growth of individual road traffic. The problem escalated especially in the area of the cities and city rings. Therefore, methods to improve the population mobility have been required. A large number of methods were designed, and they proved in practice either better or worse, but one of the methods of efficient mobility is integrated passenger transport. Integrated passenger transport represents organizational and technological platform for interweaving of different transport modes with the aim of using comparative advantages of each of them in order to optimize the usage of the means. The integrated passenger transport system offers the advantages for the user who is in the focus of interest, for local authority, carriers, and the economy as a whole. In its essence the integrated passenger transport represents a well established logistic system that optimizes the transport demand on the one hand, and transport supply on the other hand to the satisfaction of all those included in the transportation process i.e. ultimately the sustainable development of the city and the region [6].

A transport service user may, within the transport network included in the tariff, make journeys by purchasing a single unified transport ticket and follow a unified timetable. The integrated passenger transport system (hereinafter: IPTS) is used throughout the EU, where it operates on the regional basis so that the area of its application corresponds to the territory of a larger regional centre and its surrounding area.

The reasons for introducing such a system are numerous benefits for users, local authorities, operators, and the economy of the entire region. The most significant advantages, however, are the increase of mobility, a higher standard of living, better spacial planning, sustainable operation and higher profit.

In late March of 2011, the European Commission adopted the White paper 2011, a Roadmap to a Single European Transport Area which outlines 40 different initiatives to increase mobility of goods and passengers, remove barriers in key European traffic areas, and increase the employment rate in the transport and related sectors.

The current state in the Republic of Croatia indicates that public transport is not at all integrated. To tackle the issue in the area of the City of Zagreb, on 23 July 2014 the company Integrated traffic of Zagreb area Ltd. was established in order to organise an integrated passenger transport. The founders are the City of Zagreb, Zagreb county, and Krapina – Zagorje county. The company is currently set on planning and carrying out projects related to establishing a model of IPTS on the territory of the City of Zagreb, Zagreb county, and Krapina – Zagorje county [3].

The benefits of integrated passenger transport can be considered through four aspects:

- for users:
  - large number of lines,
  - increased mobility,
  - unique transport ticket,
  - better quality of life;
- for local authority:
  - optimal subsidies,
  - high-quality physical planning,

- cheaper maintenance of travel routes,
- free transport of schoolchildren;

- for operators:
  - long-term planning,
  - sustainable operation,
  - more passengers and revenues;
- for economy:
  - mobility of workforce,
  - increase of revenues.

Passenger transport in the EU is given great attention, precisely because it creates a framework of full transport mobility of citizens. It’s interesting to see data in Year 2010 on modal split of passenger transport that is in EU 27 for Passenger Cars 82,5%, Bus and Coaches is 8,9%, Railway 7,0% and Tramway and Metro is 1,6%. It’s interesting to compare EU 27 data with newcomer to the European Union – Croatia. In Republic of Croatia modal split of passenger transport is for Passenger Cars 81,9%, Bus and Coaches is 10,8%, Railway 5,6% and Tramway and Metro is 1,8%. So comparing ratio of railway in modal split Croatia has 1,4% less then the average of the European Union. Figure 1. Shows the comparison between Republic of Croatia and other European Union Countries.

It is also very interesting to see how develop public service passenger modal split in EU 27 for Bus and Coaches is 50,8%, Railway 40,2% and Tramway and Metro is 9%. Tramway and Metro by their technical and technological operation aspect are subsystem of railway, so in complete modal split picture almost half of the people use the railway system for their travel.

Railway is historically characterised like the mass carrier of transport, and in passenger transport this is reflected in the number of passengers. The last years have seen the implementation of the liberalization of railway traffic, which in fact opens up the possibility of better positioning of railway passenger transport on the total passenger transport market. The railway in passenger transport has several significant advantages: (1) speed, (2) capacity, and (3) comfort. On the average the train reaches twice the commercial speed of buses, and regarding the means the train has at least 50% greater capacity, and comfort is excellent. Unfortunately, railway has one drawback: it cannot carry the passengers from door to door. Therefore, in order to organize successful system of integrated passenger transport the excellent cooperation between the bus and railway transport is necessary. Bus transport has the function of picking up passengers at their “doorstep” and taking them to the place of integration with the railway transport, and the passengers continue their trip by train. In transport organized in this way, the comparative advantages of each transport mode are used. For this system to function successfully comprehensive research is needed, which refers especially to research of transport demand, followed by forecasting and developing of the transport model. [1]

2. RESEARCH GOAL AND MOTIVATION

The aim of this research is adapting the railway system in the integrated passenger transport system. One of the specific research goal was the mobility of population from rural areas towards urban centers. An analysis of the traffic connections between the rural regions of Sisak-Moslavina County and its urban administrative unit, the city of Sisak has been made.

A comparative analysis of the use of passenger vehicles, the analysis of public transport options together with demographic factors enables us to determine and subsequently assess the population mobility in rural areas.

Other specific research goal was to analyze transport service quality in rail and bus regional public passenger transport and provide a comparative analysis of the parameters of transport service quality in railway and bus regional traffic in the Republic of Croatia. For purposes of this research we have chosen to research the following counties: Zagreb County, Krapina – Zagorje County and the City of Zagreb. The idea of quality is to increase customer satisfaction in order to keep their loyalty and make them use the services regularly.

The fare policy or the tariff policy in transport determines how much a passenger will pay for a provided service. When making the tariff systems, the basic task is to establish a cooperation between the operators and transport users in terms of willingness to pay, in order to determine the optimal solution that would meet the demands of all the parties involved. Designing such tariff systems in not an easy task, as it requires giving in to demands and needs of all the participants.

One of the basic principles of the IPTS are establishing a unified tariff model that can be used in the mentioned regions, by the transport operators, and the commuters. Tariff integration plays a key role in the integration process. On the one side, the tariff and the terms of the tariff system need to be set up so as to create a system appealing to the passengers, but on the other side, all the operators included in the system have to be able to make a profit.

Shaping the tariff structure is an important step in modelling the tariff system within the IPTS, which is why it requires meticulous planning. There are four possible structures for modelling a tariff system: (1) Distance, (2) zonal structure, (3) concentric zone structure, and (4) honeycomb-shaped structure. All of the aforementioned forms of tariff modelling have their advantages and drawbacks. Ultimately, several parameters need to be included in the selection process of the tariff structure.

3. RESEARCH ACTIVITIES

The research activities done by the project team members are presented in this section. The two – year research activities are divided into three main parts. The first part of research is related to the possibility of using public transport in rural area. Second part of research is the Comparative Analysis of Transport Service Quality in Regional Rail and Bus Traffic. The third is about tariff model in Integrated Passengers Public Transport.

3.1 The possibility of using public transport in rural area

The area of Sisak-Moslavina County is characterized by uneven inhabitation evident in higher density urban areas (Sisak, Petrinja, Kutina and Novska), whereas certain rural regions are almost uninhabited. The issue of uneven population distribution brings about substantial differences in the degree of development of certain regions in the County. The city of Sisak is the capital of a functional region with its own traffic network (3 bus lines and a single railway line). The number of vehicles and the quantity of service are gradually adapting in order to meet the supply and demand. There are three carriers of public transport in the county – HŽ Passenger Transport, Auto promet Sisak and Čazmatrans Promet Slavijatrans. The transport between the units of local self-government in the county has not yet been developed due to the lower number of users.

For the purposes of the analysis of the connection between the rural County areas and the urban center Sisak the research will focus on the route Sisak – Volinja – Sisak. There are 15 daily passenger trains operating on the Sisak – Volinja route to Sisak Caprag station, 9 of which continue to Sunja. There are only 4 passengers trains traveling from Sunja to border crossing Volinja, where they turn around and continue to Sisak. Volinja – Sisak route is covered by 4 passenger trains from Volinja station. From Sunja to Sisak station there are 9, and from Sisak Caprag to Sisak 16 passenger trains.

The public bus transportation on Sisak – Volinja – Sisak route enables commuting to settlement Sisak Caprag. The suburban and urban transportation on Sisak – Volinja – Sisak is operated by a single line, Sisak – Blinjski kut – Sisak. In the urban transportation on Sisak –

Sisak Caprag route there are 73 daily bus departures, and the route Sisak - Caprag operates 71. The route Sisak – Blinjski Kut – Sisak is covered by a suburban line with 7 daily buses departing towards Blinjski kut, and 6 from Blinjski kut towards Sisak.

Based on the road traffic census in the Republic of Croatia in 2015, the state road 224, which passes through the municipality Sunja, has an average daily traffic of 1883 vehicles per day in the rural part of the County.

The average departure frequency of passenger trains on route Sisak-Volinja is not consistent along the entire route. There are 15 daily departures from and to Sisak and Sisak Caprag with a 1.2 hour departure frequency (the line operates 18 hours). Further away from the urban part of Sisak-Moslavina county brings fewer departures and less accessible public transport services. There are 9 daily trains operating from Sisak Caprag to Sunja in each direction departing every 2 hours on average, and only 4 daily trains between Sunja and Volinja with a 4.5 hours departure frequency. The average service speed on Sisak - Volinja route is 40.1 km/h. The urban bus transportation links the Sisak urban area and the settlement Sisak Caprag with an average departure frequency of 0.25 hours in each direction. The buses depart every 3 hours on the suburban route Sisak – Blinjski kut with an average service speed of 30 km/h.

After analyzing the public transportation options in the rural areas of the researched regions, we can clearly state that the population of Volinja, Hrvatska Kostajnica, Majur, Graboštani and Hrastovac almost entirely depends on passenger cars due to the inaccessibility of bus transportation and a very low number of departures in railway traffic (4 daily departures in each direction). The population mobility is, therefore, inadequate. The municipalities Sunja and Brđani Krajiški also have no public bus transportation, whereas the railway transport offers 9 daily departures in each direction with an average frequency of 2 hours, which is also limited. A higher number of departures compared to the previously listed settlements and municipalities does not indicate a higher mobility for the local population because of the lack of quality management, i.e. the organization of the timetable, due to the fact that bus departures coincide with train departures, which again halts the frequency to 2 hours.

The settlement Sisak Caprag is well-connected to the Sisak by both train and bus network lines, which is evident from the number of departures. The frequency in railway traffic is 1.2 hours, and 0.25 in bus traffic. The better connectivity to Sisak compared to other settlements is a direct result of a high demand of local population for daily commuting to the industrial zone Sisak Caprag.

3.2 The Comparative Analysis of Transport Service Quality in Regional Rail and Bus Traffic

For this research we chose the following counties: Zagreb County, Krapina – Zagorje County and the City of Zagreb. Krapina – Zagorje County is located in the northwestern part of country, the area which belongs to the central Croatia. The Zagreb County is situated in the center of Croatia, and it represents the central point in which the three directions of the Croatian space - the northern, southern and eastern one - intersect. At the same time, it provides the link between the Pannonian and Adriatic areas. Due to its ring-shape which borders on the City of Zagreb, the capital, it is usually referred to as “The Zagreb Ring”. Because of this territorial and geographic feature, the City of Zagreb and the Zagreb County actually make up a large economic and population whole. The geographical view of Krapina – Zagorje County, the City of Zagreb and Zagreb County is shown in Figure 1.

Figure 1 – The Geographical view of Krapina – Zagorje County, City of Zagreb and Zagreb County

The City of Zagreb has a population of 793,000 and together with the neighboring region of Krapina – Zagorje County that amounts to 1,243,000 on the total of somewhat less than 5,000 sq. km. Taking into consideration the economic, educational, cultural and other social activities, Zagreb and its region comprise an area similar to that of many Central European regions. A prerequisite for the economic, educational, cultural and social functionality of the city is the quality of its traffic connections, both infrastructural and organizational. A quality traffic system is a key to a successful operation of such an urban region which includes Zagreb and the counties of Krapina – Zagorje and Zagreb. The preconditions for quality living and working in the city is also the mobility of people, which connotes quality of personal and public transport service, i.e. traveling efficiently in the city, between Zagreb and the region, and in the region itself. This research analyzes the transport service quality in the regional public rail and bus passenger transport, and offers a comparative analysis of the quality of the before mentioned means of transport.

We have used four direct parameters (distance [km], price [€], travel time [h] and daily number of departures) and three indirect parameters (ratio between price and distance [€/km], ratio between distance and travel time [km/h], and frequency, which represents the number of trains in an 18 hour period).

Rail traffic in the researched area contains three classification type of lines: (1) international lines, (2) regional lines, and (3) local lines. Figure 2 shows railway lines in the researched area, as well as the subdivisions and names of official places. There are 30 stations, 44 stops and 5 official places where trains do not halt. The sole service provider is the national carrier HŽ Passenger Transport.

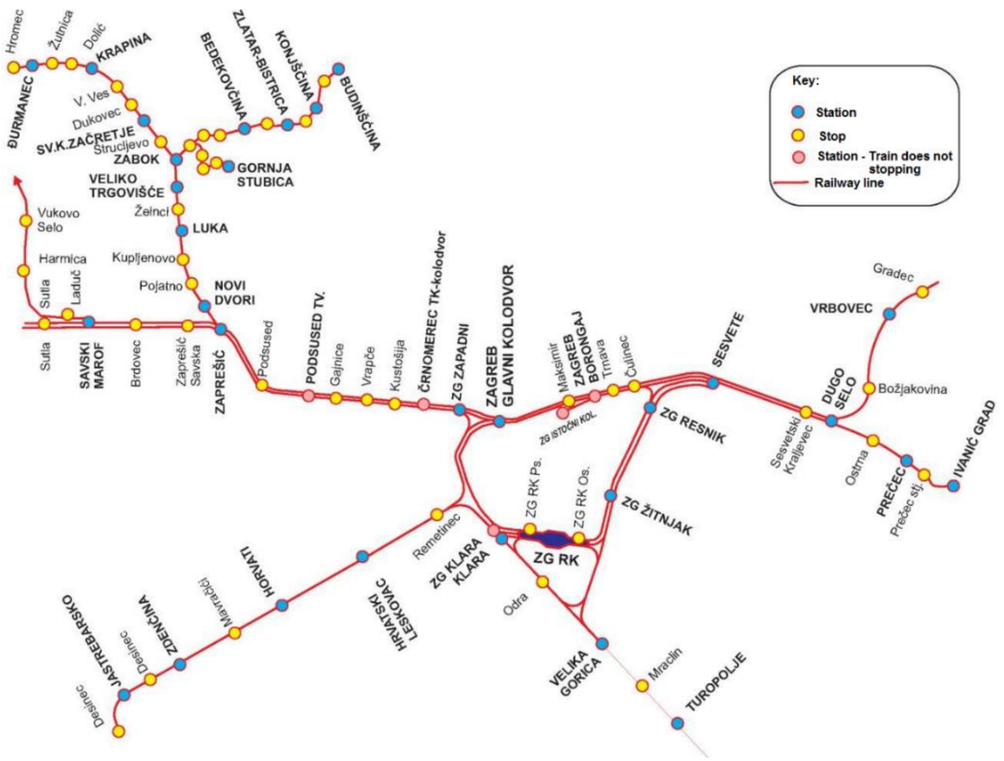

Figure 2 – Railway line in the researched area

The results of the analysis based on the direct and indirect parameters is shown in Table 1. The researched area was limited to Zagreb - bound passenger trains. Eight lines have been analyzed: Velika Gorica – Zagreb Main Station, Jastrebarsko – Zagreb Main Station, Zaprešić – Zagreb Main Station, Vrbovec – Zagreb Main Station, Ivanić Grad – Zagreb Main Station, Zabok – Zagreb Main Station, Gornja Stubica – Zagreb Main Station and Krapina – Zagreb Main Station.

