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RESEARCH ARTICLE

Theoretical investigation of emission and delay based intersection controlling and synchronizing in Budapest

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Abstract

Road transport is one of the main land transport modes providing flexible door to door services. New type of control of road traffic flows in urban intersections is modelled in this article. Furthermore the synchronizing possibilities of intersections are investigated as well. Cost of CO_2, CO, CH, NO_x, PM and value of travel time had been used by the authors in order to estimate the cost of road users as a basis of control. The article presents advice for optimal control and gives simulation results based on the emission and delay based costing. Traffic flow parameters, such as traffic flow concentration and traffic flow speed are presented based on real traffic data of investigated intersections. In this article not only single intersections were investigated, but a chain of intersections in order to analyze the recovery potential of synchronization reserves.

Keywords

intersection controlling · cost function · synchronizing

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1 Introduction

Vehicle flows carry people, distribute industrial freight and work equipment on road network elements *(Torok, Berta, 2010)*. Majority of these road vehicles are driven by internal combustion engines; therefore besides practical use they also create a lot of problems, such as air pollution and particulate matter by combustion products, noise and vibration. Various problems caused by vehicles are discussed in the article written by Makaras *(Makaras, et. al., 2011)*. Wang *(Wang. et. al., 2008)* presented various methods of fuel consumption and engines‘ emission measuring as well as coefficients of efficiency. Szendro *(Szendro, et. al., 2012)* investigated climate fluctuation changes and energy consumption in Hungary. Smit *(Smit, et. al., 2008)* presented and generalize three emission models, where the impact of congestions on motor vehicles‘ emission is evaluated differently and present indicators to identify transport congestions. Jakimavičius, and Burinskienė *(Jakimavičius, M.; Burinskienė M., 2010)* investigated vehicle flow optimization methods and their application possibilities when informing traffic users about the situation in the city. Signal control is a traditional method to improve traffic efficiency at intersection areas, and the related signal design problems have been investigated for several decades. According to the traffic flow state, two categories of signal design problems are addressed so far: static-flow-based problems and dynamic-flow-based problems *(Ren et. al., 2013)*. In order to define the level of service of intersections, it is necessary to know some of the basic parameters of traffic flow, like flow intensity, vehicles velocity and density *(Bogdanović et. al., 2013)*. Social cost intersection controlling is an up-to-date research topic as it could increase the level of intersection *(Meszaros, Markovits-Somogyi, Bokor, 2012)*. This article gives an example of applying models of traffic controlling in the basis of emission and delay based controlling and can be a solid base of further tolling development *(Torok, Siposs, Meszaros, 2011)*. The article not only investigates one intersection, but the possibility of synchronising the controlled intersections.

2 Methodology

An intersection can be characterized by directions and lanes. When describing traffic flows, a traffic lane is used as a keyword. An assumption is taken that cars cannot drive on an opposite traffic lane; therefore, the road is split into separate traffic lanes and two-way roads are described in the mathematical model as a separate one-way road with one or several traffic lanes *(Junevičius, Bogdevičius, Torok, 2011)*. In this model a traffic lane segment is taken as a finite-length line that ends in the intersection. Traffic flow was measured and emission and delay based cost was calculated as follows (1), (2):

$$TTS_i = \sum_{k=1}^{P} \left(v_{i,k} \cdot \tau_{i,k} \right) \tag{1}$$

where,

TTS_i: Estimated cost or revenue of travel time saving by direction i. [HUF]

$v_{i,j}$: Value of travel time for passenger k at direction i. [HUF/s]

$\tau_{i,k}$: Waiting time in the lane at direction i. [s]

$$EC_i = \sum_{l=1}^{r} \sum_{j=1}^{m} \left(\varepsilon_{i,k} \cdot \tau_{i,k} \cdot \rho_l \right) \tag{2}$$

where,

EC_i: Estimated Environmental Cost of direction i. [HUF];

$\varepsilon_{i,j}$: Environmental emission factor of vehicle category j in *directory i. [g/s] (Csikos, Varga, 2011), (Zoldy, 2011), (Bereczky, 2012), (Barabas, Todorut, 2011), (Negoiţescu, Tokar, 2013), (Makarevičienė, et. al., 2013);*

$\tau_{i,k}$: Waiting time in the lane at direction i. [s] *(Gal, 2012)*;

$\rho_{i,l}$: Cost of environmental emission for pollutant l [HUF/g] *(Tánczos, Bokor, 2004)*

For modelling purposes not only the detailed plan of each intersection was available but the plan of signalling as well (Fig. 1).

