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EVALUATION OF ADAPTIVE AND FIXED TIME TRAFFIC SIGNAL STRATEGIES: CASE STUDY OF SKOPJE[1]

Daniel Pavleski, Daniela Koltovska Nechoska
Faculty of Technical Sciences
St. Kliment Ohridski University, Bitola, Blvd 1st May, nn
Bitola, Republic of Macedonia
dhany_mk@hotmail.com

Edouard Ivanjko
Department of Intelligent Transportation Systems,
Faculty of Transport and Traffic Sciences,University of Zagreb,Vukelićeva 4
Zagreb, Republic of Croatia

Abstract

Signalized intersections and belonging signal plans are powerful means for effective urban traffic management. Numerous strategies have evolved over the time, from fixed time to intelligent signal plan control strategies that respond and react to traffic conditions in real time. This paper presents an evaluation and comparison of the impact of fixed time and UTOPIA adaptive traffic signal control strategies for the chosen urban corridor in the wider center area of the City of Skopje, Macedonia. A topic that still requires more attention from the research community. This paper presents a continuation of the author's previous research where a framework to test UTOPIA adaptive control using the microscopic simulator VISSIM was described. Obtained new results include the influence of fixed time signal plans which are compared with UTOPIA's results and analyzed in details using the following performance measures: delay, queue length, travel time, intersection level of service, number of stops and vehicle throughput.

Keywords - signal plan control strategies; intelligent transportation systems; UTOPIA; microscopic simulation; urban corridor

[1] professional paper

INTRODUCTION

Intelligent transport systems (ITS) that embed advanced technologies in transport are being accepted by transport authorities around the world as a viable alternative to reliance on building more roads to reduce congestion since many years [1]. In many experiments around the world, it has been shown that Advanced Traffic Management Systems (ATMS) can improve traffic quality by reducing traffic congestion, delays, and saving traveling time [2, 3]. In large cities, such systems are implemented in their respective Urban Traffic Control (UTC) centers.

Traffic signal control is a core element for efficient operation of the urban network and crucial part of ITS [1]. Traffic signal control strategies are the most common means used for managing the traffic flows at different types of intersections in the cities. Today many cities in the world still implement fixed time control strategies. The disadvantage of these strategies is that they do not respond to everyday fluctuations in traffic patterns. Adaptive traffic control strategies are designed to overcome the limitations of fixed time control and they respond to fluctuations in everyday traffic patterns by adjusting signal timing in accordance with current traffic demand and can reduce traffic congestion, delays, and travel time. As an example, systems like SCATS, SCOOT, RHODES, ImFlow, and UTOPIA (Urban Traffic Optimization by Integrated Automation) can be mentioned [2]. Each of the mentioned systems has a unique characteristic. For example, UTOPIA /SPOT (System for Priority and Optimization of Traffic), which is used in the city of Skopje, is a hierarchical decentralized traffic signal control strategy [4]. It is also used in many cities in Italy as well as Netherlands, USA, Norway, Finland, and Denmark. It minimizes the total time lost by private vehicles during their trips, subject to the constraint that public vehicles to be prioritized shall not be stopped at signalized intersections [2].

The effectiveness of the mentioned adaptive traffic control systems has to be evaluated or at least estimated on the chosen urban traffic network before implementation. As obtained in [2], 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. This paper presents an evaluation and comparison of the impact of fixed time and UTOPIA adaptive traffic signal control strategies for the chosen urban corridor in the wider center area of the City of Skopje, Macedonia. It is a continuation of the author's previous research where a framework to test UTOPIA adaptive control using the microscopic simulator VISSIM was described, implemented and tested [5]. Obtained new results about the influence of fixed time signal plans are compared with UTOPIA's results and analyzed in details in the continuation of this paper using the following performance measures: delay, queue length, travel time, intersection level of service, number of stops and vehicle throughput.

This paper is organized as follows. The second section describes the chosen performance measures for urban traffic control. Basic description of booth evaluated traffic signal strategies is presented in the third section. The fourth section presents the implemented simulation setup. The fifth section presents obtained results and discussion about them. Conclusion and future work description ends the paper.