From Table 1 we can notice substantial differences in the frequency of departures and train speeds at certain railway lines. The commercial operating speed is the highest along the Velika Gorica – Zagreb Main Station line reaching 60 km/h, and the lowest between Zabok and Zagreb Main Station, at 36 km/h. The average interval between trains is every 80 minutes with a minimum of 26 minutes (Zaprešić – Zagreb Main Station) and a maximum 108 min (Vrbovec – Zagreb Main Station).

Table 1 – The transport service quality analysis in rail traffic

Relation	Price [€]	Distance [km]	Time [h]	Number of departures	Price/ Distance [€/km]	Commercial speed [km/h]	Frequency [min]
Velika Gorica - Zagreb MS	1.54	15	0.25	15	0.10	60.00	72.00
Jastrebarsko - Zagreb MS	3.24	33	0.57	13	0.10	57.89	83.08
Zaprešić - Zagreb MS	1.54	15	0.38	41	0.10	39.47	26.34
Vrbovec - Zagreb MS	3.57	37	0.63	10	0.10	58.73	108.00
Ivanić Grad - Zagreb MS	3.57	38	0.78	14	0.09	48.72	77.14
Zabok - Zagreb MS	3.57	39	1.08	11	0.09	36.11	98.18
Gornja Stubica - Zagreb MS	4.76	51	1.41	11	0.09	36.17	98.18
Krapina - Zagreb MS	5.28	56	1.43	14	0.09	39.16	77.14

The infrastructure of public bus transport services, the level of service quality, transport frequency as well as the transport fares are all relevant factors of the levels of the development and service quality of the bus transport in the researched area. The parameters used for transport service quality, and the railway lines from the previous chapter have been applied in bus transport services in the observed regions as well.

The regional bus transportation service of the researched area is largely dominated by the carrier “ZET”, owned by the city of Zagreb, with 426 vehicles in its fleet and an average age of 8 years, specializing in all public transport activities. The bus carrier “ZET” provides passenger transport services on analyzed routes Velika Gorica – Zagreb Main Station and Zaprešić – Zagreb Main Station. A smaller share belongs to operators “Autoturist Samobor”, “Samoborček”, “Presečki grupa” and “Čazmatrans Nova”, which operate mostly on other analyzed routes. The analysis of the transport service quality based on the listed parameters is given in Table 2.

Table 2 – The analysis of the bus transport service quality

Relation	Price [€]	Distance [km]	Time [h]	Number of departures	Price/ Distance [€/km]	Commercial speed [km/h]	Frequency [min]
Velika Gorica - Zagreb MS	1.32	16	0.50	88	0.08	32.00	12.27
Jastrebarsko - Zagreb MS	5.13	37	0.85	14	0.14	43.53	77.14
Zaprešić - Zagreb MS	1.32	19	0.75	98	0.07	25.33	11.02
Vrbovec - Zagreb MS	6.71	41	0.92	14	0.16	44.57	77.14
Ivanić Grad - Zagreb MS	6.31	40	0.75	11	0.16	53.33	98.18
Zabok - Zagreb MS	4.34	40	0.84	8	0.11	47.62	135.00
Gornja Stubica - Zagreb MS	6.84	59	1.00	3	0.12	59.00	360.00
Krapina - Zagreb MS	4.74	63	1.34	2	0.08	47.01	540.00

With regard to the size of “ZET”’s vehicle fleet, the departure frequency is the highest averaging 12 minutes on operating routes. The lowest frequency is between Krapina and Zagreb, with buses departing every 9 hours. The reason for such rare departures on this route, and Zagreb Main Station – Gornja Stubica, is the focus on only the direct bus lines. The average service frequency interval per direction of travel in the analyzed area is approximately 160 minutes, at the minimal interval of 11 min, and maximum 540 min. This leads to the conclusion that the supply and demand on a working day is extremely unbalanced.

The price per kilometer in bus regional transport compared to that in rail is lower only on routes under 20 km (Velika Gorica – Zagreb Main Station and Zaprešić – Zagreb Main Station) provided by “ZET”, while other bus routes offer a higher price than railway transport. The sole exception is the railway line Krapina – Zagreb Main Station, with lower fare per kilometer than the bus, with the length of the railway line 56 km, and the bus route 63 km.

The ratio between the distance and travel time indicates the commercial travel speed. On shorter routes, such as Velika Gorica – Zagreb, Jastrebarsko – Zagreb, Zaprešić – Zagreb Main Station and Vrbovec – Zagreb Main Station, the commercial travel speed is higher in the railway transport, whereas on the longer routes it is higher in bus transport.

The frequency of trains in an 18 hour period is lower compared to buses, whereas the frequency on longer routers is higher by trains. Comparing the relationship between the distance and travel time in Figure 5 and frequency of vehicles in an 18 hour period in Figure 6, the opposite situation is applicable. The shorter bus routes offer higher frequency, but lower commercial travel speed compared to railway, while longer railway lines provide a higher frequency, but lower commercial speeds.

3.3 Proposal of the Tariff Model in Integrated Passengers Public Transport

The introduction of the integrated passenger transport in the City of Zagreb, Zagreb County, and Krapina – Zagorje County would propose a modelling of a new zonal structure of the tariff system. Modelling zones in the regions refers to determining the attribution of stations to certain zones. The choice of the zonal structure of the tariff system is based on the existing geographical and traffic situation in the regions, as well as on the advantages of the zonal structure. Namely, it is more flexible than the concentric circle and comb structure, while the determination of fare based on distances requires a more complex purchase system.

Practical examples show modelling of zones that encompass 8 – 12 kilometres. Considering the geographical circumstances this would mean dividing the region into 50 – 80 zones. Modelling minor zones around the City of Zagreb and major zones in rural areas is suggested. Figure 3 shows the rough draft of a new zonal tariff system in the region, based on the radius of 12 kilometres around the train stations.

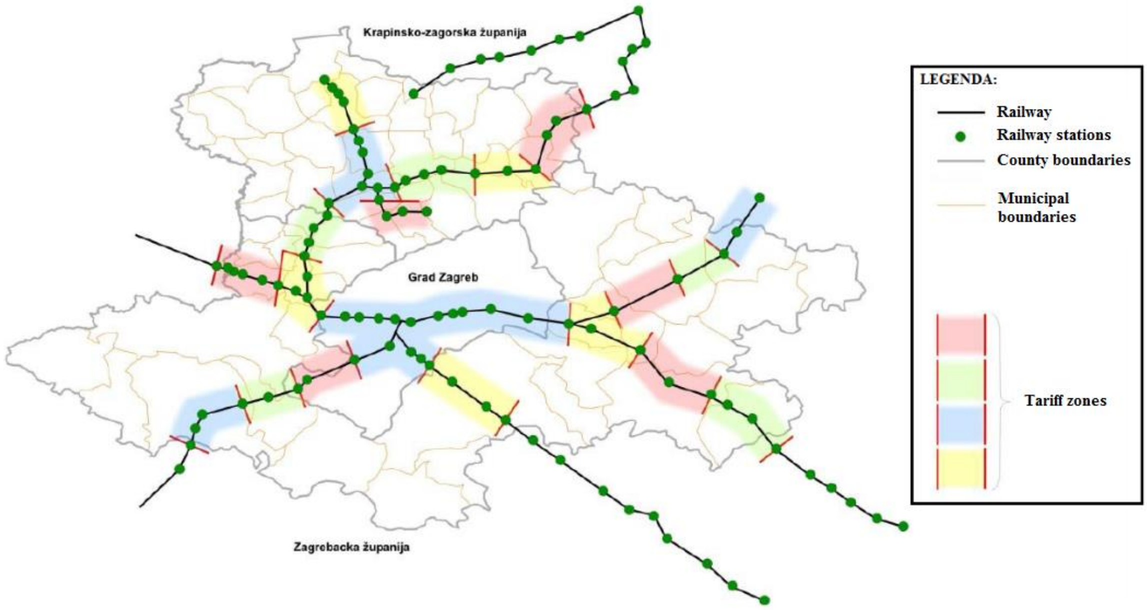

Figure 3 – Proposed potential new zonal tariff system in the region

Defining new zones in the tariff system of the IPTS can also be based on the existing administrative municipal boundaries, which could be adjusted to the traffic situation and intensity. Determining the fare in the new zonal tariff system would have to be very simple, so that at any given moment passengers are able to determine the zones they need to cover, count them and calculate the fare.

A detailed plan of tariff zones and a fare table should be based on the existing prices, traffic situation, and transport demand in the region. Structuring of fares in the integrated charging system should take into consideration a wider range of tickets. Standard set time period fares are proposed: (1) single/return journey, (2) day pass, (3), weekly pass, (4) monthly pass, and a yearly pass. Apart from the standard time fares, certain EU states (Switzerland, Germany, etc.) suggest using additional timed tickets, such as "Fare valid after 9.00", which is a useful option for equalising the transport demand during peak time. The portfolio of fares should be in accordance with reduced fare offers for targeted user groups: (1) adults (e.g. commuter fare), (2) students (e.g. student fare), (3) pupils (e.g. pupil fare), (4) family (e.g. family fare), (5) retired (retirement fare), and (6) disability fare (e.g. reduced fares for all types of journeys).

In public transport the tariffs are one of the most significant factors that affect the number of passengers, and thereby, profit. Particularly in local public transportation, there are several types of fares that can be adjusted, e.g. the single fare, monthly pass, and fares that change with distance, etc. Therefore, it is in the interest of the company providing services of public transport or the transportation authority to optimize the system of prices in order to maximize profit. Since public transportation companies often operate with losses, the aim is to minimize them as much as possible. The problems that arise when determining tariffs are in many countries purely of political nature, which means that the freedom of movement becomes limited. In reality, the price of a ticket is determined more often than not by negotiation rather than actual planning.

Introducing the system of integrated passenger transport begs the question of the financial side effects resulting from it. The basic principle of such a system is based on the idea that a passenger is issued a single unified ticket for their journey, regardless of the number of operators. In the current transportation system in the researched regions, passengers need to purchase a new fare with each new operator. Due to the digressive fares in the IPTS, the journey would cost less than the existing individual fares combined.

4. BUDGET SPENDING

In this section we are describing summary of how the budget for the project was planned and spent during the two project year. In table 3 is show the summery of planned and realized activities.

Table 3 – Planned and realized activities with budget overview [kuna]

Nr.	Planned activity	Planned budget	Achieved
1.	Brokerage Event	4,000.00	3,006.07
2.	Workshop Danube Strategy	1,000.00	650.08
3.	Paper publish on conference ICTTE 2016	2,000.00	756.50
4.	Field research	5,000.00	4,927.50
5.	Text translation and lecturing	2,000.00	4,700.00
6.	Portable batteries for field research	700.00	872.00
7.	Administrative expenses A	300.00	24.29
A.	Recapitulation of first year of project	15,000.00	14,936.44
8.	Subscription on EURAILPRESS	2,500.00	2,671.01
9.	Dissemination of results Horizons 2017, LOGI 2017, BLMM 2017	10,000.00	9,675.54
10.	Text translation and lecturing	2,000.00	2,030.00
11.	Administrative expenses B	500.00	173.26
B.	Recapitulation of second year of project	15,000.00	14,549.81
C	A + B	30,000.00	29,486.25

5. RESULTS

Railways are the traditional mass carrier. Therefore, railways in an integrated public transport service are the core carrier of traffic load in such a complex system. For passengers, railways have many advantages like: (1) speed, (2) capacity, and (3) comfort. But also planning railway services must obey the rules of good design and common sense.

The population that migrates from the analyzed rural area into the urban center of Sisak-Moslavina County has constantly been in decline, with the trend suggesting the increase of emigration with each year. The significantly inadequate mobility in the researched rural area results from the lack of spatial coverage of 70% of the area by public bus transportation services, with railway transport available only to the inhabitants residing in the vicinity of the railway track. The fact that every other working-age inhabitant possesses a vehicle is not by choice but rather due to the impossibility of using adequate public transportation services.

In order to lay the groundwork for long-term development of the analyzed rural areas, investments into the traffic sector need to be made, the investments that are going to reflect the pressing needs of the local population in terms of mobility. At the same time, these investments would effectively stimulate the economic and social development, as well as territorial cohesion. The availability of public transportation, a better management of routes and the establishment of integrated traffic systems in public transportation would contribute to the change of the emigration trends of the rural areas, thus improving the quality of life in the analyzed region [16].

The aims set for public transport services to make it more attractive, efficient, and safer are to increase the level of transport service quality. The intention of public passenger transportation is to devise a system that can compete with motorized personal transport. It is, therefore, necessary to establish certain quality standards. The basic principle of the policy for the quality of services in regional public passenger transport is to satisfy the customer's requirements. The data for the research has been collected from official sources of railway and bus operators: distance [km], price [€], travel time [h] and a daily number of departures. We have also calculated some relationships between data, such as: price - distance [€/km], distance - travel time [km/h], and frequency that represents the number of trains in an 18 hour period. The systems of public transport in Zagreb, Krapina – Zagorje County and Zagreb County are not integrated, and as such pose an obstacle in their respective development, as well as the development of the city and the region. At the same time, some lines run parallel in both bus and rail operators. The railway transport is at disadvantage due to the age of their fleet, while the bus fleet averages 15 years. The service frequency on shorter routes in regional passenger transportation is higher in bus transport, with commercial travel speed lower than in railway. Longer railway lines offer higher frequency and lower speeds compared to buses. A quality system of integrated public transport would ensure a higher level of mobility, which would, as scientifically proven, have an effect on the competitiveness of the economy, easier employment, and thus a quality of life in the entire region. Maintaining and subsequent increase of the existing number of users of buses should be the main goal of operators' transport policies. This can be achieved by raising the quality of transport, maintaining the bus and train stops, offering acceptable fares and resorting to eco-friendly fuel options [4].

The traffic problems of the cities are today a common phenomenon which disturbs the quality of living and affects the mobility of population. Everyday commuters, namely, spend more and more time on usual trips. The traffic planners have found the method of increasing mobility of population in the integrated transport of passengers.

In the users' decision-making segment regarding place, time, and mode of transport the important role belongs to the traffic demand management strategy whose aim is to provide optimal usage of the traffic capacities. Integrated transport facilitates optimal coordination of the traffic demand and the traffic supply. This means satisfaction of the main goals of the transport management strategy such as reduction of congestion, shortening of the travelling time, reduction of the costs related to increased wear of infrastructure, ensuring availability of the transport service for all the groups of users, raising the level of traffic flow safety, ensuring sustainable development of the traffic system and significant improvement of environmental protection. The introduction of high-quality organized integrated passenger transport system would reduce the use of passenger cars in everyday commuting and reduce the harmful emissions and noise.

