University of Zagreb
Faculty of Transport and Traffic Sciences

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Programming period 2015 – 2017

Proceedings of the technical reports

Zagreb, 2017

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FOREWORD

Science and research in all areas is oriented towards research groups and networks. Education, research and innovation are characterised by a strong flow of knowledge, introduction of research results and innovation practice into education, strong partnerships and intellectual property management. New ideas and knowledge, new processes, products and services, and new entrepreneurship are the ingredients of investigative creativity. In the service of a research-oriented university, the Faculty of Transport and Traffic Sciences intends to take special care of its students as potential researchers. This is especially important for postgraduate students who should have the opportunity to do research as a part of a project. However, research should be equally introduced at the graduate level where learning should be oriented towards research (as a function of the paradigm shift from learning after research to learning through research).

Faculty of Transport and Traffic Sciences established in 2014 a strategic framework in order to improve the quality of research activities and increase productivity in the field of traffic and transportation engineering. The purpose of the strategic framework is to create all necessary conditions for the development of the knowledge triangle at the Faculty, according to the following goals: establish a system for active participation in collection, processing, interpretation and publication of statistical and other indicators of research, development and innovation; encourage and evaluate the work of researchers and the establishment of research groups; encourage cooperation in research, development and innovation; develop e-infrastructure in order to facilitate research and education activity; plan research investments, and active participation in smart specialisation processes.

Critical segment of the framework is the Program for stimulation of research and innovation at the Faculty of Transport and Traffic Sciences. The goal of the Program is to encourage the development and innovative character of scientific activities at the Faculty. The program's emphasis on the outcomes of scientific research (impact of scientific activities on certain segments of society and the economy), and the outputs in the form of research results.

After only two years of active implementation of the Program, it is our pleasure that we can present general results from Faculty's research groups in forms of technical reports in this proceedings.

Faculty will continue to encourage the development and innovative character of scientific activities, with emphasis on the outcomes it terms of impact of scientific activities on specific segments of transport and traffic.

Assoc. Prof. Doris Novak
Chairman of Committee on Science and Projects
Faculty of Transport and Traffic Sciences

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NAVIGATION OF ELECTRIC VEHICLES WITH THE CRITERIA OF MINIMAL ENERGY CONSUMPTION

ABSTRACT

Electric road vehicles are more and more being included in today's traffic imposing new ways how road vehicles should be used and how the transport network should be managed. To ensure optimal usage of electric vehicles, new routing algorithms are needed that take into account the road elevation in order to minimize the energy consumption. Additionally, the charging process has to be optimized so that the electric grid is not overloaded and the electric vehicle can be used as a short-term energy source in times of increased electric energy consumption. In the same time, the charging costs have to be kept on a minimum. Additionally, traffic control should be also adapted to maximize the transport network throughput and minimize the energy consumption. Goal of this project is to build a small scale electric vehicle using the Pioneer 3AT mobile robot, to start the development of a simulation model for the built small scale electric vehicle and of new routing algorithms suitable for electric vehicles in urban environments, create a simulation framework for urban road networks and to start the development of new traffic control algorithms appropriate for traffic flows containing electric vehicles.

KEYWORDS:

Electric vehicle, route optimization, traffic control, variable speed limit

1. INTRODUCTION

Development of electric vehicles resulted with their increasing inclusion into road traffic. Republic of Croatia is following this trend and charging stations for electric vehicles are being build in cities (Labin, Biograd, Koprivnica, Zagreb) and shopping malls (IKEA), retailers are looking into possibilities of using electric vehicles connected with renewable energy sources for freight delivery, Croatian companies are investing into development of electric vehicles (Doking, Rimac Automobili), the state started to subsidy electric vehicles and citizens have started to purchase electric vehicles. New electric vehicles are opening new research topics

connected to optimal distribution of chargers for electric vehicles, production of electrical energy, development of new algorithms for route optimization, etc.