Authors have conducted a traffic measurement of each intersection in peak-time in order to estimate the traffic related social costs.

3 Results

3.1 Place 1: Gellert sqr

Authors firstly determined the optimal green time for intersection (place 1: Gellert sqr.) in case of minimizing delay (1), (Tab. 1.). For the optimal green times the total cost was determined (Tab. 2.). Authors determined the optimal green time for intersection (place 1: Gellert sqr.) in case of minimizing environmental pollution (2), (Tab. 3.): For the optimal green times the total cost was determined (Table 4.)

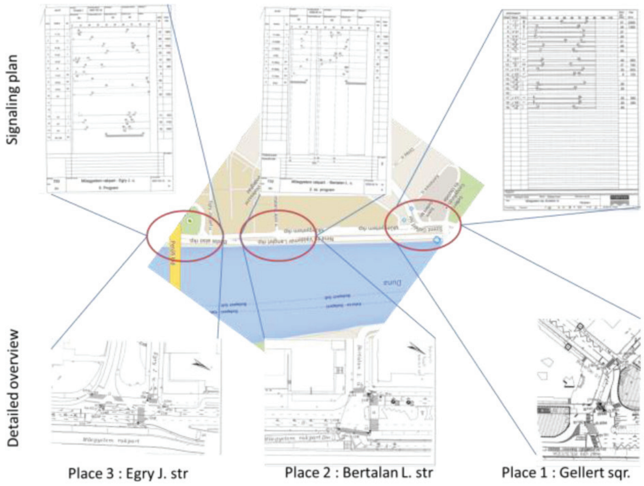

Fig. 1. Schematic overview of intersections and data availability

Tab. 1. The current and optimal (minimized delay) green times

	Direction 1: from Budafoki str	Direction 2: from Gellert sqr	Direction 3: from Műegyetem quay
Current green time [s]	30	49	37
Optimal in case of minimal delays [s]	36	43	31

Tab. 2. Cost of delay

		Direction 1: from Budafoki str	Direction 2: from Gellert sqr	Direction 3: from Műegyetem quay
Travel time delay cost of current signalling [HUF/h]	Passenger Car	81684	19772	20642
	BUS	43635	17909	-
	sum of direction	125319	37681	20642
	total sum		183642	
Travel time delay cost of new signalling [HUF/h]	Passenger Car	57517	31802	29268
	BUS	34483	24539	-
	sum of direction	92000	56341	29268
	total sum		177609	

Tab. 3. The current and optimal (minimized environmental pollution) green times

	Direction 1: from Budafoki str	Direction 2: from Gellert sqr	Direction 3: from Műegyetem quay
Current green time [s]	30	49	37
Optimal in case of minimal delays [s]	35	44	32

Tab. 4. Cost of environmental emission

		Direction 1: from Budafoki str	Direction 2: from Gellert sqr	Direction 3: from Műegyetem quay
Environ-mental emission cost of current signalling [HUF/h]	Passenger Car	196.91	47.56	50.17
	Goods Vehicle	9.57	2.32	1.16
	sum of direction	206.19	49.88	51.33
	total sum		307.69	
Environ-mental emission cost of new signalling [HUF/h]	Passenger Car	147.61	70.76	67.57
	Goods Vehicle	7.25	3.48	1.45
	sum of direction	154.57	74.24	69.02
	total sum		297.83	
Change [%]	sum of direction	-25.08%	48.81%	34.50%
	total sum		-3.14%	