Such system provides benefits for different groups of stakeholders (1) passengers - users, (2) carriers, (3) local authorities, and (4) economy. The carriers would be provided with better planning and better sustainable operation, and for the economy good mobility of labour is of utmost importance [6].

Considering the recommendations, it is necessary to follow certain steps in order to implement a fair, efficient and sustainable integrated tariff system in the City of Zagreb, Zagreb County and Krapina – Zagorje County. Based on the results and the recommendations, a detailed concept of the tariff and selling system needs to be devised, as well as the distribution of income between the operators, and the ticket inspection.

Before the start of the implementation, it is essential to make general political and organisational decisions, which, among other things, include the choice and application of technology. As far as the City of Zagreb, Zagreb County and Krapina – Zagorje County are concerned, it should be decided whether the technological solutions should come from a single manufacturer or from several. Next to the technological standardisation, a detailed distribution of income between the operators is required. This refers to a detailed analysis of the data on income and distribution channels of all the operators, as well as the accessibility and provision of the necessary information.

The operators fear for potential losses brought about by tariff integration, at the same time underestimating the prospect of more passengers. The cases in Germany confirm, however, that the process of integrated public transport is not voluntary. The public authorities have to make the operators participate in an integrated transport or convince them to do so by providing them with significant public subsidies. Legal estimates are essential in this phase for regulating the rights of operators.

Upon the contractual decision on the tariff system, the phase of operative implementation of the IT system commences. Apart from the aforementioned decision on the choice of technology, this phase also includes incorporating the customer relationship management (CRM) into different IT systems with the aim of unifying travel data gathered from various distribution channels.

The final phase before the implementation of the integrated tariff systems focuses on public relations and creating a marketing plan. This includes business trade planning, marketing activities, but also the inclusion and participation of partners such as tourist boards, car-sharing and bike-sharing companies, cultural events, etc. Unlike usual marketing activities of each individual operator, the marketing strategy of the integrated transport is focused on working towards achieving the goal, rather than each company's interest. This means that this transport tariff union is in its wholeness represented as a brand, with operators acting as part of the brand.

By going through the presented phases, a complete implementation of the integrated tariff system is theoretically possible within the period of two years. However, European experience has shown that on this path political and organisational decisions are crucial [3].

5.1 Involvement of students

During the project were actively involved in field data collection. Following students are been involve in project: Mario Čičak, Sebastijan Kamenščak, Marko Leko, Matea Mikulčić, Ivan Petrić, Josipa Puklin, Ivan Talan, Jakov Troskot, Antonio Menalo, Matea Ban, and Martina Furdić.

List of Bachler and Master thesis:

- Troskot, Jakov: Organizacija željezničkog prometa u sustavu integriranog prijevoza putnika, University of Zagreb, Faculty of Transport and Traffic Sciences, 2017
- Leko, Marko: Analiza organizacije željezničkog putničkog prijevoznika, University of Zagreb, Faculty of Transport and Traffic Sciences, 2017
- Ban, Matea: Sustavi naplate prijevoznih karata u željezničkom putničkom prometu, University of Zagreb, Faculty of Transport and Traffic Sciences, 2016

Also, PhD Student Michal Panak from University of Žilina during his Erasmus+ student mobility was the team member.

5.2 Cooperation with industry and academia

During the project period cooperation with domestic and foreign industry, companies, institutions, and academia was established. List of institution that we have fruitful cooperation:

- HŽ Putnički prijevoz d.o.o.
- Zagrebački električni tramvaj d.o.o.
- Integriani promet zagrebačkog područja d.o.o.
- Ministarstvo mora, prometa i infrastrukture (MPPI)
- EY Savjetovanja d.o.o.
- TCDD Türkiye Cumhuriyeti Devlet Demiryolları
- Univeristy of Belgrade Faculty of Transport and Traffic Engineering
- University of Žilina Faculty of Operation and Economics of Transport and Communications
- University of Ljubljana Faculty of Maritime Studies and Transport
- Vienna University of Technology Institute of Transportation
- Newcastle University Newrail - Centre for Railway Research
- University Politehnica of Bucharest Faculty of Transports

Especially we would like to thank HŽ Putničkom prijevozu d.o.o. which is completely free of charge give us train tickets for field research.

5.3 Project applications

Based on preliminary research through the support of PROM-PRO, the research group apply for a funding of a total of eight international research projects. Description of submitted international research project application including funding scheme, project name, budget, and status are shown in Table 4.

Table 4 – Overview of submitted project proposals

Nr.	Funding scheme	Project name	Budget [kn]	Status
1.	COST	20865 „A Europe-wide standard of rail training, research and education for skilled workforce”	N/A	Approved, but not on the financial list
2.	COST	21927 „Holonic Modelling Approach to Improve Door to Door Accessibility”	N/A	Rejected
3.	Bilateral agreement Croatia - Serbia	„Održivi i energetski efikasan željeznički prometni sustav: najbolji primjeri i strategije za hrvatske i srpske željeznice”	75,000.00	Rejected
4.	ERASMUS+ KA2	„WORKRAIL - Work Based Learning in Vocational Rail System Training”		Approved, but not on the financial list
5.	ERASMUS+ KA2	„MODEREN - Modernizing and Enhancing Railway Engineering Higher Education in Serbia”		Approved, but not on the financial list
6.	Danube Strategy DSPF	„The development of a future strategic project - governance -and railway”	912,000.00	Approved
7.	COST	22253 „Skills Intelligent Mobility Network”	N/A	Under Evaluation
8.	Danube Strategy DSPF	TRAIANUS – TRAnsport Interregional freight corridor linking Koper and ConstantzA – New developments, environmental and User –friendly rail-based Services for an improved intermodality and balanced accesibility in the Danube Regions	11,400,000.00	Under Evaluation

5.4 Obtained additional projects and funds

One of the prosperous results through the support of PROM-PRO is opportunity for applying for applicative project. During the 2 year of PROM-PRO project we have applied for 3 applicative projects in the process of public procurement that was accepted and funded. The toll value of the submitted and accepted projects is 1,1150,875.00 kuna. The overview of submitted applicative projects is shown in table 5.

Table 5 – Overview of submitted project proposals

Nr.	Funding scheme	Name of project or grant	Budget [kn]
1.	IPZP d.o.o.	Elaborat prilagodbe organizacijske strukture operatera modelu integriranog prijevoza putnika	998,125.00
2.	IPZP d.o.o.	Konzultatska usluga izrade prve faze integriranog prijevoza putnika	72,500.00
3.	EY Savjetovanja d.o.o.	Services of strategic monitoring and Technical assistance related to the implementation of Operational programme Competitiveness and Cohesion	80,250.00

5.5 Published papers

Members of the project team published papers in journals and presented their research work on conferences:

- Abramović B, Nedeliakova E, Panak M, Šipuš D. SYNERGY IN LOGISTICS PROCESSES FOR RAILWAY TRANSPORT. Business Logistics in Modern Management. 2017
- Abramović B, Šipuš D, Šimunović L, Panak M. PROPOSAL OF THE TARIFF MODEL IN INTEGRATED PASSENGERS PUBLIC TRANSPORT. In Competent human resources as a potential for providing the comprehensive and sustainable rail transport services 2017
- Abramović B, Šipuš D. THE COMPARATIVE ANALYSIS OF TRANSPORT SERVICE QUALITY IN REGIONAL RAIL AND BUS TRAFFIC. In Horizons of Railway Transport 2016
- Abramović B, Škrinjar JP, Šipuš D. ANALYSIS OF RAILWAY INFRASTRUCTURE CHARGES FEES ON THE LOCAL PASSENGERS LINES IN CROATIA. In ICTTE 2016
- Abramovic B, Zitricky V, Mesko P. DRAFT METHODOLOGY TO SPECIFY THE RAILWAY SECTIONS CAPACITY. LOGI–Scientific Journal on Transport and Logistics. 2017;8(1):1-0.
- Abramovic B. PASSENGER'S SATISFACTION ON LONG DISTANCE TERMINALS: CASE STUDY CITY OF ZAGREB. Periodica Polytechnica. Transportation Engineering. 2017;45(1):42.
- Černa L, Daniš J, Abramović B. THE PROPOSAL OF TARIFF TAKING INTO ACCOUNT THE RISK FROM UNOCCUPIED CAPACITY OF PASSENGER TRAINS. Komunikácie. 2017;19(2):90.
- Lalinská J, Gašparík J, Šipuš D. FACTORS AFFECTING THE DELAY OF PASSENGER TRAINS. LOGI–Scientific Journal on Transport and Logistics. 2017 May 1;8(1):74-81.
- Ljubaj I, Mlinarić TJ. SOLUTION PROPOSAL FOR BOTTLENECKS ON RIJEKA TRAFFIC DIRECTION: A CASE STUDY OF GENERALSKI STOL-GORNJE DUBRAVE. In Horizons of Railway Transport 2016

- Ljubaj I, Petrović M, Mlinarić TJ. ANALYSIS OF PUBLIC TRANSPORT OFFER IN KRAPINA-ZAGORJE COUNTY AND PROPOSAL OF INTEGRATION POINT. In Competent human resources as a potential for providing the comprehensive and sustainable rail transport services 2017
- Mikulčić M, Ljubaj I, Petrović M. ANALYSING THE RAILWAY PASSENGER TRAIN OPERATION USING A SIMULATION MODEL. In Competent human resources as a potential for providing the comprehensive and sustainable rail transport services 2017
- Nedeliaková E, Panák M, Šipuš D. INNOVATIVE TRENDS IN PROCESS-ORIENTED QUALITY MANAGEMENT WITHIN RAILWAY TRANSPORT. Periodica Polytechnica. Transportation Engineering. 2017 Apr 1;45(2):84.
- Panák M, Nedeliaková E, Abramović B, Šipuš D. SYNERGIES OF THE LIBERALIZATION OF THE RAILWAY TRANSPORT MARKET. In MATEC Web of Conferences 2017 (Vol. 134, p. 00045). EDP Sciences.
- Šipuš D, Abramović B. THE POSSIBILITY OF USING PUBLIC TRANSPORT IN RURAL AREA. Procedia engineering. 2017; 192:788-93.
- Zavada JB, Abramović B, Šipuš D. A STRATEGIC MODEL OF SUSTAINABLE MOBILITY IN THE CITY OF ZAGREB AND ITS SURROUNDING AREA. International Journal for Traffic & Transport Engineering. 2017;7(4).

6. CONCLUSION AND FUTURE WORK

Passenger transport is an interesting subject, not only for passengers and operators, but also for politics, because on the one hand it brings votes, and on the other hand needs a subsidy for operation. Therefore the European Commission in its last White Paper 2011 - Roadmap to a Single European Transport Area made it clear through a number of initiatives that it is necessary to develop an integrated public transport system. Of course, such a system is expected to be an cooperation between the different transport modes and different operators. This means that the method of transport planning should meet transport demand to cover the transport supply by implementing an integrated public transport system. The benefits of an integrated passenger public system can be considered through four aspects: (1) users, (2) local authority, (3) and operators (4) economy.

Railway is historically characterised like the mass carrier of transport, and in passenger transport this is reflected in the number of passengers. The last years have seen the implementation of the liberalization of railway traffic, which in fact opens up the possibility of better positioning of railway passenger transport on the total passenger transport market. The railway in passenger transport has several significant advantages: (1) speed, (2) capacity, and (3) comfort. On the average the train reaches twice the commercial speed of buses, and regarding the means the train has at least 50% greater capacity, and comfort is excellent. Unfortunately, railway has one drawback: it cannot carry the passengers from door to door. Therefore, in order to organize successful system of integrated passenger transport the excellent cooperation between the bus and railway transport is necessary. Bus transport has the function of picking up passengers at their “doorstep” and taking them to the place of integration with the railway transport, and the passengers continue their trip by train. In transport organized in this way, the comparative advantages of each transport mode are used. For this system to function successfully comprehensive research is needed, which refers especially to research of transport demand, followed by forecasting and developing of the transport model.

The conclusion is that the railway is the backbone for organizing integrated passenger public system services.

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REFERENCES

[1] Abramović B. Railways as a core of an integrated passenger public transport system. In Horizons of Railway Transport 2013

[2] Abramović B, Nedeliakova E, Panak M, Šipuš D. SYNERGY IN LOGISTICS PROCESSES FOR RAILWAY TRANSPORT. Business Logistics in Modern Management. 2017

[3] Abramović B, Šipuš D, Šimunović L, Panak M. PROPOSAL OF THE TARIFF MODEL IN INTEGRATED PASSENGERS PUBLIC TRANSPORT. In Competent human resources as a potential for providing the comprehensive and sustainable rail transport services 2017

[4] Abramović B, Šipuš D. THE COMPARATIVE ANALYSIS OF TRANSPORT SERVICE QUALITY IN REGIONAL RAIL AND BUS TRAFFIC. In Horizons of Railway Transport 2016

[5] Abramović B, Škrinjar JP, Šipuš D. ANALYSIS OF RAILWAY INFRASTRUCTURE CHARGES FEES ON THE LOCAL PASSENGERS LINES IN CROATIA. In ICTTE 2016

[6] Abramović B, Škrinjar JP, Šipoš L. INTEGRATED TRANSPORT OF THE CITY OF VARAŽDIN IN THE FUNCTION OF SUSTAINABLE DEVELOPMENT. ZIRP 2013

[7] Abramovic B, Zitricky V, Mesko P. DRAFT METHODOLOGY TO SPECIFY THE RAILWAY SECTIONS CAPACITY. LOGI–Scientific Journal on Transport and Logistics. 2017;8(1):1-0.

[8] Abramovic B. PASSENGER'S SATISFACTION ON LONG DISTANCE TERMINALS: CASE STUDY CITY OF ZAGREB. Periodica Polytechnica. Transportation Engineering. 2017;45(1):42.

[9] Černa L, Daniš J, Abramović B. THE PROPOSAL OF TARIFF TAKING INTO ACCOUNT THE RISK FROM UNOCCUPIED CAPACITY OF PASSENGER TRAINS. Komunikácie. 2017;19(2):90.

[10] Lalinská J, Gašparík J, Šipuš D. FACTORS AFFECTING THE DELAY OF PASSENGER TRAINS. LOGI–Scientific Journal on Transport and Logistics. 2017 May 1;8(1):74-81.