Researchers of the Faculty of transport and traffic sciences, collaborators on this project/report, have joined and started to research in this area to solve some of the mentioned problems. They are also networking with associated research groups and companies. This project represents a continuation of already finished projects and augmentation of research on existing projects on which the researchers of this report are active. Relevant projects are: short-term supports from the University of Zagreb: "Optimal navigation of small electric vehicles in indoor environments", and "Vehicle fleet route optimization using multi-agent optimization algorithms and real time traffic data", and research projects "Computer Vision Innovations for Safe Traffic (VISTA)", "System for route optimization in a dynamic transport environment (SORDITO)", and "Intelligent Cooperative Sensing for improved traffic Efficiency (ICSI)". In scope of the mentioned projects, a basic version of the mobile robot Pioneer 3AT, and laser sensor for measuring distances in outdoor environments was purchased. Additionally, research on route optimization algorithms that use speed profiles has been started, algorithms for vehicle detection and tracking in road traffic video footage have been developed, and cooperation with other research institutions (Faculty of electrical engineering and computing, and Faculty of mechanical engineering and naval architecture) and the company Mireo d.d. has been established.

This report is organized as follows. Section 2 describes the research goal and motivation of the project. In Section 3, the project research activities are described. Following Section 4 gives an overview of the budget spending including a short description of the purchased equipment. Section 5 shows the project results with emphasis on applications for new projects, obtained projects and grants, and published papers. Report ends with a conclusion and future work section.

2. RESEARCH GOAL AND MOTIVATION

Electric and hybrid vehicles are the next step in development of vehicles. For greater usage of electric or hybrid vehicles, it is essential that they have similar usability as vehicles with an internal combustion engine, but lower total cost. Firstly, it is important to develop a generalised charging/discharging model of electric vehicle. Digital map with a traffic layer should be extended with data that would help to predict energy usage when a given road segment is used. Estimation of electric energy usage for every route between certain locations could then be determined and used as input value for algorithms to route fleet of vehicles. Minimization of total energy consumption for the whole vehicle fleet is essential for green logistics. This idea is closely related to the research area that associates on this project are researching for more than ten years.

Importance of this research has become even more significant in the recent years. Tendency in growth of using electric vehicles in every day traffic can be observed in the European Union. In the Republic of Croatia, electrical vehicles are increasing its presence on the market also and for that reason, charging stations are being built in the last couple of years in every larger city. Logistic companies also make enquiries of current possibilities to replace their existing fleet of vehicles with internal combustion engines with more energy efficient and green equivalents (e.g. HRZZ project led by prof. Joško Deur that researched energy efficient routing for the retail company Konzum). In addition, it is important to notice that two Croatian companies (Doking and Rimac automobili) are currently developing electric vehicles.

Envisaged goals of this project are to:

1. Establish a research team on the Faculty of transport and traffic sciences for navigation of electric vehicles;

2. Create a plan to upgrade the mobile robot Pioneer 3AT to become a research platform for small electrical vehicles;
3. Develop a methodology to enhance digital maps with information regarding road altitude and slope;
4. Introduce new lecture materials for courses held by the project associates connected with the needs of the industry sector;
5. Enhance already developed algorithms for the vehicle routing problem by adding constraints regarding energy consumption.

3. RESEARCH ACTIVITIES

This project was applied with the aim to do research related with navigation of electric vehicles. Planned research activities were related to making a small electric vehicle platform and developing route optimization algorithms with the criteria of minimal energy consumption. However, by attending the Workshop on Smart Urban Mobility in Edinburgh in the end of 2015 researchers got informed about the possibility to achieve energy efficient crossroads based on cooperation between electric vehicles and traffic control [5]. Therefore, a new research activity was added to examine traffic control approaches in urban environments. In continuation more details about research activities in all three parts are given.

3.1 Small electric vehicle setup

Transport Optimization Group is equipped with a four-wheel drive robotic platform P3AT. The mobile robot Pioneer 3AT comes complete with battery, emergency stop switch, sonars, bumper switches, wheel encoders and a microcontroller with ARCOS firmware, as well as a Pioneer SDK (included advanced mobile robotics software development package). The originally purchased Pioneer 3AT is additionally enhanced with an embedded computer and a solid-state hard drive for both, indoor and outdoor mapping and localization. Specially designed construction is added on the top of the robot for additional devices such as the Kinect camera, ZED stereo camera, GPS tracking device, additional batteries, laser range finder, etc. Additional sensors open the way for on-board vision and localization. The additional sensors are used for research involving mapping, navigation, monitoring, vision, manipulation, etc. Current form of the upgraded mobile robot Pioneer 3AT is shown in Fig. 1.