PERFORMANCE MEASURES FOR URBAN TRAFFIC CONTROL

To evaluate the performance of different traffic signal control strategies appropriate measures of effectiveness (MoE) should be determined and discussed. The available literature describes a variety of MoEs that can be used for this task in order to cope with different site-specific issues and with different performance metrics that can be applied for an urban environment [6, 7]. One of the site-specific issues can be the influence of traffic from side streets [8]. In this use case, a part of the urban network with several main streets is analyzed so MoEs for side street traffic like side street delay and delays for major turning approaches are not examined.

To give a clear description and to understand traffic flow conditions at an individual intersection under fixed time and adaptive traffic control strategies the following performance measures are being applied: delay, level of service (LoS), average queue length, max queue length, numbers of stops and vehicle throughput. MoEs defined in previous author's work [5] are augmented with vehicle throughput to better evaluate the performance of fixed traffic signal strategies and UTOPIA. The reasons for determining these parameters are as follows. Delay and LoS play a primary role in determining individual intersection performance. LoS can be used to understand the quality of traffic conditions on a particular intersection and delay exposes the difference between free-flow and congested traffic conditions. Frequent stops due to congestion are a typical characteristic of urban traffic. One of the reasons for this is the presence of signalized intersections. Therefore, the information of queue length and number of stops must be included as a performance measure also. The vehicle throughput can provide useful information about the maximum number of vehicles which can be discharged during the time as a measure of the comparative effectiveness of the two evaluated traffic control strategies. In addition, for an in-depth analysis of the arterial section in the analyzed urban traffic network, travel time, delay and number of stops were obtained.

VISSIM microscopic traffic simulator software was used to obtain all these mentioned MoEs [9].

TRAFFIC SIGNAL STRATEGIES FOR EVALUATION

As mentioned, the primary emphasis of this paper is to evaluate and compare the impact of fixed time and UTOPIA adaptive traffic signal control strategies. A brief review regarding these strategies is presented below as a background for further analysis.

Fixed time control

Conventional traffic signal control approaches are either fix-timed or vehicle actuated [2]. Fixed time control uses predetermined green and cycle time that has a fixed duration, regardless of changes in traffic volumes during the day. This type of control gives the most of the green time to the heaviest traffic movement based on historical data. Some fixed-time systems use different preset time intervals for the morning peak hour, evening peak hour, and other busy periods. For this reason, such an approach cannot cope with an unexpected change in traffic demand. To improve this, vehicle actuated traffic signals are implemented. Conventional vehicle actuated signals in principle work with green-demand and green-extension based on vehicle detection, within pre-set limits, as long as the headways in the traffic stream are short enough to be accurately measured. The cycle time is variable, and adjacent signalized intersections can therefore only be coordinated in special cases [2].

In Macedonia, signal control strategies are signal group based and they operate under isolated and coordinated fixed time control. Exclusion is the city of Skopje where the UTOPIA adaptive traffic signal control has been implemented in order to reduce traffic congestion. Before UTOPIA was implemented, the city of Skopje also used isolated and coordinated fixed time control.

Adaptive control system UTOPIA

As mentioned, UTOPIA is an adaptive traffic control system designed to optimize traffic flows and give selective priority to public transport without sacrificing travel times for private traffic [2, 3]. UTOPIA is an innovation in Urban Traffic Control (UTC) i.e. it is a hierarchical, adaptive, distributed and open traffic control system [4]. Hierarchical means that it has goal related coordination and includes cooperative control. Adaptive means that the system monitors the traffic on-line and optimizes the signal plans to ensure fast responses to changes in traffic demand. A distributed system comprises decomposition, looking ahead, strong interaction and looking for terminal costs. The overall network optimization is decomposed into problems of coordinated junctions solved by the intersection units (SPOT) in collaboration with the central system. In Torino UTOPIA/SPOT has resulted in reduced travel times of 2-7% for public transport (PT) vehicles and 10% for cars [10]. Field tests of UTOPIA/SPOT in Skopje have shown 20% travel time reduction in peak hours [11].

SIMULATION SETUP

For evaluation and comparison of the impact of fixed time and UTOPIA adaptive signal control strategies in this research, the microscopic simulator VISSIM was applied. VISSIM is a microscopic, time step and behavior based simulation model developed to analyze the full range of functionally classified roadways and public transportation operations [4, 9]. VISSIM can model integrated roadway networks found in a typical corridor as well as various modes consisting of general purpose traffic, buses, light rail, heavy rail, trucks, pedestrians, and bicyclists. This section presents the simulation framework for strategies evaluation, chosen urban network for testing and simulation parameters.