Tab. 5. The current and optimal (minimized environmental pollution) green times

	Direction 1: from Petőfi bridge	Direction 2: from Gellert sqr	Direction 3: from Alsorakpart
Current green time [s]	35	37	38
Optimal in case of minimal delays [s]	42	44	31

3.2 Place 2: Bertalan L. str.

The same methodology was used to calculate the costs and green times related to Place 2: Bertalan L. str (1), (Tab. 5.). For the optimal green times the total cost was determined (Tab 6.). Authors determined the optimal green time for intersection (place 2: Bertalan Str.) in case of minimising environmental pollution (2), (Tab. 7.). As it can be seen in Tab. 7 the same result was find as in case of delay minimising. It can be easily understandable as there are no buses or goods vehicles in the traffic flow. For the optimal green times the total cost was determined (Tab. 8.).

Tab. 6. Cost of delay

		Direction 1: from Petőfi bridge	Direction 2: from Gellert sqr	Direction 3: from Alsorakpart
Travel time delay cost of current signalling [HUF/h]	Passenger Car	23152	25396	25157
	total sum		73705	
Travel time delay cost of new signalling [HUF/h]	Passenger Car	14587	15607	38292
	total sum		68486	

Tab. 7. The current and optimal (minimized environmental pollution) green times

	Direction 1: from Petőfi bridge	Direction 2: from Gellert sqr	Direction 3: from Alsorakpart
Current green time [s]	35	37	38
Optimal in case of minimal delays [s]	42	44	31

Tab. 8. Cost of environmental emission

		Direction 1: from Petőfi bridge	Direction 2: from Gellert sqr	Direction 3: from Alsorakpart
Environ-mental emission cost of current signalling [HUF/h]	Passenger Car	56.26	61.77	60.9
	Goods Vehicle	1.45	1.45	2.03
	sum of direction	57.71	63.22	62.93
	total sum		183.86	
Environ-mental emission cost of new signalling [HUF/h]	Passenger Car	35.38	37.99	92.8
	Goods Vehicle	0.87	0.87	3.19
	sum of direction	36.25	38.86	95.99
	total sum		171.1	
Change [%]	sum of direction	-36.99%	-38.55%	52.21%
	total sum		-6.95%	

3.3 Place 3: Egry J. str.

The same methodology was used to calculate the costs and green times related to Place 3: Egry J. str, (1), (Tab. 9.). For the optimal green times the total cost was determined (Tab. 10.). Authors determined the optimal green time for intersection (place 3: Irinyi J. str) in case of minimising environmental pollution (2), (Tab 11.). For the optimal green times the total cost was determined (Tab. 12.).

4 Analysis

After analyzing the intersections separately the authors have investigated the possibility of synchronizing of basis of delay minimizing or minimizing environmental pollution. Due to the same optimal solution for Place 2: Bertalan L. str and Place 3: Egry J. str the synchronizing can be easily done in both case (See Fig. 2 and Fig. 3.).

5 Conclusions

In this article we have introduced the social cost based intersection synchroning as a form of network controlling. As the single programmed intersections can be grouped to chains and can be synchronized the same algorithm can be derived for more complex social cost based intersections (Fig. 4.). As it has been shown the social interest would lead to different optimum in case of intersection controlling compared to single program (traffic) controlled situation. Further reserved potential can be recovered with synchroning these social cost controlled intersections.