Figure 1 – Upgraded mobile robot Pioneer 3AT

3.2 Energy efficient route optimization

Traditional vehicle routing problem (VRP) heuristic methods are minimizing total distance or time vehicles travelled as the main objective function, while energy consumption minimization is the objective function of energy efficient VRP heuristics. Senior researcher assoc. prof. Tonči Carić mentored two students who modified the standard Dijkstra algorithm for calculation of energy optimal routes. They proposed a method of simulating the terrain with different percentage of gradient adding charts for simulation. Artificial traffic network was represented by a directed asymmetric graph with following attributes for all edges: length, slope and energy needed to traverse an edge. Figure 2 shows created graph on which the modified Dijkstra algorithm was tested.

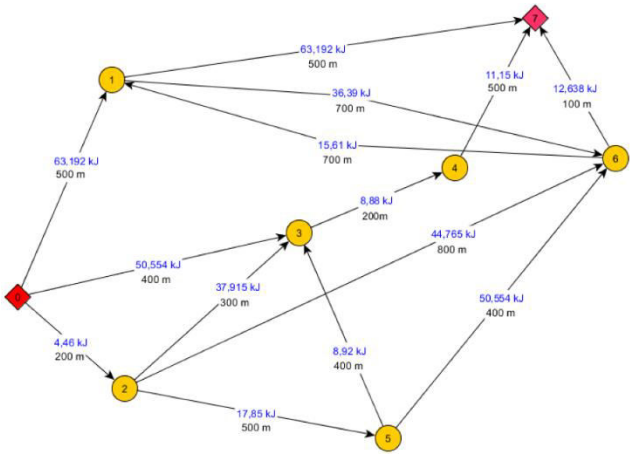

Figure 2 – Asymmetric graph used for testing

Modified Dijkstra algorithm was used to find the most energy efficient path through graph. Minimal state of charge (SOC) of the electric vehicle's battery for selected route is also estimated. Algorithm was implemented in the C# programming language. Results were tested using the mobile robot described in the previous subsection. With certain modifications, this idea can be applied to navigation systems for real electric vehicles in order to find the most energy efficient route from current location to given destination. If SOC is a known value to the navigation system, described route optimizer can estimate if current SOC is sufficient for the trip, and if it is, what will be its state after arrival to destination. These kind of systems have significant importance when routes are planned for autonomous electric vehicles also.

3.3 Traffic control approaches

This research activity was led by assist. prof. Edouard Ivanjko. Aim of traffic control is to enhance the level of service of a traffic network. With the implementation of intelligent transport systems services traffic control has become even more important because a control loop can be closed between the vehicle and the traffic control system. So pre-emptive actions on crossroads for emergency or priority (public transportation, taxis) vehicles can be taken to minimize their travel time on their assigned route. Such pre-emptive actions can be applied for heavy polluting vehicles and electric vehicles also. Electric vehicles would be in this case favoured in order to increase their share in the overall vehicle population. On urban motorways traffic control can detect build-up of congestion and by appropriate control actions slow down or stop incoming vehicles preventing the occurrence of congestion. Additionally, traffic control increases the network throughput enabling the users of electric vehicles a larger autonomy and faster access to a charging station in case of congested traffic.

In order to combine traffic control and vehicle navigation cooperation has to be established between these two systems. That means the traffic control centre and the vehicle

have to exchange information. To simulate such systems the microscopic traffic simulator VISSIM was chosen. Its advantage is that it can be connected with the program package Matlab/Simulink and vehicle emissions simulator EnViVeR. This can be done by using the simulation framework given in Fig. 3 developed during this project. VISSIM is applied to simulate the road traffic, Matlab executes the traffic control law during simulation in a closed loop and EnViVeR computes the vehicle emissions when the simulation is finished.