Simulation framework

A. Fixed time control

The steps for developing the simulation model were the following: (i) creation of the road network using background image with links and connectors; (ii) definition of traffic compositions observed from the field; (iii) definition of speed distributions; and (iv) definition of routing which was done based on the observed travel pattern of vehicles entering and leaving the study area. The real-time traffic volumes were obtained by Traffic Management Control Centre (TMCC) in Skopje of every signalized intersection. Traffic signal controls were defined in VISSIM using the internal fixed time controller. Signal heads were placed in the model to represent available stop lanes. Signal timings of fixed controllers have been obtained from the detailed TMCC traffic design projects. Data collection points were added to the simulation model to correspond with actual data collection points in the real world urban network.

B. VISSIM-UTOPIA

The adaptive traffic signal control system UTOPIA and microscopic simulator VISSIM were connected using the UTOPIA-VISSIM Adapter (UVA). The UTOPIA system is used as” black box” control unit connected to the traffic network simulated in VISSIM. The method used in this research was ”software-in-the-loop simulation environment”. More information regarding the simulation framework and detailed description of testing of the UTOPIA and VISSIM connection can be found in [5].

Chosen urban road network

In order to evaluate the impact of traffic signal control strategies, a simulation model was created in VISSIM for the congested corridor of 7 signalized intersections in the wider center area of the City of Skopje, Macedonia as illustrated in Fig. 1.

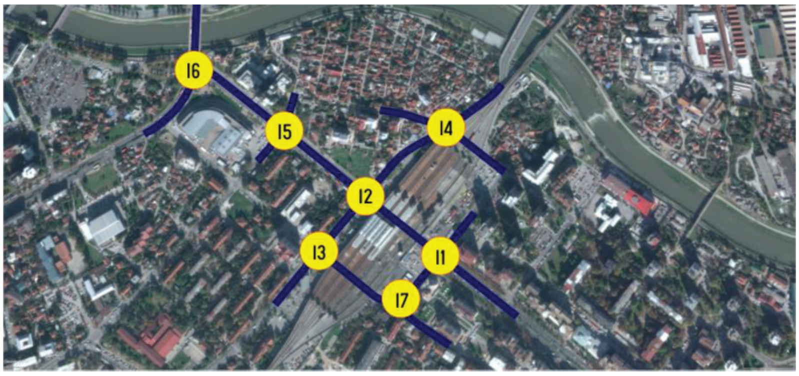

Fig. 1. Spatial configuration of the study area [5]

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 the city center. Therefore, this peak hour is used for evaluation in this paper. Total traffic flows in the morning peak hour for all examined intersections respectively are presented in Table 1. The highest traffic flows occur at the intersection I6.

Table 1. Total traffic flows at the analyzed intersections [5]

Intersection	Total traffic flow (veh/h)
I1	3,614
I2	4,055
I3	1,913
I4	2,147
I5	3,907
I6	**5,110**
I7	1,477

Simulation parameters

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 VISSIM model also. Bus routes of public transport are modeled using officially published timetables. In this phase of research bicycle and pedestrian traffic is not analyzed. Five simulations were performed for booth traffic signal control strategies and average values were computed to obtain realistic results. The simulation time covers 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.

RESULTS AND DISCUSSION

Obtained averaged simulations results for booth strategies are presented in this section. Tables 2 and 3 contain the simulation results for MoEs obtained from the evaluation of fixed time traffic signal strategy. Table 2 presents LoS, delay, average queue length, max queue length, number of stops and the vehicle throughput obtained for every single intersection in the study area. Additionally, Table 3 presents the travel time, delay, number of stops, and number of vehicles obtained for the arterial section between intersections I1 and I6.

