PROCEEDINGS OF ELMAR-2017

59th International Symposium ELMAR-2017

18-20 September 2017, Zadar, Croatia

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Published by:	Faculty of Electrical Engineering and Computing, University of Zagreb
Edited by:	Mario Muštra, Dijana Vitas, Branka Zovko-Cihlar
Front Cover:	Painting by artist Mrs Ljerka Njerš
Printed by:	LotusGRAF, Zagreb
ISBN:	978-953-184-230-3
ISSN:	1334-2630
IEEE Catalog Nr.:	CFP17825-PRT

Printed in Croatia.

59th International Symposium ELMAR-2017 is organised by:

Croatian Society Electronics in Marine - ELMAR, Zadar

University of Zagreb Faculty of Electrical Engineering and Computing, Department of Wireless Communications

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Evaluation of Adaptive Traffic Control System UTOPIA using Microscopic Simulation

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***Abstract*—Adaptive traffic control systems are designed to overcome the limitations of fixed time control of signalized intersections in urban environments. They respond to fluctuations in traffic patterns by adjusting signal timing in accordance with traffic demand and can reduce traffic congestion, delays, and decrease travel time. One of such systems is UTOPIA (Urban Traffic Optimization by Integrated Automation). It is advisable to evaluate such a system using microscopic simulation before implementation. A framework to connect UTOPIA with the microscopic simulator VISSIM is implemented in this paper to enable such evaluation. The framework is tested using real-world traffic data from a congested corridor of 7 signalized intersections in the wider center area of the City of Skopje, Macedonia. Obtained results are analyzed using chosen performance measures suitable for urban environments like delay, queue length, travel time, intersection level of service and number of stops.**

***Keywords*— Intelligent transport systems, UTOPIA, Microscopic simulation, Urban intersections, Adaptive traffic control system**

I. Introduction

The apparent state of the art in urban traffic signal control includes a substantial number of sophisticated, complex, and highly developed adaptive systems used and implemented in bigger cities as part of an urban traffic control (UTC) center. Systems like SCATS, SCOOT, RHODES, ImFlow, and UTOPIA (Urban Traffic Optimization by Integrated Automation) are widely used in such UTC centers [1]. Each of these systems has a unique characteristic. They respond to fluctuations in traffic patterns and can reduce traffic congestion, delays and travel time.

The effectiveness of the mentioned systems has to be evaluated or at least estimated on the chosen urban traffic network before implementation. As obtained in [1], adaptive traffic control cannot obtain an optimal solution in all traffic scenarios. Especially in a case of a corridor or a larger complex urban traffic network. To find which traffic control approach is optimal and to tune the controller, simulations are used. In [2] a hybrid simulation framework is implemented for simulation of a larger urban area. In it, the mesoscopic simulator MEZZO [3] is used to simulate a larger urban network and the microscopic simulator VISSIM [4] is used to simulate parts of the network that are of special interest. The microscopic simulator VISSIM has been used also in [1] to test UTOPIA and ImFlow on a five intersection area in Stockholm, Sweden. VISSIM was connected with EC1 signal controller simulators to enable a software in the loop simulation. Mentioned signal controller is the most used signal controller in Sweden [2] and the developed simulation framework can be augmented to establish a connection with other signal controllers.

The purpose of this paper is to describe the process of evaluation of the effectiveness of the adaptive control system UTOPIA on a chosen urban traffic network in the city of Skopje. For this evaluation process, a simulation framework was developed to enable a software in the loop simulation of the adaptive traffic control UTOPIA using the microscopic simulator VISSIM. The framework used in [1] is augmented to establish a connection with SPOT signal controllers usually used with UTOPIA.

This paper is organized as follows. The second section describes the performance measure for evaluation of adaptive traffic control. Basic features of UTOPIA are presented in the third section. The fourth section presents the implemented simulation framework and obtained results. Conclusion and future work description ends the paper.

II. Performance measures for urban traffic control

First appropriate measures of effectiveness (MoE) should be determined in order to evaluate the impacts of an adaptive traffic control system implemented in an UTC centre on traffic conditions. A variety of MoEs has been used to measure the performance of adaptive traffic control systems in the literature.