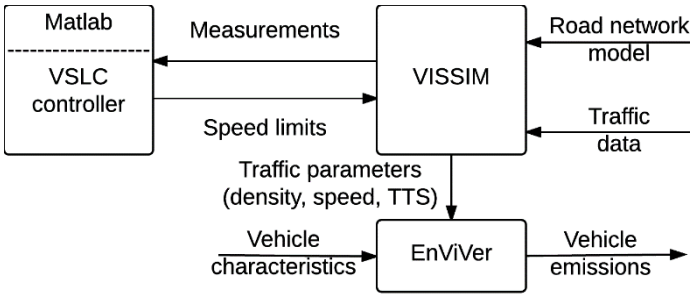

Figure 3 - Block scheme of the developed simulation framework [4]

As the first phase, a simple traffic control case of an urban motorway with variable speed limit control (VSLC) has been chosen. Cooperation between the vehicle and traffic control centre in this case include information exchange about the current speed limit value and current vehicle speed. Such information interchange can be used to ensure that vehicles comply with the current speed limit or to adapt the current speed limit value to reduce the speed variability on the urban motorway. Research activities done so far resulted with an urban motorway model with two on-ramps, one off-ramp and four sections (first three with VSLC) as given in Fig. 4. Two reactive VSLC approaches (mainline virtual metering (MVM)) and simple proportional speed controller (SPSC)) were simulated and both showed an improvement regarding mainstream travel time (TT) and the total time spent (TTS) by the vehicles in the simulated urban motorway section as shown in table 1 [4]. Additionally, vehicle emission are reduced as shown in table 2. These results are obtained when all vehicles comply with the imposed speed limit and the situation that not all vehicles are complying with the imposed speed limit has to be yet examined as well as the cooperation between the vehicles traffic control centre.

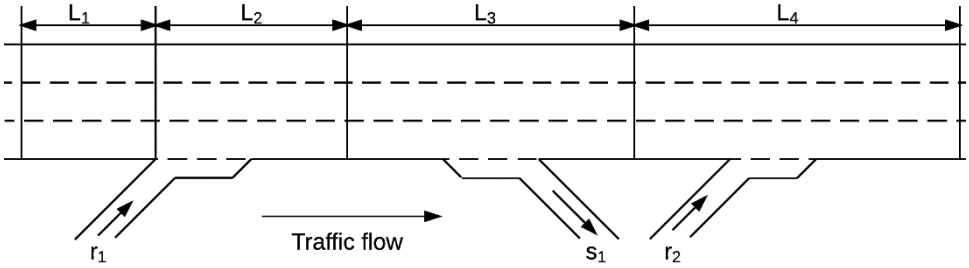

Figure 4 – Urban motorway section used for simulation [4]

Table 1 – Obtained traffic measures of effectiveness [4]

Measure of effectiveness	No VSLC	MVM	SPSC
Maximal TT [s]	228	205	216
Average TT [s]	160	151	156
TTS [veh·h]	716	675	701

4. BUDGET SPENDING

In the two application forms (first and second year) for this project a cumulative amount of 94,000.00 HRK was defined/asked for. Only a cumulative amount of 30,000.00 HRK was approved (15,000.00 HRK for the first and the second year respectively). Additionally, one

project associate that was involved in creation of the proposal for this project left the Faculty of transport and traffic sciences and another project associate was on a longer leave. From these reasons, originally, planned activities could be only done on a smaller scale and some expensive research equipment could not be obtained. Most of the work was done by the senior researchers assist. prof. Edouard Ivanjko and assoc. prof. Tonči Carić, and the students that the senior researchers managed to attract.