[11] Ljubaj I, Mlinarić TJ. SOLUTION PROPOSAL FOR BOTTLENECKS ON RIJEKA TRAFFIC DIRECTION: A CASE STUDY OF GENERALSKI STOL-GORNJE DUBRAVE. In Horizons of Railway Transport 2016

[12] Ljubaj I, Petrović M, Mlinarić TJ. ANALYSIS OF PUBLIC TRANSPORT OFFER IN KRAPINA-ZAGORJE COUNTY AND PROPOSAL OF INTEGRATION POINT. In Competent human resources as a potential for providing the comprehensive and sustainable rail transport services 2017

[13] Mikulčić M, Ljubaj I, Petrović M. ANALYSING THE RAILWAY PASSENGER TRAIN OPERATION USING A SIMULATION MODEL. In Competent human resources as a potential for providing the comprehensive and sustainable rail transport services 2017

[14] Nedeliaková E, Panák M, Šipuš D. INNOVATIVE TRENDS IN PROCESS-ORIENTED QUALITY MANAGEMENT WITHIN RAILWAY TRANSPORT. Periodica Polytechnica. Transportation Engineering. 2017 Apr 1;45(2):84.

[15] Panák M, Nedeliaková E, Abramović B, Šipuš D. SYNERGIES OF THE LIBERALIZATION OF THE RAILWAY TRANSPORT MARKET. In MATEC Web of Conferences 2017 (Vol. 134, p. 00045). EDP Sciences.

[16] Šipuš D, Abramović B. THE POSSIBILITY OF USING PUBLIC TRANSPORT IN RURAL AREA. Procedia engineering. 2017; 192:788-93.

[17] Zavada JB, Abramović B, Šipuš D. A STRATEGIC MODEL OF SUSTAINABLE MOBILITY IN THE CITY OF ZAGREB AND ITS SURROUNDING AREA. International Journal for Traffic & Transport Engineering. 2017;7(4).

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VEHICLE DETECTION FROM VIDEO IN BAD WEATHER CONDITIONS

ABSTRACT

Video surveillance techniques are an important segment in traffic surveillance because they offer a lot of information about the current traffic situation. This would be ideal in cases of optimal light and visibility but that often is not the case. In order to overcome that obstacle, we have proposed the usage of thermal cameras, which can give some enhancement in detection results due to the poor optical visibility. Thermal cameras operate in so-called near infrared part of the electromagnetic spectrum and are sensitive to thermal radiation of captured objects. However, thermal cameras alone are not the ideal tool for the following reasons: usually lower resolution which masks details in image, more difficult and less precise automatic segmentation of vehicles, and very high price when comparing to the standard cameras operating in the visible part of the spectrum. One of the proposed solutions is pairing a low-cost thermal camera with a standard camera and providing a multispectral sensor of reasonable price with possibility to detect vehicles in bad weather conditions. Traffic surveillance should also include some sort of vehicle identification for tracking and building traffic models of certain areas. That task is difficult using the video equipment, because the system would have difficulties in vehicle recognition, which a much more difficult task than detection solely. For that purpose we have decided to investigate different markers which allow anonymous identification of vehicles and as the best one and easiest to implement was Bluetooth.

KEYWORDS:

Video detection, thermal camera, Bluetooth detector

1. INTRODUCTION

One of the easiest and most comprehensive ways of traffic surveillance is through video surveillance. It gives good and complete information about the current state of the traffic flow, it allows vehicle counting and classification, and detection of possible incidents. Classic video surveillance systems are operated and monitored by human operators and require a lot of manpower in order to function correctly. Video cameras are only sensors and cannot be considered as detectors, because the detection part is done by humans. In order to provide automatic video detection, which can be based in camera housing or on a remote location, a lot of knowledge must be put in the dedicated hardware and software. Having all this in mind, we also need to consider some disadvantages of automatic vehicle detection systems. Automatic vehicle detection from video suffers from different weather conditions, and even in the case of good weather conditions, there are some problems which occur rather often. One of the worst is fluctuation in illumination, due to clouds on a sunny day, which results in problematic segmentation of vehicles from the road because of the sudden change in intensity of pixels belonging to the road [1]. Because of these limitations, which are unavoidable by cameras operating in visible spectrum, we considered a different approach and that is combination of an affordable thermal camera sensor coupled with the standard camera of moderately good characteristics. To further develop capabilities of the developed detector we decided to include Bluetooth detection, which would make anonymous vehicle detection possible.

This report is organized as follows. Section 2 gives description of research goals and motivation. Section 3 brings overview of the research activities. In Section 4 an overview of the spent budget is given. Section 5 shows the project results with emphasis on applications for new projects and projects accepted for financing. Finally, Section 6 brings a conclusion and a proposal for future work.

2. RESEARCH GOAL AND MOTIVATION

As stated in the previous section, cameras operating in the visible spectrum suffer from many problems caused by changing or bad weather conditions. To partially overcome problems caused by water-spray during rainy weather or poor visibility because of fog, rain or snow, we are proposing usage of thermal cameras combined with the standard cameras to get the best possible detection and preserve level of detail needed for vehicle classification. In this field we have proposed a project entitled: "Advanced traffic counter based on multispectral video" to Croatian Agency for SMEs, Innovations and Investments (HAMAG-BICRO) which was not selected for financing. Writing of this project proposal gave us plenty information about the cost and obstacles of traffic detectors in general and the greatest obstacle of thermal camera combined detectors is a unit price of around €15.000 for one detector (sensor). Since preliminary research requires some laboratory testing, our motivation was to obtain some sort of detector which would give us possibility to make some measurement for development of the automatic segmentation methods. For that purpose we think that combination of these, rather cheap, sensors would give very good detection results while maintaining level of detail needed for object classification. An example of the sensor-pair would be FLIR Lepton as a thermal sensor and Sony IMX219 as a visible spectrum sensor. Combination of these sensors allows vehicle detection with one parameter missing, and that is recognition. Video-based systems for vehicle recognition are usually based on detection of the license plate and for that they require a special camera position, good resolution and combination of image powerful image processing methods and OCR (Optical Character Recognition). This procedure is obviously difficult to implement and gives a privacy issue, which can present a problem. A solution to this problem is a system which gives an anonymous ID of the vehicle or passengers inside the vehicle. The most common ID of such kind, which is being used a lot by car manufacturers, is Bluetooth. As a communication protocol it is well known and used in almost every mobile phone and in all smartphones but it also became used by car manufacturers in multimedia systems. Good thing about Bluetooth is that it (usually) has a unique MAC address which is not related to the user in any way, so there is no intrusion of privacy. Another good thing is that it emits its identification which can be seen without the need to establish connection to the device. There are, of course, some negative aspects as well, and the most obvious is number of vehicles equipped with the hardware which has some Bluetooth radio switched on [2, 3].

The goal of our research was to build a rather cheap sensory infrastructure, which would perform equal to the professional solutions, but for the fragment of the price. The sensor which we built currently incorporates a camera which operates in visible part of the electromagnetic spectrum, a Bluetooth detector, and hardware which enables real-time detection from the captured data. The next step is integration of the thermal camera which should provide a robust system capable of detecting vehicles in all weather conditions and allow classification as well as building traffic models in case of multiple sensors on different locations.

3. RESEARCH ACTIVITIES

The proposed project consisted of many solutions regarding vehicle detection and throughout the two-year duration there have been many changes and new approaches were introduced. The initial idea was development of techniques for vehicle detection and segmentation from the background, with good results even in severe weather. Application for larger projects in this field funded by different Croatian and EU agencies requires a large research team, with a good background in the stated research fields. Preliminary testing that needs to be done to prove an idea to be worthily of writing a project proposal requires funding much larger than one at our disposal. Therefore, we have concentrated on using as much as possible data available online and hardware that is not off-the-shelf but custom built by researchers on the project.

Image and video processing-wise, project members collaborated with the researchers from the Faculty of Transport and Traffic Sciences who were developing automatic vehicle detection algorithms from videos. This collaboration gave the information about all the weaknesses of the proposed methods and ways to overcome them with the usage of different hardware and processing methods. In order to outperform a simple background subtraction method for moving object detection we are proposing a feature classification method which gives better results of object tracking in changing lighting conditions [1] as shown in Fig. 1.

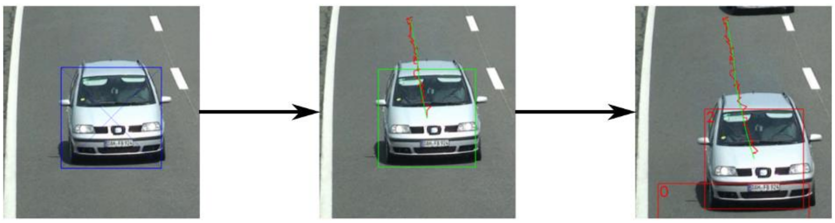

Figure 1 – Detection of the vehicle on the road using feature classification. [1]

Enhancement of this method, which even might eliminate need for a huge computational effort, is usage of thermal imaging combined with visible spectrum imaging. An example of the thermal image, where dissipated heat is mapped as intensity is shown in Fig. 2 [4].

Figure 2 – Thermal image of vehicles with temperature mapped as intensity. [4]

Improvement, or additional functionality, of video-based sensors and detectors are Bluetooth traffic detectors. During the project we have established collaboration with one of the pioneers in Bluetooth detectors, company TrafficNow. They produce different kinds of traffic detection sensors but their most promising product is Bluetooth detector which provides possibility to monitor traffic in large urban areas and create origin-destination (OD) matrices, Fig. 3.

Figure 3 – Bluetooth detector for traffic detection DeepBlue v2t D-model. Courtesy of TrafficNow.

As stated in the previous section, solutions which integrate thermal and standard cameras are rather expensive and, at a given time, we did not receive enough funds to purchase one of the commercial solutions. Therefore we decided to assemble a solution from rather cheap hardware which was possible to purchase with funds at our disposal. The first solution includes RaspberryPi Model 3 which is slightly modified to accommodate antenna connector for higher Bluetooth detection range and a camera with the Sony IMX219 sensor in the same housing as shown in Fig. 4.

Figure 4 – Camera and Bluetooth detector built during this project.

Further development of this detector will include integration of the FLIR Lepton thermal camera which operates in longwave infrared spectrum, 8 μm to 14 μm, has 80×60 or 160×120 resolution and 8.6 Hz frame rate.

4. BUDGET SPENDING

For the period of two years this project received a total funding of 30,000 HRK. One half of the amount was granted for each year of the project. Majority of the granted amount was spent on various activities and equipment purchase. During that time one project associate involved in creation of the proposal for this project left the position at the Faculty of Transport and Traffic Sciences. For this reason some of the planned activities could be only done on a smaller scale and part of the research was changed from the one stated in the application. Since there was a significant difference in planned and achieved activities, especially for the year #1, in Table 1 we give a sum of realized activities and spent budget for both years.

Attendance of conferences was financed in order to present latest research results to the international community and to use conferences for networking, while attendance of summer schools was intended to provide project researchers with the state-of-the-art knowledge in novel methods for data processing. For connecting with national researchers and companies no amount was spend since all the meetings took place in Zagreb. Some funds left are planned to be spent on small equipment related to the activity nr. 1 from the year #2.

Table 1 – Realized activities and spent budget on the for both years

Nr.	Realized Activities, year #1		Realized Activities, year #2
1	Gathered a research group to deal with vehicle detection using different technologies		Building and tweaking of the wireless sensors network for vehicle detection using Bluetooth
2	Bluetooth signal detector prototype built		Organization of ITS Special Session at International Scientific Symposium ELMAR-2017
3	Contact and collaboration with thermal camera vendor		Attendance of 2nd International Summer School on Data Science (SSDS-2017)
4	Application on two large scientific projects funded by HRZZ (1) and NATO (2), accepted funding for (2)		Application on two large scientific projects IRI and one MZO
5	Organization of ITS Special Session at International Scientific Symposium ELMAR-2016		Attendance at International Conference on Smart Systems and Technologies 2017 with presentation of one paper
6	Attendance of 1st International Summer School on Data Science (SSDS-2016)		Purchase of FLIR Lepton for integration with vehicle detector (estimated at 2,500 HRK)
7	Design of solar power supply system for different detectors		
Awarded budget in HRK:		**15,000.00**	**15,000.00**
Total budget spent in HRK:		**11,145.37**	**11,740.50**

5. RESULTS

This project achieved results of the call regarding establishment of the collaboration with researchers from the Faculty of Transport and Traffic Sciences and from other institutions. Besides that, it gave project team members a better insight in the field of traffic detection and monitoring. Researchers achieved collaboration on five large project proposals, one of which is accepted before writing this report, three are under review, and one is not accepted for financing.

Results obtained in this project can be divided into five subsections: involvement of students, cooperation with industry and academia, submitted project applications, obtained additional projects and funds, and published papers. In continuation, each subsection is explained into more details.

5.1 Involvement of students

In this project we were able to gather couple of students to work on topics related with the research activities. Two students from ITS, Leo Tišljarić and Dominik Cvetek, were included in assembly of the solar-powered supply for detectors and were developing an Arduino-based Bluetooth detector.

PhD Student Tomislav Erdelić did a large amount of work in assembly and software tuning of the RaspberryPi Bluetooth detector with a standard camera. This resulted in a functional prototype, which needs to be further developed and upgraded with thermal camera to allow video detection.

5.2 Cooperation with industry and academia

As a part of the related research on this project we have organized several meetings with companies and academic institutions with the goal to establish cooperation in research, education, and joint project proposals. Regarding cooperation with industry, meetings with LED elektronika Ltd., Promel projekt Ltd., TrafficNow Ltd., Audio-Video Trend Ltd., Combis Ltd., Mireo Inc., and VIP Inc. were held. These meetings resulted in informal agreement about cooperation in research and education as well as collaboration of future projects.

Cooperation with academia resulted in collaboration with the Faculty of Electrical Engineering and Computing (FER) and the Faculty of Mechanical Engineering and Naval Architecture (FSB) of the University of Zagreb, University of St. Andrews, Scotland, and University of Banja Luka, BiH. Achieved results are joint project proposal with all of the stated institutions.

5.3 Project applications

The goal of this project call was basically to establish collaboration with partners, form teams, and finally submit project proposals. Researchers working on this project have managed to achieve that and applied at four different calls with five proposals, as summarized in Table 2. Until writing of this report one project was accepted for funding and started in November 2017, one was rejected, and three were still under review process, all in the last phase.

Table 2 – Overview of submitted project proposals

Nr.	Funding scheme	Project name	Budget	Status
1.	HRZZ	Optimization of Routes for ElectricDelivery Vehicles - OpRED	702,000.00 HRK	Rejected
2.	NATO SPS	Biological Method (Bees) for Explosive Detection - Bee4Exp	2,959,575.00 HRK	Accepted
3.	IRI	Povećanje sigurnosti u zračnom prometu ispitivanjem parametara umora kontrolora leta, utemeljenim na simuliranim parametrima okoline - FLICON	8,811,250.00 HRK	In review
4.	IRI	Skalabilni, visoko dostupni, distribuirani sustav za optimizaciju kompleksnih dostavnih ruta	2,527,508.26 HRK	In review
5.	MZO	Razvoj pametne platforme za slijetanje bespilotnih letjelica - Dronoport	6,881,773.18 HRK	In review

5.4 Obtained additional projects and funds

Additional project and funds were obtained on a small scale but we can note that researchers working on this project were part of the team which received short-term researcher support from the University of Zagreb of 23,412.56 HRK yearly.

5.5 Published papers

Research results in topics related to this project were published in two full papers on international peer-reviewed conferences, two abstracts international peer-reviewed conferences, one abstract on international workshop, and one poster on international workshop.