According to the research described in [5] the impacts on performance can be different according to site-specific issues and selected performance metrics [6]. These two studies developed procedures to access the overall impacts of adaptive signal control on arterial roads, including travel time, side street delays, and system-wide performance based on the data collected from probe vehicles. Another study accounted for the performance of side streets [7] used parameters such as side street delay and delays for major turning approaches. According to the results of these studies, total travel times, as well as the average delay times of vehicles within a given route, could be considered as two main parameters in determining the effectiveness of a given traffic control system or method applied on a signalized intersection. After computing these parameters in an intersection, other related parameters like the number of stops, and the probable improvements in fuel consumption and air pollution levels can be calculated also [8].

The following performance measures: delay, level of service (LoS), average queue length, max queue length, and numbers of stops at a single intersection are used in this paper to evaluate UTOPIA. LoS of a particular intersection is an important MoE for evaluating of the existing traffic conditions on this particular intersection. It reveals the waiting time on the particular intersection. Delay is another important indicator for the evaluation of service level of an urban road intersection and vehicle traffic efficiency. It reveals the difference between free-flow and congested traffic situations. For an in-depth analysis of the arterial section in the analysed urban traffic network, additional MoEs were collected. Travel time, delay and number of stops were obtained to analyse the traffic conditions on the arterial section. All of these mentioned MoS were obtained using the microscopic simulator VISSIM.

III. Adaptive traffic control using UTOPIA

UTOPIA is the name given to the control strategies used in the real-time traffic control implemented over a wide area of Turin since 1984. This was the first implementation of UTOPIA over a significant area of Turin named ”Progetto Torino”, and has been running successfully since 1984 [9]. UTOPIA belongs to the third generation of adaptive control systems and it is an innovation in UTC as a hierarchical, adaptive, distributed and open traffic control system [10].

UTOPIA has a two-level distributed architecture. The upper level consists of a central subsystem responsible for medium and long term forecasting and control over the whole area concerned. At this level, the traffic light reference plans and also the criteria needed for the adaptive coordination are calculated dynamically. In addition, a continuous diagnostic activity is carried out for the whole network. The lower level consists of a network of multi-function units working as local controllers. They are called SPOT roadside units. These are interconnected, and each is responsible for the management of one intersection. Local controllers determine in real time the sequence and optimum length of traffic light phases using the coordination criteria established by the upper level, traffic measurements detected locally and information received from the controllers of adjacent intersections. Each SPOT roadside unit carries out a permanent diagnostic activity in relation to the system components, peripheral units and traffic sensors, and communicates the situation to the upper level. The physical view of UTOPIA is displayed in Fig. 1.

Main functions of UTOPIA are: (i) Monitoring (stores all gathered traffic data and estimated parameters for both, on- and off-line analysis); (ii) Public Transport Priority (provided according to several schemes, ranging from functional integration with automatic vehicle monitoring systems to local and dedicated detectors managed through the public transport locator functionality); (iii) Diagnostics (stores all the data and makes them available through dedicated screens and detailed reports, and elaborates performance indicators); and (iv) Control (fully dynamic and adaptive control, traditional traffic responsive strategies, plan selection, and fixed signal plans can be implemented).

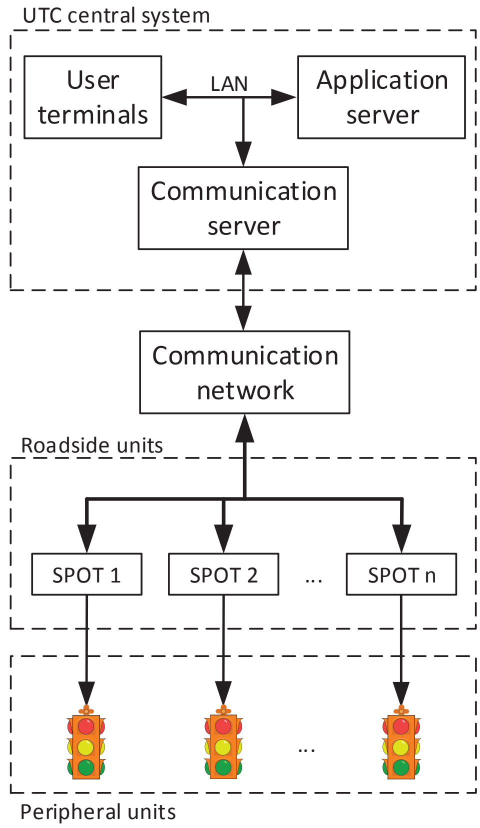

Figure 1. Physical view of UTOPIA.

IV. Simulation framework and results

The implemented simulation framework consists of the system UTOPIA and microscopic simulator VISSIM. The UTOPIA system is used as ”black box” control unit connected to the traffic network simulated in VISSIM. Measured traffic parameters obtained from VISSIM are then used for evaluation of the system UTOPIA after the simulation.