Table 2 – Obtained vehicle emissions [4]

Emission type	No VSLC	MVM		SPSC	
		Obtained	Reduction [%]	Obtained	Reduction [%]
CO_2	$15.42 \cdot 10^6\ g$	$14.98 \cdot 10^6\ g$	2.85	$15.21 \cdot 10^6\ g$	1.36
	$6.167 \cdot 10^6 g/h$	$5.994 \cdot 10^6\ g/h$	2.81	$6.084 \cdot 10^6 g/h$	1.35
	$223.5\ g/km$	$217.2\ g/km$	2.82	$220.5\ g/km$	1.34
NO_x	$42.53 \cdot 10^3\ g$	$41.16 \cdot 10^3\ g$	3.22	$41.78 \cdot 10^3\ g$	1.76
	$17.01 \cdot 10^3\ g$	$16.46 \cdot 10^3 g/h$	3.23	$16.71 \cdot 10^3 g/h$	1.76
	$0{,}6164\ g/km$	$0{,}5966\ g/h$	3.21	$0.6056\ g/km$	1.75
$PM10$	$3080\ g$	$3040\ g$	1.30	$3068\ g$	0.39
	$1232\ g/h$	$1216\ g/h$	1.30	$1227\ g/h$	0.41
	$0{,}04465\ g/km$	$0{,}04407\ g/km$	1.30	$0.04447\ g/km$	0.40

In table 3 overview of the budget spending is given. Most important budget spending is related to items 2 and 4 in table 3. In scope of these two items new research equipment to build a small electrical vehicle and to start making experimental setups to teach students programming of the Arduino prototyping platform was obtained. Purchased equipment includes: (i) embedded computer for the Pioneer 3AT mobile robot; (ii) traffic data for the Republic of Slovenia; and (iii) parts for experimental setups with the Arduino platform.

Table 3 – Planned and realized activities with budget overview

Nr.	Planned activity	Planned budget	Realized	Cost
1.	New project applications (workshop, application counsellor, attending networking events, application meetings, attendance to conferences)	10,000.00 HRK	Two HORIZON2020 applications, one HRZZ application, two applications for short term support from the University of Zagreb, one Scientific centre of excellence application, four new COST action applications, one BICRO application, 9 papers published	4,098.85 HRK
2.	Establishing a local research group related to electric vehicles	10,000.00 HRK	Laboratory equipment purchased for a small scale electric vehicle platform based on the mobile robot Pioneer 3AT	6,886.39 HRK
3.	Connecting with national researchers and companies related to electric vehicles	5,000.00 HRK	Collaboration agreement signed with the company Promel projekt Ltd., connection established with companies Alfatech Group, VIP and LED elektronika Ltd., joint project proposals started with the group of prof. Joško Deur from the Faculty of mechanical engineering and naval architecture University of Zagreb and prof. Daniela Nechoska Koltovska from Faculty of Technical Sciences St Kliment Ohridski University, Bitola, Macedonia	0.00 HRK
4.	Making a proposition for a new course related to autonomous and electric vehicles	5,000.00 HRK	Laboratory equipment purchased for workshops about programming the Arduino prototyping platform	3,691.14 HRK

Other budget spending is related to new project applications and networking with other researchers and industry. Attendance to conferences was financed in order to present latest research results to the international community and use the conference for networking. For connecting with national researchers and companies no amount was spend since all interested researchers and companies were in Zagreb. Meetings were held in own premises were no lease fee and no travel costs had to be paid. Currently there are some funds left and it is planned to spend them to the end of the duration of the project on items 2 and 4 listed in table 3.

5. RESULTS

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

During the project duration, the researchers succeeded to gather two student teams to work on topics related with the research activities. First team, lead by assoc. prof. Tonči Carić, consists of students Leo Tišljarić and Dominik Cvetek, and they were working on the project ”Dynamic measuring the energy consumption of electric vehicle with Arduino prototyping platform” for which they received the rector price. They proposed a method of collecting data on the energy consumption of electric vehicles. Electronic circuit for measuring necessary parameters was made using the Arduino prototyping platform. Mobile robot Pioneer 3AT was used as an experimental setup of a small electric vehicle. Data of energy consumption of the robot with regard to the configuration of the terrain was collected. That research carries out the simulation of the gradient of terrain adding a simulation cart with added weight. They have proposed a modification Dijkstra's algorithm for the calculation of an energy optimal path.