6. CONCLUSION AND FUTURE WORK

Aim of this project was to start the research related to the detection of vehicles from videos in different weather conditions. During the project, we have also considered an idea which was not presented in the proposal, and that is detection of the Bluetooth signal. Because of a large number of new vehicles equipped with multimedia systems incorporating Bluetooth radios, we have concluded that Bluetooth is the detection marker of the near future, including Wi-Fi signals from smartphones.

Researchers build a detector prototype which consists of a RaspberryPi computer with the possibility of Bluetooth detection and a video camera operating in visible spectrum with a planned upgrade with thermal camera which is being ordered. Besides that, we have designed and built a solar power supply unit capable of providing power to the detector and wireless or mobile communication system.

Thermal imaging gives good results in some aspects of detecting objects of different temperature than their surrounding but it is still rather expensive, especially when it comes to high resolution images. Therefore, we have a plan to purchase a high-resolution and highly sensitive thermal camera with the funds obtained from a large project accepted for financing, which could be used later in continuation of this research.

During this project we managed to either write or co-author five different project proposals with different funding schemes, mostly financed by the EU, one of which is already accepted. Total amount of funds applied for is around 21 million HRK.

Future work on this research activity will include testing of the built prototype and comparison with the commercial products. Sensor integration should provide a capable detector built for research purposes which can give guidelines for choosing good and capable commercial product optimal for the surveillance and traffic modelling in urban areas of larger cities in Croatia.

REFERENCES

[1] Kovačić, K.; Ivanjko, E.; Muštra, M.: Computer Vision Based Measurement of Road Traffic Parameters, First International Workshop on Data Science (IWDS 2016), Zagreb, Croatia, 2016.

[2] Michau, G., Nantes, A., Bhaskar, A., Chung, E., Abry, P. and Borgnat, P.: Bluetooth Data in an Urban Context: Retrieving Vehicle Trajectories, IEEE Transactions on Intelligent Transportation Systems, 2017, pp. 2377-2386.

[3] Díaz, J.J.V., González, A.B.R. and Wilby, M.R.: Bluetooth Traffic Monitoring Systems for Travel Time Estimation on Freeways, IEEE Transactions on Intelligent Transportation Systems, 17(1), 2016, pp. 123-132.

[4] Iwasaki, Y., Misumi, M. and Nakamiya, T.: Robust vehicle detection under various environmental conditions using an infrared thermal camera and its application to road traffic flow monitoring, Sensors, 13(6), 2013, pp. 7756-7773.

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PLANNING SUSTAINABLE URBAN MOBILITY USING TRANSPORT DEMAND MANAGEMENT

ABSTRACT

The research plan covers the area of urban mobility with an emphasis on the application of transport demand management measures. The research group addressed all segments of urban mobility that were mostly carried out within the projects received at the Department of Urban Transport. The research group includes students of all levels of study: undergraduate, graduate and postgraduate doctoral studies. During the future work the research group will be modified and supplemented with experts from companies and city administrations.

KEYWORDS:

Urban transport; sustainable urban mobility; transport demand management; public transport; urban road safety.

1. INTRODUCTION

The increase in the number of motor vehicles in the cities resulted in continuous traffic congestion. The increased transport demand, especially in peak periods, can be solved by transport demand management strategies. The transport demand management strategies have a goal to optimally use the available transport infrastructure in urban areas, with rationalization and discouraging private car usage. Therefore, the approach of transport demand management is transferred into the Sustainable Urban Mobility Plans, as a response to the ever-increased transport problems in urban environment. Developing Sustainable Urban Mobility Plans by implementing transport demand management measures contributes to the sustainable development in cities. By combining strategies aimed to reduce private car usage and strategies for increasing the attractiveness among other modes of transport (public transport, non-motorized transport), the improvements of transport system in general can be achieved.

A Sustainable Urban Mobility Plan is a strategic document which represents an upgrade of the current planning practice and involves integration, participation and evaluation principles in order to satisfy the needs of citizens for mobility, now and in the future, ensuring better liveability in cities and surrounding areas. The goal of the Sustainable Urban Mobility Plan in cities is to create sustainable transport systems in urban areas by: ensuring accessibility of businesses and services, increasing efficiency and effectiveness in transporting people and goods, and increasing attractiveness and quality of urban environment.

The Sustainable Urban Mobility Plan encourages balanced development of every corresponding transport modes, with simultaneous encouragements to shifting to sustainable modes. The usual are the following areas: public transport, system integration, road safety, optimizing road infrastructure use, city logistics, mobility management and intelligent transport systems (ITS).

2. RESEARCH GOAL AND MOTIVATION

The goal of the suggested project is to improve the accessibility of city areas and to ensure sustainable mobility by applying, developing and evaluation appropriate strategies and measures of transport demand management.

The purpose of the project is to expand the current traffic information database, and the get the insight into travel behaviour among the participants.

The project is expected to deal with transport problems more efficiently in urban areas by developing and implementing the Sustainable Urban Mobility Plan.

3. RESEARCH ACTIVITIES

The main activities on the project include the cities of Zagreb and Sisak, encompassing the development of Sustainable urban mobility plans, improving road safety, and creating traffic databases by using technology and human resources to collect the relevant data.

3.1 Constructing geo-referenced public transport networks in the cities of Zagreb and Sisak

The public transport network in the mentioned cities can be divided into three large groups: nodes, links, and public transport stops. The data consisting all these elements were provided mostly by using public transport network schemes with the lists of every public transport stop, real-time geo-spatial data, and the knowledge by the local experts among the project team members. The *QGIS* software was used for network construction on the digital map on the official websites. To calculate several network elements, the *MS Excel* software was also used.

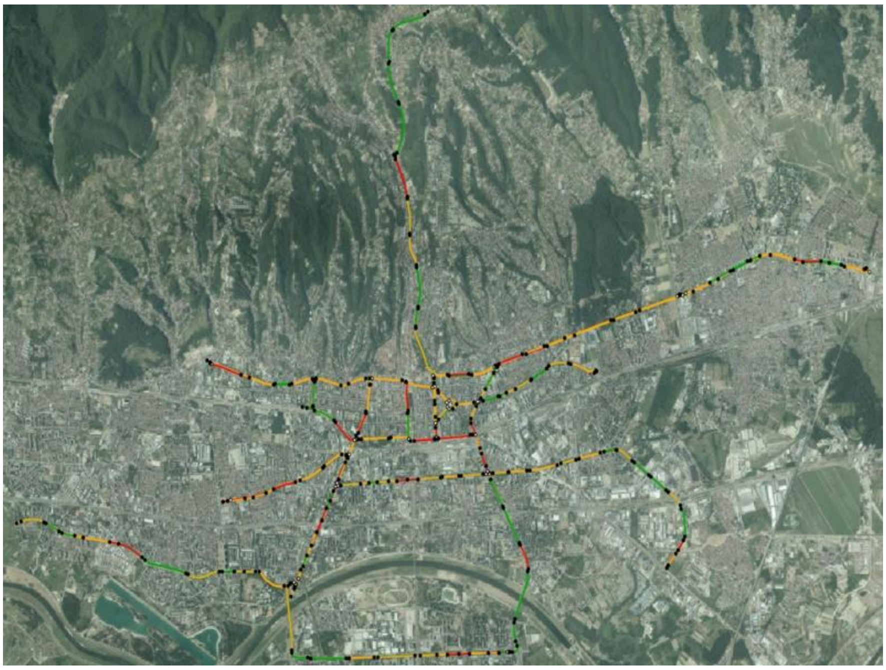

Figure 1 – An example of a geo-referenced public transport network - Zagreb

3.2 Data collection using GPS data loggers

To get the dynamic characteristic of vehicles in transport networks, the data was collected using GPS data loggers SEEWORLD GT40FL. If the desired route was wanted to be obtained in public transport, the data loggers were attached onto the driver console in public transport vehicles (Figure 2) to get the best possible signal reception, while drawing the route in the middle of a road lane. On the other hand, if the route was used to get the information about individual trips and their characteristics (for each segment of the trip), the data loggers were then simply carried by the participants. After the data collection, using the *CanWay* and *Google Earth* software, the data was processed manually to be input into the geo-referenced software.

Figure 2 – The location of GPS data loggers in public transport vehicles

3.3 Data collection using traffic counters and manual traffic counting

In the City of Sisak, a large-scale traffic counting was conducted to get the current traffic flow state for every mode of transport – motor, bicycle and walking. Since the resources for automatic traffic counting were limited by time, costs and quantity, the other traffic counting (mostly in city centre) had to be done by manual counting – entirely for bicycle and pedestrian traffic, and partially for motor transport as well.

3.4 Developing a Sustainable Urban Mobility Plan for the City of Sisak

Since in 2015 the City of Sisak was granted a loan to procure new buses aimed to operate at least until 2030, the city had to develop a sustainable urban mobility plan, covering ever mode of transport, and with time horizons 2017, 2020, and 2030 by the Public Service Contract. The plan included improving the public transport service, constructing a pedestrian and bicycle zone in the city centre, reorganizing delivery traffic, improving road safety, constructing new road infrastructure, and road network reconstruction.

3.5 Improving road safety in the school zones

Using the input data regarding children fatalities in the City of Zagreb, an accident blackspot network was created to investigate the elementary schools with most road accidents involving casualties. In those schools, education for children (any age) was conducted, emphasizing the importance of good behaviour in traffic, and factors influencing pedestrians, cyclists and drivers that can result in accidents with severe consequences. For the purpose of showing the most critical situations in traffic for schoolchildren, *PTV Vissim* tool was used for visualization. To create solutions eliminating accident blackspots, *AutoCad* was implemented for road reconstructions. This activity has a goal to raise road safety awareness for both for children pedestrian and drivers.

4. BUDGET SPENDING

This section describing summary of how the budget for the project was planned and spent during the two project years.

Most of the cost is planned and spent for traveling to emerging consortium meetings. The consultants for preparing the projects were not taken, and the project team translated the applications by themselves in English.

Table 1 – Planned and realized activities with budget overview

Nr.	Planned activity	Planned budget (kn)	Achieved	Cost (kn)
1.	Engagement of consultants	2.000,00	NO	
2.	Translation of project applications in English	9.000,00	NO	
3.	Traveling to emerging consortium meetings	19.000,00	YES	Meeting in Wiesbaden at University of Applied Science - Cost for travel and stay for Marko Slavulj and Dino Šojat 11.500,00

5. RESULTS

Results during the two project years are described into five subsections related to involvement of students (including PhD students), cooperation with industry and academia (domestic and foreign), submitted project applications, obtained additional project and funds, and finish with a list of published papers.

5.1 Involvement of students

During the project students were actively involved in data collection and data processing on project: Sisak Urban Transport – Sustainable Urban Mobility Planning, Evaluating the effects of sustainable transport measures and strategies in cities and Mobility Indicators in the Smart City Concept. Data collected during this research project was used for seven undergraduate, five graduate and one PhD thesis.

List of undergraduate, graduate and PhD thesis:

- Gabrić, Tin Filip: Analysis of Urban Mobility Trends, master thesis, Faculty of Transport and Traffic Sciences, 27.09.2017.
- Govorčinović, Domagoj. Delivery Traffic Management by Bicycles in Urban Centres, master thesis, Faculty of Transport and Traffic Sciences, 28.09.2017.
- Birin, Ivana: Implementation of Electric Vehicles in Urban Transport, bachelor thesis. Faculty of Transport and Traffic Sciences, 12.09.2017.
- Hanžek, Domagoj: Development Possibilities of Zagreb Coach Station, master thesis, Faculty of Transport and Traffic Sciences, 29.08.2017.
- Oštrina, Danijel: Tariffs in public transport, bachelor thesis. Faculty of Transport and Traffic Sciences, 07.03. 2017.
- Bator, Ivan: Integrated passenger transport, master thesis, Faculty of Transport and Traffic Sciences, 27.09.2016.
- Čižmešija, Kristijan: Application of Geographic Information Systems in Public Transport, bachelor thesis. Faculty of Transport and Traffic Sciences, 13.09.2016.
- Oršić, Dario: Comparison of Transport Modes with Regard to Energy Consumption and Environmental Pollution, bachelor thesis. Faculty of Transport and Traffic Sciences, 01.03.2016.

- Puljić, Drago: Role of Metro System in Urban Transport, bachelor thesis. Faculty of Transport and Traffic Sciences, 13.09.2016.
- Radulović, Božo: Sustainable urban mobility plans, master thesis, Faculty of Transport and Traffic Sciences, 27.09.2016.
- Sikirić, Matija: Quality of service in public transport, bachelor thesis. Faculty of Transport and Traffic Sciences, 13.09.2016.
- Budimir, Damir: Mobile Sensor-Based Estimation Method of Spatio-Temporal Indicators in Public Urban Transportation, doctoral thesis. Faculty of Transport and Traffic Sciences, 09.03.2016.
- Švajda, Marko: Personal Rapid Transit, bachelor thesis. Faculty of Transport and Traffic Sciences, 01.03.2016.

5.2 Cooperation with industry and academia

Cooperation is established with domestic and foreign industry and academia. Invited lectures are held by project leader Marko Slavulj, Ph.D. at University of Applied Sciences in Wiesbaden (Germany), and three students will write master thesis within ERASMUS+ in summer semester 2017/2018. List of institution:

- City of Zagreb
- City of Sisak
- City of Samobor
- City of Velika Gorica
- Civinet Network Croatia-Slovenia-SEE
- Zagreb Public Transport Authority (ZET)
- Sisak Public Transport Authority (Autopromet Sisak)
- School of road traffic, Zagreb
- Ministry of the Interior (MUP)
- NGO Udruga gradova
- NGO Sigurnost u prometu
- University of Applied Sciences in Wiesbaden

5.3 Project applications

Through the support of PROM-PRO, the research group apply for a funding of 10 projects. Funding scheme, project name, budget and status are shown in Table 2.

Table 2 – Overview of submitted project proposals

No.	Funding scheme	Project name	Budget	Status
1.	University of Zagreb	Evaluating the effects of sustainable transport measures and strategies in cities	15.000,00 HRK	Approved
2.	European Bank for Reconstruction and Developing	Sisak Urban Transport – Sustainable Urban Mobility Planning	170.000,00 EUR	Approved
3.	Horizon 2020, Smart, green and integrated transport, MG-8-4-2017 & MG-8-5-2017	Shifting from car ownership to sharing - SCORING	1.839.495,00 EUR	Rejected
4.	National Road Safety Programme 2011-2020	Children Road Safety at School Zones	400.000,00 HRK	Approved
5.	University of Zagreb	Mobility Indicators in the Smart City Concept	15.000,00 HRK	Approved
6.	National Road Safety Programme 2011-2020	Notice Me	600.000,00 HRK	Waiting for results

No.	Funding scheme	Project name	Budget	Status
7.	Interreg Europe 3rd call	Sustainable and Accessible Mobility in the Tourist destinations of excellence	185.000,00 EUR	Waiting for results
8.	Urban innovative actions 2nd call	VG Mobile	290.000,00 EUR	Rejected
9.	European Bank for Reconstruction and Developing	Pula Sustainable Urban Mobliliy Plan	180.000,00 EUR	Waiting for results
10.	City of Zagreb, Department of Strategic Planning and City Development	Traffic study of the area within the railway, Marin Držić Avenue, Vukovarska Street and Savska Street	198.000,00 HRK	Approved

5.4 Obtained additional projects and funds

Description of During the two years of project, five project proposals are accepted. Accepted projects are shown in Table 3.