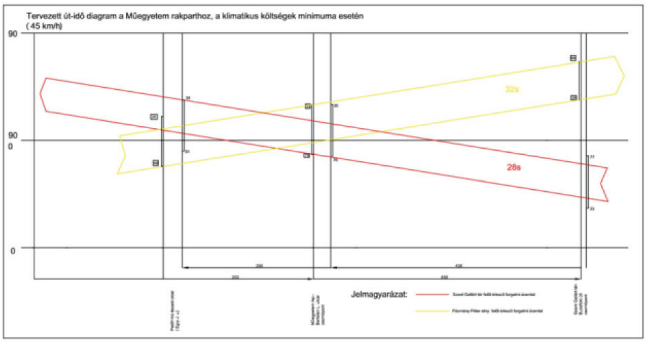

Fig. 2. Delay minimized synchronizing

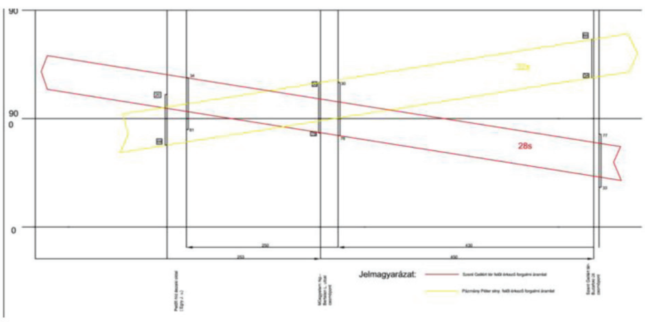

Fig. 3. Emission minimized synchronizing

Tab. 9. The current and optimal (minimized delay) green times

	Direction 1: from Petőfi bridge	Direction 2: from Gellert sqr	Direction 3: from Irinyi J. str	Direction 4: from Egry J. str
Current green time [s]	33	34	19	14
Theore-tical case of minimal delays [s]*	45	46	7	2
Optimal in case of minimal delays [s]	42	43	10	5

Tab. 10. Cost of delay

		Direction 1: from Petőfi bridge	Direction 2: from Gellert sqr	Direction 3: from Irinyi J. str	Direction 4: from Egry J. str
Travel time delay cost of current signalling [HUF/h]	Passenger Car	58204	64544	37295	25481
	total sum	185524			
Travel time delay cost of new signalling [HUF/h]	Passenger Car	32472	35587	54782	36853
	total sum	159694			

Tab. 11. The current and optimal (minimized environmental pollution) green times

	Direction 1: from Petőfi bridge	Direction 2: from Gellert sqr	Direction 3: from Irinyi J. str	Direction 4: from Egry J. str
Current green time [s]	33	34	19	14
Theore-tical case of minimal delays [s]*	45	46	7	2
Optimal in case of minimal delays [s]	42	43	10	5

Tab. 12. Cost of delay

		Direction 1: from Petőfi bridge	Direction 2: from Gellert sqr	Direction 3: from Irinyi J. str	Direction 4: from Egry J. str
Environ-mental emission cost of current signalling [HUF/h]	Passenger Car	156.6	136.59	60.9	89.61
	Goods Vehicle	4.35	16.53	4.06	4.35
	sum of direction	160.95	153.41	65.25	94.25
	total sum	437.57.86			
Environ-mental emission cost of new signalling [HUF/h]	Passenger Car	86.42	76.27	88.16	131.95
	Goods Vehicle	2.32	9.28	6.09	6.38
	sum of direction	88.74	85.55	94.25	138.33
	total sum	406.87			
Change [%]	sum of direction	-44.86%	-44.21%	44.63%	46.89%
	total sum	-14.10%			

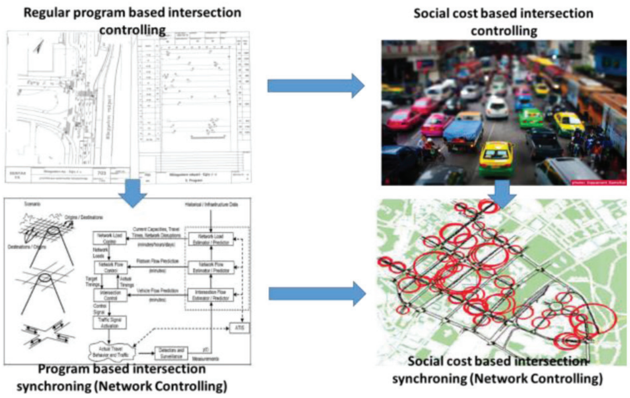

Fig. 4. Hierarchy structure of intersection controls

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