Second student team tackled the problems related to road traffic control. Students Krešimir Kušić and Nino Korent managed to implement the simulation framework given in Fig. 1 and test the VSLC approach MVM. Their efforts were awarded with the rector's price for their work entitled "Analysis of the Impact of Variable Speed Limit Control on Traffic Throughput and Environmental Pollution" made under supervision of assist. prof. Edouard Ivanjko and young researcher Martin Gregurić. Currently they are both working on their master theses with topics related to control of urban motorway traffic. Students Borna Kapusta and Mladen Miletić joined recently into the team and started they work on traffic control tackling the problem of pre-emptive traffic light control for emergency vehicles. Additional help to solve traffic problems on urban motorways can be expected from the foreign student Gabriel Melo from São Carlos School of Engineering, University of São Paulo, Brazil who will perform an internship from the 15 January 2017 until 15 July 2017 under the supervision of assist. prof. Edouard Ivanjko. Goal of this internship is to make a calibrated model of a chosen segment of an urban motorway in California, USA using the PEMS traffic data database, implement a fuzzy logic based VSLC, and evaluate the implemented VSLC with emphasis on traffic and vehicle emission criteria.

5.2. Cooperation with industry and academia

During the project duration, several meetings with companies and academic institutions were held 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., AlfaTec Group Ltd. and VIP were held. Results of these meetings can be summarized with the following: (i) informal agreement about cooperation in research and

education; (ii) bachelor and master thesis topics interesting to particular companies will be defined to attract perspective students; (iii) student visits to mentioned companies during class will be made in order to introduce the companies to perspective students; and (iv) information about possible interesting grant calls will be shared. In cooperation with the company LED elektronika Ltd. the first bachelor thesis was made with the title "Possibilities for Complementation of Measured Traffic Parameters Data Based on Historic Values", author Pavao Petrač and supervisor assist. prof. Edouard Ivanjko. With the company Promel projekt Ltd. a cooperation agreement was signed and a student visit to this company in scope of the course Artificial intelligence was organized under supervision of assist. prof. Edouard Ivanjko.

Regarding academia, cooperation with the Faculty of electrical engineering and computing, Faculty of mechanical engineering and naval architecture (both part of the University of Zagreb), Energy Institute Hrvoje Požar and Faculty of Technical Sciences St Kliment Ohridski University, Bitola, Macedonia was extended. Results achieved can be summarized as following: (i) joint project proposal with the Faculty of mechanical engineering and naval architecture for the Croatian science foundation has been submitted; (ii) project proposal with Energy Institute Hrvoje Požar as one of the partners of an international consortia has been submitted; and (iii) funds for researcher visit between the Faculty of transport and traffic sciences University of Zagreb and Faculty of Technical Sciences St. Kliment Ohridski University, Bitola, Macedonia have been granted (grants for one researcher from each institution). Two student visits to the Institute Ruđer Bošković and the Faculty of Kinesiology were also organized in scope of regular class of the course Systems of virtual reality in traffic under supervision of assist. prof. Edouard Ivanjko.

5.3. Project applications

In table 4 all submitted project proposals that got rejected or are currently in review are listed. The first two project proposals are result of participation in EU COST actions. In this case the actions TU1102 Towards Autonomic Road Transport Support Systems and TU1305 Social networks and travel behaviour. In these two proposals, researchers from this project were included to bring knowledge related to road traffic control, modelling and simulation of urban traffic networks, and route optimization. Networking done during mentioned two COST actions resulted also with proposals for new COST actions and entrance in consortia for applications to the program Interreg Central Europe.

5.4 Obtained additional projects and funds

In table 5 accepted project proposals and other grants received during the duration of this project are listed. Most successful project granted is the "Scientific centre of excellence for data science and cooperative systems" were researchers from this project are participating in the Research unit data science, Research area Multidisciplinary Data Intensive Applications, subarea Real-time intelligent transport analytics. Participation in this scientific centre of excellence opens access to new grant calls in the next five years for financing PhD students, research equipment, summer schools and scientific conferences. Other important grants are the two COST actions enabling networking with international researchers in the area of data science, and priority to attend to short-term scientific missions and summer schools organized in scope of these two COST actions.

5.5. Published papers

Research results related to vehicle routing are published in papers [6] to [9]. Research published in paper [10] describes a method to obtain optimal locations of charging stations based on a large set of GPS tracks of commercial vehicles.