Table 3 – Overview of submitted project proposals

Nr.	Funding scheme	Name of project or grant	Short description	Budget
1.	University of Zagreb	Evaluating the effects of sustainable transport measures and strategies in cities	15.000,00 HRK	Approved
2.	European Bank for Reconstruction and Developing	Sisak Urban Transport – Sustainable Urban Mobility Planning	170.000,00 EUR	Approved
3.	National Road Safety Programme 2011-202	Children Road Safety at School Zones	400.000,00 HRK	Approved
4.	University of Zagreb	Mobility Indicators in the Smart City Concept	15.000,00 HRK	Approved
5.	City of Zagreb, Department of Strategic Planning and City Development	Traffic study of the area within the railway, Marin Držić Avenue, Vukovarska Street and Savska Street	198.000,00 HRK	Approved

5.5 Published papers

Members of project team published papers in journals and presented on conference and round tables. List of published papers [1-7]:

- Brčić, D., Slavulj, M., Šojat, D., Jurak, J.: The role of public transport in sustainable urban mobility plans, Smart Mobility – Synergy Between Sustainable Mobility and New Technologies, University of Novi Sad Faculty of Technical Sciences Department of Traffic Engineering, 2017.
- Šojat, D Brčić, D., Slavulj, M.: Analysis of public transport service improvements on tram network in the City of Zagreb, Izvorni znanstveni članak, Tehnički vjesnik, Vol.24 No.1 Veljača 2017., DOI: 10.17559/TV-20151123143049
- Šimunović, Lj., Šojat, D., Krijan, I.: Carsharing - using instead of owning. Keeping up with technologies in the context of urban and rural synergy, Arhitektonski fakultet Univerziteta u Sarajevu, 2017.
- Šolman, S., Štefančić, G., Slavulj, M.: Restructuring Models for Road Traffic Inspections in Republic of Croatia, Prethodno priopćenje, Tehnički vjesnik, Vol. 24 (2017) No. 6 Prosinac 2017., DOI: 10.17559/TV-20150626120344
- Brčić, D., Šoštarić, M., Šojat, D: Sustainable Urban Mobility Plans // Road and Rail Infrastucture IV, Proceedings of the Conference CETRA, Šibenik 2016.

- Slavulj, M., Kanižaj, K., Đurđević, S.: The Evolution of Urban Transport – Uber, Road and Rail Infrastructure IV. Proceedings of the Conference CETRA, Šibenik 2016.
- Slavulj, M., Brčić, D., Lisicin, G D., Jurak, J: European Night without Accident - Situation in Croatia. Road safety in local community. Academy of Criminalistic and Police Studies, Vrnjačka Banja 2016.

6. CONCLUSION AND FUTURE WORK

The challenges facing urban transport in European Union and the Republic of Croatia are becoming more serious. Urban areas are facing almost everyday congestion and other transport issues. By implementing Sustainable Urban Mobility Plans, several cities in the European Union were significantly able to solve traffic problems and improve the quality of life.

The research conducted in the countries of the European Union showed that 87 % of participants consider poor coordination between city authorities and the other participants involved into urban mobility planning as the key factor. Most participants (91 %) agrees that the integration of urban planning is a useful tool for promoting cooperation on the local and the regional level.among the participants, 86 % consider that EU support will contribute to promoting Sustainable Urban Mobility Plans in the future. The research on priorities between mobility topics in the Plans resulted with a conclusion in which two subjects have priority – non-motorized transport (pedestrian, cycling) and public transport [9].

The research group plans to continue future work on developing Sustainable urban mobility plans with focusing on measures involving public transport and mobility management for large institutions. Also, the establishment of a new Laboratory for Urban Mobility within the Department of Urban Transport is in the plan.

REFERENCES

[1] Brčić, D., Slavulj, M., Šojat, D., Jurak, J.: The role of public transport in sustainable urban mobility plans, Smart Mobility – Synergy Between Sustainable Mobility and New Technologies, University of Novi Sad Faculty of Technical Sciences Department of Traffic Engineering, Novi Sad, 2017.

[2] Šojat, D Brčić, D., Slavulj, M.: Analysis of public transport service improvements on tram network in the City of Zagreb, Izvorni znanstveni članak, Tehnički vjesnik, Vol.24 No.1 Veljača 2017., DOI: 10.17559/TV-20151123143049

[3] Šimunović, Lj., Šojat, D., Krijan, I.: Carsharing - using instead of owning. Keeping up with technologies in the context of urban and rural synergy, Arhitektonski fakultet Univerziteta u Sarajevu, Sarajevo, 2017.

[4] Šolman, S., Štefančić, G., Slavulj, M.: Restructuring Models for Road Traffic Inspections in Republic of Croatia, Prethodno priopćenje, Tehnički vjesnik, Vol. 24 (2017) No. 6 Prosinac 2017., DOI: 10.17559/TV-20150626120344

[5] Brčić, D., Šoštarić, M., Šojat, D: Sustainable Urban Mobility Plans // Road and Rail Infrastucture IV, Proceedings of the Conference CETRA, Šibenik, 2016.

[6] Slavulj, M., Kanižaj, K., Đurđević, S.: The Evolution of Urban Transport - Uber // Road and Rail Infrastructure IV. University of Zagreb, Šibenik, 2016.

[7] Slavulj, M., Brčić, D., Lisicin, G D., Jurak, J: European Night without Accident - Situation in Croatia. Road safety in local community. Academy of Criminalistic and Police Studies, Vrnjačka Banja, 2016.

[8] "SUMP Challenges." [Online]. Available: http://www.sump-challenges.eu/. [Accessed: 10-Jul-2015].

[9] “Final report, Result of the public consultation ‘The urban dimension of the EU transport policy’, European commision DG MOVE, April 2013.”

[10] Wefering F., Rupprecht, S., Bührmann, S., Böhler-Baedeker S.: “Developing and implementing a sustainable urban mobility plan,” 2013.

[11] “Action Plan on urban mobility [COM(2009) 490].” [Online]. Available: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52009DC0490&from=EN. [Accessed: 06-Jul-2015].

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THE USE OF UNMANNED AERIAL VEHICLES IN THE TRAFFIC INCIDENT MANAGEMENT

ABSTRACT

General purpose of the project "The Use of Unmanned Aerial Vehicles (UAV) in the Traffic Incident Management" was the expansion of the Faculty of Transport and Traffic Sciences research profile in the field of the use of unmanned aerial vehicles in ITS, namely traffic control systems and incident situations management. The research focused on the establishment of a research group, strengthening competencies in the field of unmanned aerial vehicles in the ITS area, networking with similar research groups in Croatia and the EU, and the preparation of the H2020 project. The conducted research has resulted in preliminary concepts of more efficient way of managing incidents in traffic by using unmanned aerial vehicles. In this particular case, an innovative concept was proposed to improve the process of 3D modeling traffic accidents.

KEYWORDS:

unmanned aerial vehicles; traffic incident management; 3D modelling.

1. INTRODUCTION

In this project, we investigate the feasibility of using an Unmanned Aerial Vehicles (UAV) to improve traffic incident management. UAVs can cover a large area in traffic network. They can travel at higher speeds than ground vehicles and they are not restricted to traveling on the road network. Specific objectives of this project were the use of unmanned aerial vehicles in various areas of intelligent transport systems.

The focus of the research was on finding a more efficient way of managing traffic incidents by using unmanned aerial vehicles, and to find ways for extending existing ITS applications, such as eCall and so on, to innovative functionalities.

2. RESEARCH GOAL AND MOTIVATION

This research is motivated by the Strategic Program of Scientific Research at the Faculty of Traffic Sciences for the period from 2015 to 2020. Research in the field of unmanned aerial vehicles in the management of incident traffic situations contribute to the Strategic Goal 3 of the FPZ Development Strategy for the period 2012-2017, i.e. expanding the Faculty of Transport and Traffic Sciences research profile in the field of application of new technologies in ITS. Also, this research has promoted FPZ's scientific-research and innovation activities. This project also contributes to Measure 2.9 of the above-mentioned strategy in terms of increasing the specialization of ITS laboratories to increase the quality of teaching in the Case Management of incidents in traffic.

This research has a significant impact on the establishment of research teams at the Faculty of Transport and Traffic Sciences. Two researchers and one doctorate from the Faculty of Transport and Traffic Sciences were involved. During the project implementation, researchers joined scientists with related institutions and formed a joint research group that participated in joint applications of the most demanding European research projects. These project activities are in line with Measure 4 (Foster Research and Innovation) and Measures 7. (Develop a Mobility and International Co-operation Promotion Program) Faculty of Transport and Traffic Sciences Development Strategy for the period 2012-2017.

3. RESEARCH ACTIVITIES

Asst. Prof. Pero Škorput, as the team leader, was in charge of project management and administration, procurement of equipment and coordination activities for the purpose of forming a research team, initiated and organized networking activities with potential partners, ie activities aimed at raising the competences of the research team. He was also in charge of coordinating and developing project proposals with the rest of the research team.

Full. Prof. Sadko Mandžuka has an active mentoring role in the preparation of project proposals, and as a collaborator in a team with the greatest research experience, has conducted a continuous evaluation of project elements.

Ph.D. Candidate Hrvoje Vojvodić, mag. ing. traff., as an associate in the team and a young researcher, he was in charge of enhancing competencies in the area of cooperative communication between existing ITS systems and unmanned aviation systems and the development of software support on the SDK platform of unmanned aerial vehicles. In addition to the project mentioned above, he participated in the elaboration and presentation of scientific work.

Assoc. Prof. Markus Schatten from the Faculty of Organization and Informatics as an associate in the team, he was in charge of analyzing software support on the SDK platform of the unmanned aircraft system and the preparation and implementation of project proposals.

Asst. Prof. Ivana Nižetić Kosović from the Faculty of Electrical Engineering and Computing as associate in the team, she was in charge of the analysis of program support and the preparation and implementation of project proposals.

Research and Innovation Activities at the Project The use of unmanned aerial vehicles in incident traffic management was aimed at improving the investigation of traffic accidents by using unmanned aerial vehicles.

Traffic accident scenarios are traffic and technical-technological processes that basically contain two mutually opposing demands. The first requirement relates to the need for a shorter time to clear the traffic accident site to prevent secondary accidents, and for the route returning to its full operational capacity for traffic and for fully normalization of the traffic flow. The second request relates to the conduct of an investigation as an investigative measure whose purpose is to establish the existence or non-existence of elements of a criminal offense of causing a traffic accident or a traffic offense. Obtaining an eyewitness today is a time-dependent process that requires a relatively long period of time to gather evidence, perform necessary measurements, describe traces, and so on.

This project has created a DEMO system that allows the creation of 3D models of a traffic accident scene. Using innovative technologies, such as the development of three-dimensional (3D) computer models of a real-world traffic accident with the help of unmanned aerial vehicles and photogrammetric procedures, can significantly shorten the time needed to investigate a traffic accident while increasing the quality and quantity of evidence, measurements and etc.,

In addition, the data collected in this way are significantly better and have wider possibilities for further processing in terms of digitization of the process of investigation.

Figure 1 – 3D computer model of a traffic accident

On Figure 1., a computer 3D model is shown of a traffic accident site, that was developed during this research.

Bodies conducting traffic accident investigations such as the police and the judiciary, as well as criminal-technical, traffic and other professionals face daily demands on how to normalize traffic in the shortest possible time, as well as provide enough time for a complete process of investigation.

The basic requirement or request relates to the shortest time to clear the locations of traffic accidents, preventing secondary accidents, and for returning the traffic to the full profile and normalization of traffic profile. Equally important is the application of the evidence as an investigative measure whose purpose is to establish the existence or absence of elements of a criminal offense of causing a traffic accident or a traffic offense. The implementation of an eyewitness is a time dependent process that requires a relatively long period of time to gather evidence, perform necessary measurements, describe traces, etc.

The above-mentioned needs are substantively contradictory because the competent bodies need to conduct the investigations as soon as possible for returning traffic to full profile, while for good quality eye investigation it is necessary to provide enough time.

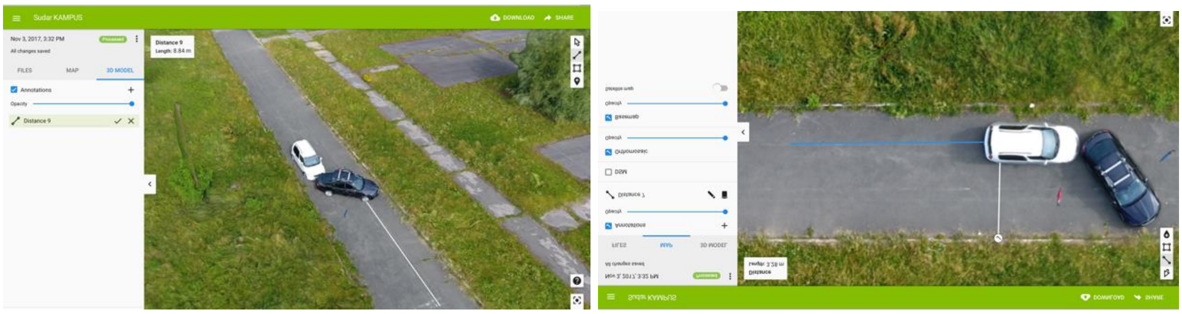

Figure 2 – Performed measurement of traffic accident on computer 3D and Ortofoto model

This project has proposed the use of innovative support technologies to investigate traffic accidents that enable significantly higher quality observation in a significantly shorter period of time. Innovative technologies include georeferenced documentation of the complete site of events in the form of a three-dimensional cloud of points from which it is possible to measure the traces, position and distance of vehicles and objects mutually, and in relation to the geometry of the roadway, as shown in Figure 2.

4. BUDGET SPENDING

This section describing summary of how the budget for the project was spent during the two project years. Most of the cost is spent for increase the specialization of ITS laboratories and increase the quality of teaching from the course of Traffic incidents management.

Table 1 – Planned and realized activities with budget overview

Nr.	Planned activity	Planned budget (kn)	Achieved	Cost (kn)
1.	Unmanned aircraft Mavic PRO	12.000,00	YES	12.000,00
2.	VR Glasses DJI Goggles	5.000.00	YES	5.000.00
3.	Camera GoPro HERO 5	3.000,00	YES	3.000,00
4.	Other small equipment	4,000.00	YES	4,000.00
5.	Traveling to emerging consortium meetings	6.000,00	YES	6.000,00

During this project, valuable research equipment was acquired that increased the specialization of the ITS Laboratory. The equipment will be used to complete the teaching and preparation of final and postgraduate studies in the course of Traffic Incident Management.