Table 2. Obtained MoE for all intersections under fixed time traffic signal strategy

MoE	I1	I2	I3	I4	I5	I6	I7
LoS	D	C	B	**E**	A	**E**	D
Delay (s)	54.11	27.77	18.64	55.68	7.50	**68.98**	53.75
QLen (m)	**75.01**	19.98	7.52	23.46	4.26	56.78	56.47
QLenMax (m)	**510.1**	161.33	83.65	127.91	77.17	242.08	240.59
Stops	0.92	0.64	0.56	0.96	0.30	**1.46**	1.34
Vehicle throughput (veh/h)	2,830	3,314	1,485	1,727	3,303	**4,587**	997

Table 3. Obtained MoE for arterial sections under fixed time traffic signal strategy

MoE	I1 → I6 (L = 1,080 m)	I6 → I1 (L = 679 m)
Travel Time (s)	**442.80**	70.06
Delay (s)	**368.28**	22.87
Stops	**8.29**	1.12

As shown in Table 2, the majority of the intersections operate at an acceptable LOS of B, C, or D during the morning peak hour. Only two intersections (I4 and I6) operate at unacceptable LoS E during the peak hour. A significant delay is occurring at intersections I4 and I6, the ones with the worst LoS. Regarding other MoEs, the longest average queue length and the maximal queue length is appearing at intersection I1. The worst number of stops is appearing at intersection I6. The maximum number of vehicles which can be discharged during the time appears at I6. From Table 3 one can conclude that travel time, delay, and the number of stops is higher in direction I1 → I6 during the morning peak hour.

Table 4. Obtained MoE for all intersections under UTOPIA

MoE	I1	I2	I3	I4	I5	I6	I7
LoS	D	D	B	D	A	**E**	B
Delay (s)	52.08	43.47	15.89	38.10	7.23	**65.21**	16.43
QLen (m)	**64.84**	39.92	6.58	17.70	3.76	43.87	8.86
QLenMax (m)	**409.84**	213.59	87.95	135.62	108.55	273.03	55.32
Stops	**1.50**	1.24	0.57	1.14	0.34	1.38	0.50
Vehicle throughput (veh/h)	3,163	3,712	1,861	2,065	3,593	**4,795**	1,421

Table 5. Obtained results for arterial sections under UTOPIA

MoE	I1 → I6 (L = 1,080 m)	I6 → I1 (L = 679 m)
Travel Time (s)	**366.72**	97.02
Delay (s)	**292.68**	50.04
Stops	**9.53**	1.39

Tables 4 and 5 contain the simulation results for MoEs obtained from the evaluation of UTOPIA adaptive traffic signal strategy. As shown in Table 4, most of the intersections operate at an acceptable LoS of B, C, or D during the morning peak hour. Only one intersection (I2) operate at unacceptable LoS E during the peak hour. A significant delay is occurring at intersection I6, the one with the worst LoS. Regarding other MoEs, the longest average queue length and the maximal queue length is appearing at intersection I1. The worst number of stops is appearing at intersection I1 also. The maximum number of vehicles which can be discharged during the time appears at intersection I6. From Table 5 one can conclude that travel time, delay, and the number of stops is higher in direction I1 → I6 during the morning peak hour.

Adaptive traffic signal control strategy shows better results regarding LoS, average queue length, maximal queue length, and vehicle throughput. Only the number of stops increases under this type of control. From the analysis of obtained results for arterial sections, adaptive control strategy shows an overall decrease of travel time and delay. A small increase can be noticed in the number of stops. Field tests show even better results because in the congested period the traffic operator includes a preemption strategy that was not investigated in this phase of research.

CONCLUSION AND FUTURE WORK

The results of the evaluation showed that the performance of the UTOPIA adaptive traffic signal control provided better LoS, average queue length, maximal queue length and vehicle throughput across the intersections versus fixed time control. A small increase can be noticed in the number of stops under adaptive control strategy. The overall travel time is decreased in the examined arterial corridor showing the influence of adaptation to different traffic demand regarding travel direction. Namely, UTOPIA decreases the travel time in the congestion direction and at the same time the travel time in the opposite direction increases. Thereby, the benefits gained in the congested direction are larger than the drawback in the opposite direction.

In the recent decade, algorithms from the domain of artificial intelligence are being used for traffic control. They have the ability to accumulate and use knowledge, set a problem, learn, process, conclude, solve the problem and exchange knowledge with other systems. Future work on this topic will include comparison and testing of self-learning urban traffic control strategies versus UTOPIA adaptive control.

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