Table 4 – Overview of submitted project proposals

Nr.	Funding scheme	Project name	Budget	Status
1.	HORIZON2020	Eliminating air QUality problems using an Autonomic Layer In the Smart city Environment EQUALISE	6,580,578.75 EUR	Rejected
2.	HORIZON2020	COLlective TRAnsport/TRAvel INtelligence COLTRAIN	3,440,000.00 EUR	Rejected
3.	HRZZ	Optimization of Routes for Electric Delivery Vehicles OpRED	702,000.00 HRK	Rejected
4.	PoC BICRO	Advanced traffic counter based on multispectral video	260,000.00 HRK	Rejected
5.	COST	OC-2016-1-20366 "Cooperative intelligent systems for transport "	Yearly defined	Rejected
6.	COST	OC-2016-2-21618 " Intelligent Mobility Pan European Skills Network "	Yearly defined	In review
7.	Interreg CENTRAL EUROPE	Transport and Energy Initiatives for a Low-carbon Europe (TEILE): electric vehicles and the smart grid	1,399,400.00 EUR	In review
8.	Financing scientific centres of excellence in Croatia	Scientific centre of excellence for data science and cooperative systems	5,000,000.00 EUR	In review

Research results related to control of road traffic are published in papers [1] to [4]. Three of them (papers [1], [3] and [4]) are student papers describing the results students obtained during their work on their bachelor and master thesis. In [1] a framework in VISSIM for simulation of cooperative ramp metering is described. Possibilities of applying urban traffic control approaches based on artificial intelligence are discussed in [2]. Short review of control approaches for variable speed limit control on urban motorways in [3] served as a starting point for a simulation based comparison of two chosen variable speed limit controllers given in [4].

6. CONCLUSION AND FUTURE WORK

Aim of this project was to start the research related to the navigation of electric vehicles and to tackle the problem of finding energy optimal routes. During the project, a new research activity was added in order to include traffic control into improvement of energy consumption.

Regarding the build-up of a small electric vehicle setup, achieved results include an upgraded mobile robot Pioneer 3AT ready to make outdoor experiments. First outdoor experiments were performed successful in order to make an energy consumption model of the small electric vehicle setup. Future work on this research activity will include preparation of the Campus Borongaj area (WLAN coverage, road map, points of interest) to perform longer outdoor experiments.

To improve the existing vehicle routing optimization algorithm in order to include energy consumption, the standard Dijkstra algorithm was modified to be able to calculate energy optimal routes. For this, the classical graph based road network presentation was augmented so that all edges contain additional attributes to describe length, slope and energy needed to traverse a particular edge.

Current results related to the research activity of traffic control include a framework for simulation of road traffic including vehicle emissions and the associated control law, urban motorway simulation model with two on-ramps and one off-ramp, and two basic VSLC algorithms. With this, there exist basic prerequisites for development, simulation and analysis of more advanced traffic control laws. Future work on this research activity will include modelling of a larger urban motorway segment and part of a city with signalized intersections using real world data, development of traffic control laws based on learning, and its simulation and analysis regarding traffic and environmental parameters.