5. RESULTS

This project has expanded the research profile of the FPZ in the field of the use of unmanned aerial vehicles in ITS.

5.1 Establishment of research group and networking

With this project, a research group has been successfully established. The research group consists of teachers in scientific and teaching profession Asst. Prof. Pero Škorput and Full. Prof. Sadko Mandžuka. In the research group, a Ph. D. Candidate was also successfully involved. The research group was established on the principles of multidisciplinary research so that researchers from different faculties are involved in the research team. Assoc. Prof. Markus Schatten works at the Faculty of Organization and Informatics and researches in the field of application of semantic technologies, while Asst. Prof. Ivana Nižetić Kosović works at the Faculty of Electrical Engineering and Computing in Zagreb and researches in field of software core computing sciences.

During the project, the research team successfully networked with the international research group consisting of representatives of twelve institutions:

- Universiteit Hasselt, Belgium
- Abeonaconsult (Bvba), Belgium
- Universite de Technologie de Belfort – Montbeliard, France
- University of Zagreb, Faculty of Electrical Engineering and Computing, Croatia
- University of Zagreb, Faculty of Traffic and Transport Science, Croatia
- University of Novi Sad, Faculty of Technical Science, Serbia
- Unabhaengiges landeszentrum fuer datenschutz, Germany
- Teamnet world professional services SRL, Romania
- Velocity RDT Limited, England
- Ben-Gurion University of the negev, Israel
- Tel Aviv University, Israel
- Instituto pedro nunes, Associacao para a inovacao e desenvolvimento em Ciencia e Tecnologi, Portugal

As a result of networking, this broader research group has participated in the application of H2020 projects, which are described in detail in Section 5.2.

5.2 Application of H2020 projects and other projects

Project 1: CityFLY – H2020 project - Research group within project-targeted activities ”The use of unmanned aerial vehicles for incident traffic situations” has prepared the application for the H2020 project (**Horizon 2020 Call: H2020-MG-2016-2017** (2016-2017 Mobility for Growth), **SECOND STAGE, Topic: MG-1.4-2016-2017 Type of action: RIA** (Research and Innovation action), **Proposal number: 723092-2, Proposal acronym: CityFly,** Deadline Id: H2020-MG-2016-Two-Stages) on the topic Smart CITY’s Traffic Control Infrastructure for Societies of FLYing Vehicle – CityFly. The goal of CityFly is to identify and assess the effects and risks brought by the widespread use of unmanned aerial vehicles (UAV) in the airspaces of future Smart Cities. CityFly will develop an intelligent infrastructure for supporting multiple numbers of UAVs, a framework for governing their behaviour in aerial traffic and thoroughly investigate and provide the supporting data of the societal and environmental impacts of UAV traffic in Smart Cities. The primary motivation is the lack of holistic aviation regulations of 3D spaces of up to 300 meters across Europe. Unchallenged, this could cause numerous problems once numbers of UAVs flying in the airspaces of Smart Cities reaches a critical number. CityFly will analyze the behavior and impact of societies of flying vehicles (SoFV) via simulation and smaller-scale of field based tests in controlled environments.

In order to achieve its goals CityFly will focus on:

- an intelligent infrastructure for UAVs to establish self-awareness and environment-awareness abilities, taking into consideration the semantics of surrounding static and dynamic spatial and environmental elements and their relationships;
- a framework consisting of a proposed set of aviation protocols, policies and rules governing the 3D urban airspaces below 300 meters;

- investigating the societal and environmental impacts of UAV traffic via agent-based simulations, immersive gaming environments, smaller-scale field-based experiments with real UAV and infrastructure, and finally real deployment in controlled environments in the pilot cities.

Project 2: Development of Low-altitude Airspace Surveillance System Based on The UAV Platform – project application of scientific and technological cooperation with NR China - This project will develop technologies for discovering and tracking low altitude aircrafts based on high altitude monitoring UAV. The main goal of cooperation is to investigate the existing low altitude aircraft sensors and transmission technology, build up a "Signal Processing Software" system which is based on the hardware of low cost sensors and existing UAV platform. With the help of the existing UAV platform in the specific complex urban terrain, monitoring and identifying low altitude aircrafts accurately, attempting to build a small range of air traffic control system, providing a persistent, wide-area surveillance protect service.

Project 3: Application of Innovative Support Technologies for Traffic Accident Investigation - Report on the Project on Road Safety in the Republic of Croatia for 2018 - This project aims to develop a new methodology and prototype of a system for detecting traffic accidents based on unmanned aerial vehicles and software tools for 3D modeling, and the development of an appropriate program interface for other reconstruction tools and expert analysis of the traffic accident dynamics. Determine the methodological basis for the application of unmanned aerial vehicles, photogrammetric techniques and modern tools for the development of three-dimensional computer models in the process of detecting traffic accidents. Determining measurable indicators of the quality and quantity of the evidence gathered and shortening the duration of the investigation.

5.4 Published papers

Members of project team published papers in journals and presented on conference: List of published papers [1-3]:

[1] P. Skorput, S. Mandzuka, and H. Vojvodic, "The use of Unmanned Aerial Vehicles for forest fire monitoring," in ELMAR, 2016 International Symposium, 2016, pp. 93-96.

[2] Z. Kljaić, P. Škorput, and N. Amin, "The challenge of cellular cooperative ITS services based on 5G communications technology," in Information and Communication Technology, Electronics and Microelectronics (MIPRO), 2016 39th International Convention on, 2016, pp. 587-594.

[3] M. Schatten, "Multi-agent based Traffic Control of Autonomous Unmanned Aerial Vehicles," Researchgate, Researchgate.net, 2015.

6. CONCLUSION AND FUTURE WORK

With the PROM-PRO project, the use of unmanned aerial vehicles in incident traffic management has expanded the Faculty of Transport and Traffic Sciences research profile in the area of unmanned aviation systems in ITS, traffic control systems and incident situations management. A research group has been set up and competences have been strengthened in the field of unmanned aerial vehicles in the ITS area. Also, with this project, the research group from the Faculty of Transport Sciences has networked with similar research groups in Croatia and prepared the H2020 application in two cycles.

The conducted research has resulted in preliminary concepts of more efficient way of managing incidents in traffic by using unmanned aerial vehicles. In this particular case, an innovative concept was proposed to improve the process of managing traffic accidents.

The proposed concept of improvement of the traffic accident investigation process has a significant research potential in terms of configuring the prototype system, designing interfaces according to the tools of expertise, establishing a methodological basis for the application of unmanned aerial vehicles, photogrammetric techniques, and applying modern tools to produce three-dimensional computer models in traffic accident investigation processes.

REFERENCES

[1] P. Skorput, S. Mandzuka, and H. Vojvodic, "The use of Unmanned Aerial Vehicles for forest fire monitoring," in ELMAR, 2016 International Symposium, 2016, pp. 93-96.

[2] Z. Kljaić, P. Škorput, and N. Amin, "The challenge of cellular cooperative ITS services based on 5G communications technology," in Information and Communication Technology, Electronics and Microelectronics (MIPRO), 2016 39th International Convention on, 2016, pp. 587-594.

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THE IMPACT OF ADVANCED URBAN TRAFFIC CONTROL ON ENERGY EFFICIENCY

ABSTRACT

In urban areas one of the most important causes of pollution (that directly affects climate changes and air quality) is traffic, considering that almost 50% of delays are produced on signalized intersections. Modern methods for the reduction of the exhaust emission are focused on advanced traffic control in order to decrease travel times and the number of stop-and-go actions. In this research, the application of adaptive traffic control on signalized intersections is considered and a simulation model of demonstration corridor in the city of Zagreb was made (with real traffic data implemented in the model). The main goal of this research is to demonstrate the significance of adaptive traffic control on the road vehicles energy efficiency. The algorithms used to address optimization in harmonization and increasing of traffic flow was made. This method outperforms traditional fixed cycle management of intersections, which use predetermined green time split. The case study illustrates the benefits of using adaptive control algorithm, which controls green time splits on demand. The impact of adaptive traffic control is measured on two scenarios – fixed control and adaptive control and their comparison on a signalized grid of seven intersections. Within this research several benefits were achieved: the reduction of CO2 emission by 2,302%, for NOX it is 3,283% and for PM10 it is 1,32% regarding personal vehicles (PV), while for heavy duty vehicles(HDV) the reduction CO2 emission is 3,02%, for NOX it is 2,982% and for PM it is 0,75%. It should be noted that these results are based on a one hour simulation, so by observing a longer period of time, the reductions are multiplied.

KEYWORDS:

emission reduction; advanced intelligent traffic control; intelligent transport systems; vehicle actuated control.

1. INTRODUCTION

Constant increase of the number of vehicles in urban traffic network directly affects overall traffic quality because of the infrastructure limitations. Frequent congestions in the cities cause the increase of delays, stop-and-go actions and travel times especially, so the overall life quality in cities is decreasing. International Energy Agency (IEA) is estimating that by 2050. more than 50% of spent fuel will be caused by traffic and transport [1]. European Environment Agency (EEA) has determined that traffic in urban areas causes 40% of CO2 emission and over 70% of other exhaust emission [2]. It is necessary to influence on traffic system quality increase (especially in urban areas where the population is bigger and the consequences of traffic are increasing exponentially). Exhaust emissions have different causes; according to the paper [3], 22% of spent fuel is the consequence of ineffective acceleration and deceleration, with the lack of traffic predictions. Congestions cause 15% of exhaust emission and excessive speed, inefficient traffic control, incidents, etc. cause additional 11%.

Rational usage of time and energy means that the research must be oriented to modern traffic control strategies and technologies. The research within the eCoMove project shows a great development and progress in the mentioned area – "beyond-state-of-the-art" strategies are defined with the implementation of the cooperative systems (vehicle-to-vehicle and vehicle-to-infrastructure communication). A part of the eCoMove project was to develop a simulation model in the city of Rotterdam using PTV VISSIM and EnViVer simulation software and to prove that with speed recommendations only, major improvement of CO2 and NOX emission can be achieved [4]. Further research within the eCoMove project is presented through the "green priority strategies", where a part of the urban network was controlled by UTOPIA (Urban Traffic Optimization by Integrated Automation) software and similar results were gathered [5]. According to the authors [6], a different focus was selected – better vehicle routing in the urban traffic network can impact fuel consumption and CO2 emission. The CVIS (Cooperative Vehicle-Infrastructure Systems) project defines that the efficiency of the system is drastically increased with the number of vehicles that are equipped with the new ITS applications [7]. According to the project results [8], by the implementation of the cooperative approach and the generic algorithms, the improvements were achieved at the stop-and-go actions and the average delay decrease which is directly related to exhaust emissions. The paper [9] says that the benefits of the combination of analytical and simulation data were presented in the means of average travel time and overall fuel consumption. Simulation based optimization was used on the model of the city of Lausanne, Switzerland, and a microscopic evaluation model of fuel consumption was implemented in the Aimsun simulation software. The presented research upgrade was made by the integration of the q-learning algorithms (model-free reinforcement learning technique) in the SUMO (Simulation of Urban MObility) simulation software, where the improvements in CO2 reduction and the number of vehicles in queue length were presented [10]. With the integration of collected traffic data, PTV VISSIM micro simulation software and MOVES (MOtor Vehicle Emission Simulator), another research [11] presented the difference between a macro simulation tool (which calculates emissions according to average vehicle speed) and a micro simulation tool (which calculates emissions according to current vehicle speed and acceleration), considering the results of the exhaust emissions. The research [12] proved that the evaluation of the exhaust emissions is more accurate using second-by-second model examination because of the emission sensitivity on stop-and-go actions, acceleration/deceleration and idle engine state. The possibilities of integration of the micro simulation models with the exhaust emission models was presented in [13] where the reduction in the emission of CO2, NOX and particulate matter (PM) was achieved with the implementation of k-means and LOESS (Locally Weighted Scatterplot Smoothing) algorithms. Authors in the paper [14] presented the improvements of CO emissions and overall travel time by integrating emission model VT-micro, model predictive control (MPC) and dynamic speed limit control on a motorway model. The research [15] presented an impact of the implementation of the adaptive priority strategies on the travel time's reduction in urban areas regarding public transport.

The main purpose of this research is to explore the implementation of the advanced intelligent traffic control algorithm's benefits with a direct impact on the stop-and-go actions reduction, vehicle delay and emission of harmful gases. Research goals and motivation for such a research is presented in second chapter. In third chapter research activities are presented with the results and evaluation from simulation models (both existing situation and improved model with advanced vehicle actuated traffic control). Conclusions and further research plans are presented in the last chapter.

2. RESEARCH GOAL AND MOTIVATION

When a demonstration corridor was selected, relevant traffic data was gathered and analysed. Afternoon peak hour was taken as relevant for this research. Physical components (the number of lanes, the position of signal heads, signal plans for selected time intervals, etc.) were measured within the creation of a simulation model. After it was completed, the simulation model was calibrated according to the existing traffic situation.

The main problem in the city of Zagreb is traffic fluctuation (westbound and eastbound) in the morning and afternoon peak hours. The defined demonstration corridor is located in the west part of the arterial route which is important for connecting the west part of the city with its centre. The defined demonstration corridor with its signalized intersections is presented in the Figure 1.

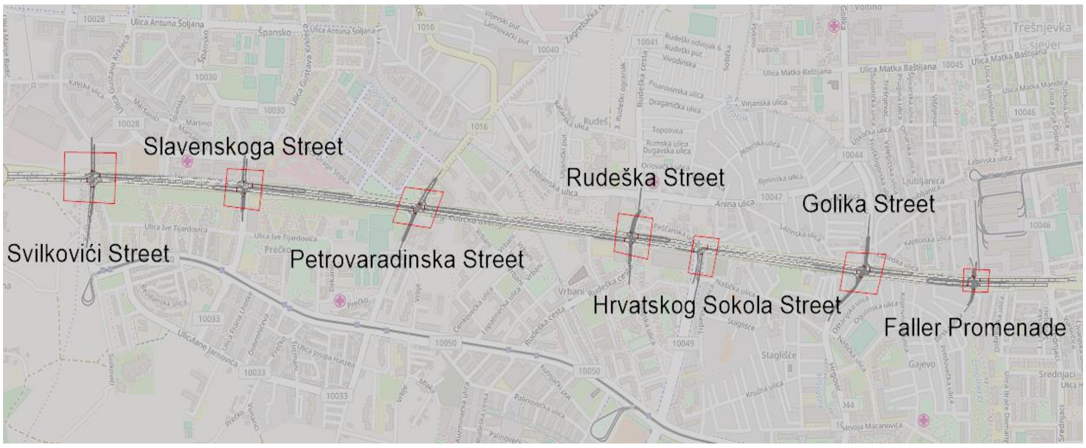

Figure 1 – Demonstration corridor: Zagrebacka Avenue in the city of Zagreb with its signalized intersections

The demonstration corridor is 3500 [m] long and is consisted of seven signalized intersections where six of them have four approaches and one of them has three approaches. The average distance between intersections is 500 [m]. The main corridor path consists of two-direction roads with three lanes in each direction. On every intersection there are separate approaches for left-turns on main corridor paths. The side approaches on every intersection are problematic regarding traffic demand, so the algorithm had to be personalized for each intersection. The existing traffic control situation has fixed signal plans. The main direction has a green-wave simulation from both sides (offset). Every intersection signal cycle is 150 [s] long, with the implemented intergreen matrix regarding pedestrians. In this research, the pedestrian flow was not generated, but it was included in the calculations.