A. Connecting VISSIM and UTOPIA

The adaptive traffic signal control system UTOPIA and microscopic simulator VISSIM were connected using the UTOPIA-VISSIM Adapter (UVA). UVA is an MS Windows based, dynamically linked library developed by the company SWARCO Mizar that is produced UTOPIA. This adapter allows connecting of the adaptive traffic control system UTOPIA to the microscopic simulator VISSIM. In this connection, UTOPIA computes the traffic signals for the simulated road network and VISSIM provides the needed traffic data from the sensors. Both, traffic signal commands and sensor measurements are refreshed every second. The communication flow when UTOPIA controls a traffic network simulated in VISSIM is shown in Fig. 2.

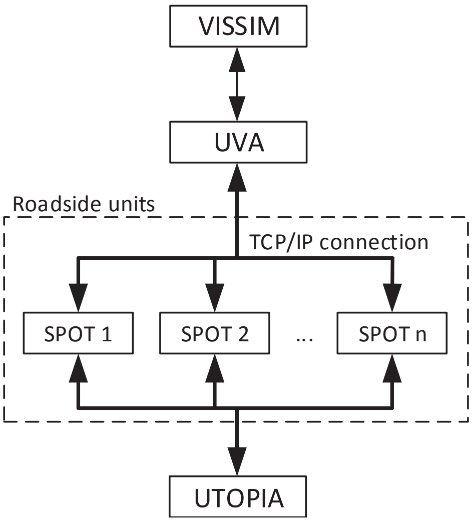

Figure 2. Block scheme of the connection between VISSIM and UTOPIA.

B. Chosen urban road network

The chosen urban network consists of 7 signalized intersections located in the wider center area of the City of Skopje as displayed in Fig. 3. The blvd. Kuzman Josifovski Pitu is in the middle of the chosen urban network containing four intersections denoted as $I1$, $I2$, $I5$, and $I6$. It is an arterial section and represents the main route for all sorts of transport from the east city entry to the city center and vice versa. In its immediate neighborhood is an intermodal terminal containing a railway station, long distance and city bus station, and several taxi stations creating high traffic demand. It is located under the multi-lane railway tracks visible in the middle in Fig. 3. North and south of the mentioned boulevard are three signalized intersections denoted as $I3$, $I4$, and $I7$, respectively. All seven intersections are controlled using UTOPIA.

The traffic demand is higher in the morning peak hour (07:20-08:20) for the chosen urban network because most of the trips are realized from the east part of the city to city centre. Therefore this peak hour is used for evaluation in this paper. Total traffic flows in the morning peak hour for all examined intersections are presented in Table I. Presented data

TABLE I
TOTAL TRAFFIC FLOWS AT THE ANALYZED INTERSECTIONS

Intersection	**Total traffic flow** $[veh/h]$
$I1$	3614
$I2$	4055
$I3$	1913
$I4$	2147
$I5$	3907
$I6$	**5110**
$I7$	1477

were obtained from the TMCC for the year 2017. It can be noticed that intersection $I6$ is the one with the highest traffic demand.

C. Simulation setup

To create a realistic simulation model, traffic data were obtained from loop detectors mounted in the study area as mentioned. All bus stops located in the study area have been included in the simulation model also. Bus routes of public transport are modeled using officially published timetable. Infrastructure for pedestrian and bicycle traffic is not represented in the current model, and therefore bicycle and pedestrian traffic is not analyzed. One simulation was performed and it lasted one hour with a resolution of 10 simulation steps per second. The simulation time was chosen to take into account the morning peak hour in a typical working day. A 900-second warm-up period was used before data collection for analysis started. This warm-up period is needed to fill the empty road network with vehicles and create a realistic traffic situation for simulation testing. The VISSIM model of the study area is shown in Fig. 4.