Table 5 – Overview of obtained project proposals

Nr.	Funding scheme	Name of project or grant	Short description	Budget
1.	EU JRC	Road-transport & Emissions Modelling (REM) workshop	Networking event and workshop regarding modelling and simulation od road vehicles emissions. Held in Skopje, Macedonia and Edouard Ivanjko participated.	700.00 EUR
2.	Scientific centres of excellence	Scientific centre of excellence for data science and cooperative systems	Research and collaboration project related to establishing a scientific centre of excellence in data science and advanced cooperative systems. Project associates are members of the research unit related to data science.	Yearly 550,000.00 HRK
3.	ERASMUSplus	Teaching visit to the Department for traffic and transport Faculty of Technical Sciences St Kliment Ohridski University, Bitola, Macedonia	Grant holder is Edouard Ivanjko. Aim of the visit is to teach the foreign students to new developments in application of artificial intelligence in road traffic control and how to simulate such systems using VISSM, EnViVeR and Matlab. Additionally, existing research cooperation will be extended.	1,000.00 EUR
4.	COST	IC1406 High-Performance Modelling and Simulation for Big Data Applications (cHiPSet)	Researchers Tonči Carić and Edouard Ivanjko are management committee members for Croatia. They are also members of the traffic group of the application workpackage.	Yearly defined for networking meetings
5.	Program contracts of the University of Zagreb	Supporting students to attend scientific conferences	Student registration fee for the conference ZIRP2016	200.00 EUR
6.	COST	COST Action TU1305 Social networks and travel behaviour.	Researcher Tonči Carić works as the management committee member for Croatia.	Yearly defined for networking meetings
7.	IPA CBC Adriatic Programme	Adriatic IPA project Traveller Information System for the Adriatic Region (TISAR)	The aim of the project was implementation of an ICT platform where public transport and journey planning data will be merged and made available in the languages of the IPA Countries.	1,514,012.43 EUR
8.	University of Zagreb	Route optimization for small electric vehicles with the criteria of minimal consumption	The aim of the project is to develop method of collecting data of the energy consumption of electric vehicles and construct electronic circuit for measuring necessary parameters of electric vehicle.	3,121.67 EUR

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REFERENCES

[1] Pandža, H.; Vujić, M.; Ivanjko, E.: A VISSIM based framework for simulation of cooperative ramp metering, International Scientific Conference ZIRP2015: Cooperation Model of the Scientific and Educational Institutions and the Economy, Zagreb, Croatia, 2015, pp. 151-162

[2] Ivanjko, E.; Koltovska Nechoska, D.: Intelligent traffic control in urban areas, First international conference Transport for today's society, Bitola, Macedonia, 19.-21. May 2016

[3] Gregurić, M.; Ivanjko, E.; Korent, N.; Kušić, K.: Short Review of Approaches for Variable Speed Limit Control, Proceedings of the International Scientific Conference Perspectives on Croatian 3pl Industry in Acquiring International Cargo Flows ZIRP2016, Zagreb, Croatia, 12.04.2016, pp. 41-52

[4] Kušić, K.; Korent, N.; Gregurić, M.; Ivanjko, E.: Comparison of Two Controllers for Variable Speed Limit Control, Proceedings of 58th International Symposium ELMAR-2016, Special session Intelligent Transport Systems, Zadar, Croatia, 12.-14.09.2016, pp. 101-106

[5] Vreeswijk, J.; Vernet, G.; Huebner, Y.; Jeftić, Ž.; lo Tona, P.; Manuel Martinez, J.; Mitsakis, E.; Alcaraz, G.: Compass4D: Cooperative Mobility Pilot on Safety and Sustainability Services for Deployment, 10th ITS European Congress, Helsinki, Finland, 16-19 June 2014, TP-CP 0011

[6] Muštra, M.; Fosin, J.; Carić, T.: Comparison of Calculated and Measured Travel Times with PND Prediction, Proceedings of 58th International Symposium ELMAR-2016, Special session Intelligent Transport Systems, Zadar, Croatia, 12.-14.09.2016, pp.107-110.

[7] Rožić, L.; Fosin, J.; Carić, T.: Solving the Time Dependent Vehicle Routing Problem Using Real-world Speed Profiles, Central European Conference on Information and Intelligent Systems CECIIS2015, Varaždin, Croatia, 23-25.9.2015, pp. 193-200

[8] Muštra, M.; Fosin, J.; Carić, T.: Validation of speed profiles using FMCW radars, 10th Annual Baška GNSS Conference, Baška, Croatia, 8.-10.05.2016

[9] Erdelić, T.; Ravlić, M.; Carić, T.: Travel time prediction using speed profiles for road network of Croatia, Proceedings of 58th International Symposium ELMAR-2016, Special session Intelligent Transport Systems, Zadar, Croatia, 12.-14.09.2016, pp. 97-100.

[10] Ravlić, M.; Erdelić, T.; Carić, T.: Optimizing Charging Station Locations for Fleet of Electric Vehicles Using Multi-Source Weber Problem, Proceedings of 58th International Symposium ELMAR-2016, Special session Intelligent Transport Systems, Zadar, Croatia, 12.-14.09.2016, pp. 111-114.