After the collection of the traffic data, the afternoon peak hour (4 PM - 5 PM) was selected as relevant for simulation modelling because of major traffic demand. The traffic data was collected on every signalized intersection simultaneously and two major road vehicles categories were defined - personal vehicles (PV) and heavy duty vehicles (HDV). Regarding vehicle composition, personal vehicles make 95,95%, while heavy duty vehicles make 4,05%. The OD matrices were made for every intersection individually and for the entire corridor. The speed limits on the selected corridor are set to 60 [km/h].

The average CO_2 emission of 166 [g/km] for petrol engines and 158 [g/km] for diesel engines was selected as a basic parameter for emission evaluation.

Vehicle acceleration/deceleration and the correlation with speed has great impact on exhaust emission. When the vehicle is in the state of starting/braking, smoother acceleration/deceleration will produce less exhaust gases, while in the sudden acceleration/deceleration, the vehicle will produce more exhaust gases.

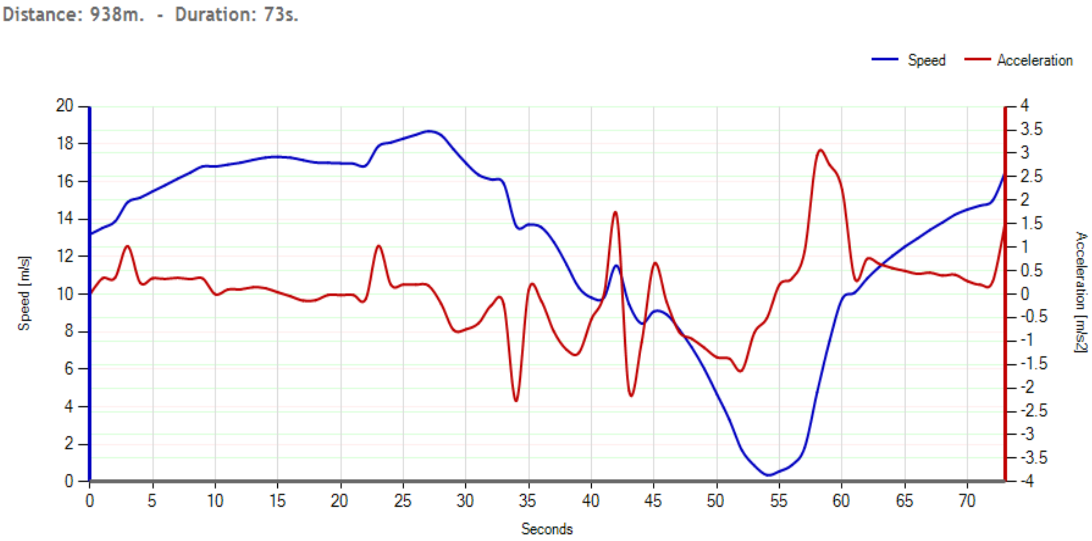

Figure 2 – Relations between the exhaust emission and vehicle acceleration/deceleration

Figure 2 presents the evaluation of the exhaust emission based on current vehicle speed, where the results are more accurate and precise than the results of macro simulated emissions that evaluate emission based on the average vehicle speed.

3. RESEARCH ACTIVITIES

This research was conducted in two cycles with overall duration of two years. That period was divided in five phases. In the first phase relevant literature was collected and analysed, hypothesis and expected scientific contribution were also defined. The second phase includes selection of demonstration corridor in the city of Zagreb. After the selection of demonstration corridor traffic data (number of vehicles, signal plans, the geometry of intersections, etc.) was collected. In this phase the evaluation parameters were defined. In the third phase the simulation model of selected corridor was made in PTV VISSIM software. Also, the calibration of simulation model was made. With this step, the simulation model of existing traffic situation was finished. The fourth phase included the definition of advanced intelligent traffic control algorithms with the goal of improvement of previously defined evaluation parameters. In the final, fifth phase, the evaluation of implemented algorithms was made, and results were presented on different conferences.

After the development of the defined demonstration corridor simulation model, the evaluation parameters were selected. The simulation was conducted ten times for each defined scenario with the random seed number increment of 1. The simulation duration was set on 4500 [s] where the data from the last 3600 [s] was collected considering 900[s] for network charging. Apart from the parameters regarding the exhaust emission, other relevant parameters that directly affect the quality of traffic system on demonstration corridor were defined. The defined parameters for the measurement of the quality of the traffic network are:

- The average queue length [veh],
- The maximum queue length [veh],

- The traffic flow [veh/h],
- The number of stops,
- The delay on the intersection/Level of Service [s].

After gathering the simulation results (regarding the exhaust emissions), the data for the existing traffic situation and the proposed adaptive traffic control were gathered. The results are presented in the Tables 1 and 2.

Table 1 – The results of the exhaust emission for the existing traffic situation

	CO_2	NO_x	PM_{10}
PV	294,4483 [g/km]	677,6785 [mg/km]	54,7952 [mg/km]
HDV	1867,5229 [g/km]	12,2948 [g/km]	273,0529 [mg/km]

Table 2 – The results of the exhaust emission for the proposed traffic situation with the implemented adaptive traffic control algorithms

	CO_2	NO_x	PM_{10}
PV	287,6693 [g/km]	655,4248 [mg/km]	54,0686 [mg/km]
HDV	1811,0881 [g/km]	11,9348 [g/km]	271,0046 [mg/km]

Tables 1 and 2 show the reduction of CO2 emission by 2,302%, for NOX it is 3,283% and for PM10 it is 1,32% regarding personal vehicles (PV), while for heavy duty vehicles(HDV) the reduction CO2 emission is 3,02%, for NOX it is 2,982% and for PM it is 0,75%. It should be noted that these results are based on a one hour simulation, so by observing a longer period of time, the reductions are multiplied.

The secondary element of the adaptive traffic control impact was the overall variation on the traffic network quality which is directly assigned to the relevant parameters defined before. The methods of data collection and the analysis are based on standard equations of TRANSYT 7-F tool for a signal program optimization [20]. The selected corridor consists of 178 links on seven signalized intersections which produce a vast amount of traffic data.

For example, the data below is presented for just one intersection (Zagrebacka Avenue – Faller Promenade). This is the first intersection of the corridor (westbound). With previously defined parameters, Tables 3 and 4 present the results of the existing traffic situation and the results of the traffic situation with the adaptive traffic control algorithms.

Table 3 – Relevant parameters on a selected intersection for the existing traffic situation

	Q-length average [veh]	Q-length max [veh]	Traffic flow [veh/h]
Link 1	6,2700	53,9523	2651
Link 2	3,4970	31,2601	90
Link 3	229,4365	384,9527	3098
Link 4	13,7685	71,4647	31
Node evaluation	31,6199	384,9572	6355

Table 4 – Relevant parameters on a selected intersection for a proposed traffic situation with the implemented adaptive control algorithms

	Q-length average [veh]	Q-length max [veh]	Traffic flow [veh/h]
Link 1	12,0206	99,7778	2730
Link 2	12,6240	56,9432	89
Link 3	53,9323	309,7049	3190
Link 4	17,3631	70,9112	32
Node evaluation	14,7319	309,7049	6534

The presented results show that the traffic flow on the main approaches has increased and the secondary approaches are unmodified. A total number of vehicles have increased by 2,884 % westbound and 2,889 % eastbound, a significant improvement considering the percentage of the oversaturation. The average Q-length (the number of vehicles in a queue) is increased on Link 2 by 9 vehicles and on Link 4 by 4 vehicles. The reason for that is a different green time distribution considering the same traffic flow on both links with fixed and adaptive control. Link 1 has increased values of average vehicles in the line by 6 vehicles, which is a slight impairment considering the increscent traffic flow. Link 3 has the best performance with a high increase of all the performance factors. Although the average number of vehicles in the queue on the secondary approaches has increased, the total traffic flow on the intersection has increased by 2,7%. The reduction of the average Q-length is 53,4% and the reduction in maximum Q-length is 19,54%, considering all links in node. The main contributor to that result is the traffic flow from link 3 which has the highest traffic flow as shown in table 4.

4. BUDGET SPENDING

Within this research, several activities were achieved, but not all as planned. In table 5 planned and achieved activities are presented.

Table 5 – Planned and realized activities with budget overview

Nr.	Planned activity	Planned budget (Kn)	Achieved	Cost (Kn)
1.	Simulation SW – TTS Aimsun, EnViVer, COOPERT 4 data	24,680,00	Free/academic versions of EnViVer and PTV VISSIM SW were used	-
2.	Paper publication	6,200,00	Three papers published – two from Faculty's own funds	4,092,84
3.	Educational activities	27,500,00	Two educational classes finished (PTV VISSIM, HORIZON2020 workshop)	11,430,00
4.	Measuring equipment	3,500,00	GoPRO HERO 4	4,583,00

5. RESULTS

As a two year period research, several results were achieved. The most important result was to build simulation model of real corridor in the city of Zagreb (Zagrebacka Avenue) and to calibrate the simulation model according to existing traffic situation. Second goal was to develop advanced intelligent control algorithms for signalized intersections in order to improve energy efficiency on urban traffic network.

5.1 Involvement of students

In research activities undergraduate, graduate and PhD students were engaged. Some of results are presented below.

- Dedic, L.: Energy efficient traffic control – Dean's award 2016./2017.
- Dedic, L.: Application of advanced telematics systems in optimization of the energy efficiency in transport, 2017. – master thesis
- Kodrnja, M.: Analysis of telematics solutions quality in the city of Zagreb, 2017. – master thesis
- Kobetic, I.: Analysis of Advanced Traffic Control Systems in Urban Areas, 2017. – bachelor thesis

5.2 Obtained additional projects and funds

Nr.	Funding	Name of project	Description
1.	University of Zagreb – support programme	The application of cooperative systems in optimization of energy efficiency in urban areas	Similar to this research with extension to cooperative systems in traffic

5.3 Published papers

- Vojvodic, H., Vujic, M., Skorput, P.: Cooperative Architecture of Data Acquisition for Emission Reduction in Traffic, Proceedings of 25th Telecommunications Forum - TELFOR 2017, Beograd: Telecommunications Society, School of Electrical Engineering, IEEE Serbia and Montenegro COM Chapter, Belgrade, Serbia, 21 -22. November 2017.
- Vujic, M., Dedic, L., Vojvodic, H.: *The Benefits of Adaptive Traffic Control for Emission Reduction in Urban Areas*, Proceedings of International Conference on Traffic Development, Logistics & Sustainable Transport – ZIRP, 1. – 2. June 2017. p. 419-428
- Vojvodic, H., Mandžuka, S., Vujic, M.: *The Use of Cooperative Intelligent Transport Systems for Vehicle Emission Charging*, Proceedings of 24th Telecommunications Forum - TELFOR 2016, Beograd: Telecommunications Society, School of Electrical Engineering, IEEE Serbia and Montenegro COM Chapter, Belgrade, Serbia, 22 -23. November 2016. (ISBN: 978-1-5090-4085-8)

6. CONCLUSION AND FUTURE WORK

A sustainable growth of traffic in urban areas is not possible without the advanced intelligent transport systems applications. The results of this research show that the impact of the adaptive traffic control affects the quality of urban traffic network, which is demonstrated through a simulation model of the selected corridor in the city of Zagreb. The corridor, consisting of several signalized intersections, has been simulated with the adaptive traffic control algorithms, which ensure green lights to dedicated groups of vehicles. The algorithm enables giving partial green times to defined groups of vehicles and with this concept, the "lost" green times are minimized. The calculated signal cycle enables a partial green wave concept through an offset but the oversaturation of the corridor increases fuel consumption, overall delays, queue lengths, etc. With adaptive management improvement was made, and traffic flow was increased with minimization of stop-and- go action and total Q-length which resulted in emission reduction up to 3,28%. The future research is focused on the upgrade of the existing algorithms with the intelligent systems that develop their own knowledge according to the previously gathered data and decisions.

REFERENCES

[1] IEA Tehnology roadmap. Fuel economy of road vehicles. Tehnical report, Internacional Energy Agency, Paris, 2012.
[2] European Commission, "Green paper-Torwards a new culture for urban mobility," COM(2007) final, Brussels, 2007.
[3] eCoMove Consortium, "eCoMove-Description of Work", Brussels, Belgium, 2010.
[4] Vreeswijk JD, Mahmod MKM, van Arem B, "Energy Efficient Traffic Manegement and Control-the eCoMove Approach and Expected Benefits"
[5] Turksma S, Vreeswijk, "Fuel Efficiency in cooperative network control systems" in Proceedings of the 14th ITS World Congress, New York, 2008.
[6] Ahn R, Rakha H, "The effects of route choice decision on vehicle energy consumption abd emission, "Transportation Research Part D: Transport and Environment, vol.13, pp. 151-167, 2008.
[7] Leistner D, "Impact of cooperative systems", University of Dresden, Germany, 2009.
[8] Uffmann A, Friedrich B,"Online optimization within cooperative systems in urban road networks" in
[9] Osorio C, Nanduri K, (2015) Energy-Efficient Urban Traffic Manegemant: A Microscopic Simulation-Based Approach. Transportation Science 49(3)637-651. http:// dx.doi.org/ 10.1287/ trsc.2014.0554
[10] M. Stevens and C. Yeh. Reinforcement learning for traffic optimization. Technical report, Stanford University, 2016.
[11] Den Braven KR, Abdel-Rahim A, Henrickson K, Battles A, "Modeling vehicle fuel consumption and emissions at signalized intersection approaches: integrating field-collected data into microscopic simulation", final report, National Institute for Advanced Transportation Tehnology, University of Idaho, 2012.
[12] Abdu-Senna H, Radwan E, Westerlund K, Cooper CD. "Using a traffic simulation model (VISSIM) with an emission model (MOVES) to predict emissions from vehicles on a limited-acces highway, Journal of the Air & Wastw Managemant Association, 63:7, 819-831, DOI:10.10080/10962247.2013.795918, 2013.
[13] Chamberlin R, Swanson B, Talbot E, Dumont J, Pesci S, "Measuring the Emissions Impact of a Traffic Control Change" University of New Hampshire, 2011.
[14] Zegeye S.K., De Schutter B., Hellendoorn J., Breunesse e.A., "Model-based traffic control for the reduction of fuel consumption, emission, and travel times," Proceedings of mobil.Tum 2009 – international Scientific Conference on Mobility and Transport, Munich, Germany, 11, pp., May 2009.
[15] Vujić M., Šemanjski I., Vidan P., "Improving Energy Efficiency by Advanced Traffic Control System" Transaction on maritime science Trans.marit.sci. 2015; 02:119-126