D. Obtained results

Tables II and III show MoEs obtained for the evaluation of UTOPIA. Table II presents LoS, delay, average queue length, max queue length, and the number of stops obtained for each single intersection in the study area. Additionally, Table III presents the travel time, delay, number of stops, and number of vehicles obtained for the arterial section between intersections $I1$ and $I6$. These MoEs were obtained at the arterial level

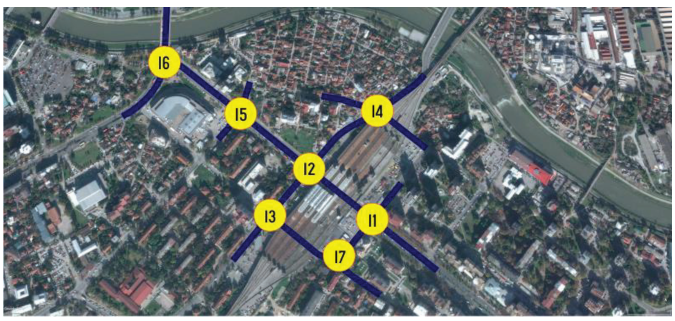

Figure 3. Spatial configuration of the study area.

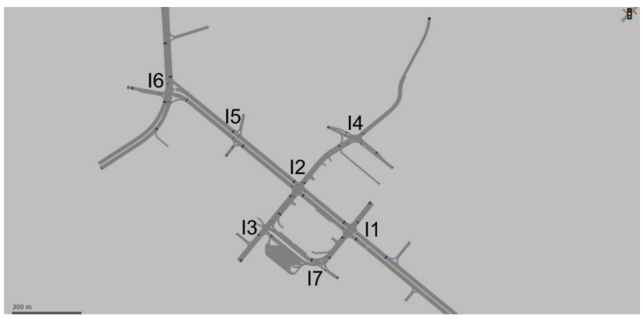

Figure 4. Model of the study area in VISSIM.

TABLE II
OBTAINED MOE FOR ALL INTERSECTIONS

MoE	Intersection						
	I1	**I2**	**I3**	**I4**	**I5**	**I6**	**I7**
LoS	D	**E**	D	D	C	**E**	B
$Delay\ [s]$	47	61	45	50	28	**67**	18
$Q_{Len}\ [m]$	54.6	50.5	17.7	24.6	32.3	**55.4**	9.3
$Q_{LenMax}\ [m]$	**407.3**	209.5	146.3	179.1	258.1	249.9	55.7
Stops	1.3	1.2	**1.5**	1.2	1.3	1.4	0.5

TABLE III
OBTAINED MOE FOR ARTERIAL SECTION $I1 \leftrightarrow I6$

MoE	Direction	
	I1 → I6	**I6 → I1**
$Travel\ time\ [s]$	**230**	153
$Delay\ [s]$	**184**	106
Stops	**5.7**	2.7
Vehicles	**742**	328

during the simulation to conduct an in-depth analysis of this arterial section. The highlighted cells in Tables II and III represent the parameters whit largest values.

As shown in Table II, the majority of the intersections operate at an acceptable LOS of B, C, or D during the morning peak hour. Only two intersections ($I2$ and $I6$) operate at unacceptable LOS E during the peak hour. A significant delay is occurring at intersections $I2$ and $I6$, the ones with the worst LoS. Regarding other MOEs, the longest average queue length is appearing at intersection $I6$ and the maximal queue length is appearing at intersection $I1$. The worst number of stops is appearing at intersection $I3$. From Table III one can conclude that travel time, delay, and the number of stops are higher in direction $I1 \rightarrow I6$ during the morning peak hour.

V. CONCLUSION AND FUTURE WORK

Adaptive traffic control systems such as SCATS, SCOOT, RHODES, ImFlow, and UTOPIA are used in UTC centres in order to reduce congestion and to improve performances of an urban traffic network. A simulation framework is needed in order to evaluate the impacts of such systems. In this paper, such a framework is implemented and tested for the adaptive traffic control system UTOPIA.

An urban traffic network of 7 signalized intersections located in the wider center area of Skopje, Macedonia has been analyzed using the implemented framework. The chosen urban network is modeled using real traffic data. Performance measures such as delay, LoS, average queue length, max queue length, and numbers of stops at a single intersection were analysed for every intersection. Additionally, travel time, delay, and the number of stops were evaluated for the arterial section of the chosen urban network.

Future work on this topic will include multimodal LoS analysis to include bicyclist and pedestrian traffic. Additionally, the analysis will be extended with a fixed time control scenario for a complete evaluation and comparison of the impact of different traffic signal strategies in urban environments. For this, the used MoEs will be augmented with the percentage of arrivals on green, phase green to occupancy ratio, and degree of saturation.

ACKNOWLEDGMENT

The authors would like to thank the companies PTV Group and SWARCO MIZAR S.r.l., the Traffic management and control centre of the City of Skopje, and the Faculty of Transport and Traffic Sciences, University of Zagreb for supporting the work published in this paper.

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