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Simulations of road traffic at light-controlled intersections

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Abstract

Light-controlled intersections represent important traffic points within urban road networks. The application of specific traffic control plans within this type of intersections affects not only the traffic capacity of these parts of the network, but also traffic on roads in their immediate or more distant surroundings. For control plans, it is appropriate to assess their various variants in order to subsequently determine the most suitable solution for deployment in real operation. For the needs of examining different traffic control strategies, it is possible to take advantage of road traffic simulations. Detailed simulation-based assessment of specific variants of traffic control (within limited segments of road networks) represents a suitable support for the implementation of efficient and smooth traffic inside of a given part of the real network (or inside of a designed network, the construction of which is planned in the future). The case study presents the examination of road traffic in a smaller city using the simulation tool Aimsun. The investigated system includes one central light-controlled intersection, two smaller intersections and also parts of adjacent roads. The aim of the research is to assess traffic variants that use different traffic control signal plans, especially within the central intersection. Variants are evaluated and appropriate recommendations are formulated.

Keywords: Road traffic simulations, light-controlled intersections, traffic signal plan

1. Introduction

Transportation planning associated with road infrastructure and road traffic within urban areas represents an important part of the city councils' agenda. This planning is considered successful if it contributes to ensuring safe, smooth and, if possible, ecological road traffic on urban roads.

City councils cooperate with traffic designers and traffic engineers on the mentioned traffic planning, while such construction and traffic control solutions are required, which will create conditions for the implementation of quality traffic. From the point of view of assessing the variants of the planned operation, it is very advantageous to apply the experimental research method of computer simulation. This method makes it possible to objectively evaluate a number of characteristics of the planned traffic before its implementation in reality.

This paper focuses mainly on the issue of verification of road traffic within the zones of light-controlled intersections and their surroundings. Attention is paid mainly to the evaluation of the characteristics of simulated traffic (during rush hours) when applying different signal plans within light-controlled intersections in cities.

2. State-of-the-art

Simulation-based testing (Barcelo et al., 2005; Mahmud et al., 2019; Alasova et al., 2018; Křivka, 2010 etc.) of different road traffic and road infrastructure variants represents a suitable method for inspecting prospective traffic reflecting relevant solutions.

One part of the research related to the road traffic is the optimization of traffic at light-controlled intersections. Within this type of intersections, so-called signal plans play a key role, which can be both static (Webster, 1958; Webster et al, 1966; Cheng et al, 2003; Zakariya et al, 2016) and dynamic (Yanguang, 2012). Appropriate optimization can be represented, for example, by minimizing the mean waiting/stop times of vehicles, minimizing the production of emissions, etc.

In recent years, various solutions for so-called Intelligent Transportation Systems have also been successfully promoted (Rida et al., 2020; Valente et al., 2018).

3. Light-controlled intersections

Light-controlled intersections are important traffic points within urban road networks. The application of specific signal plans for traffic control within the mentioned type of intersections affects not only the traffic throughput of these parts of the network, but also traffic on roads in their immediate or more distant surroundings.

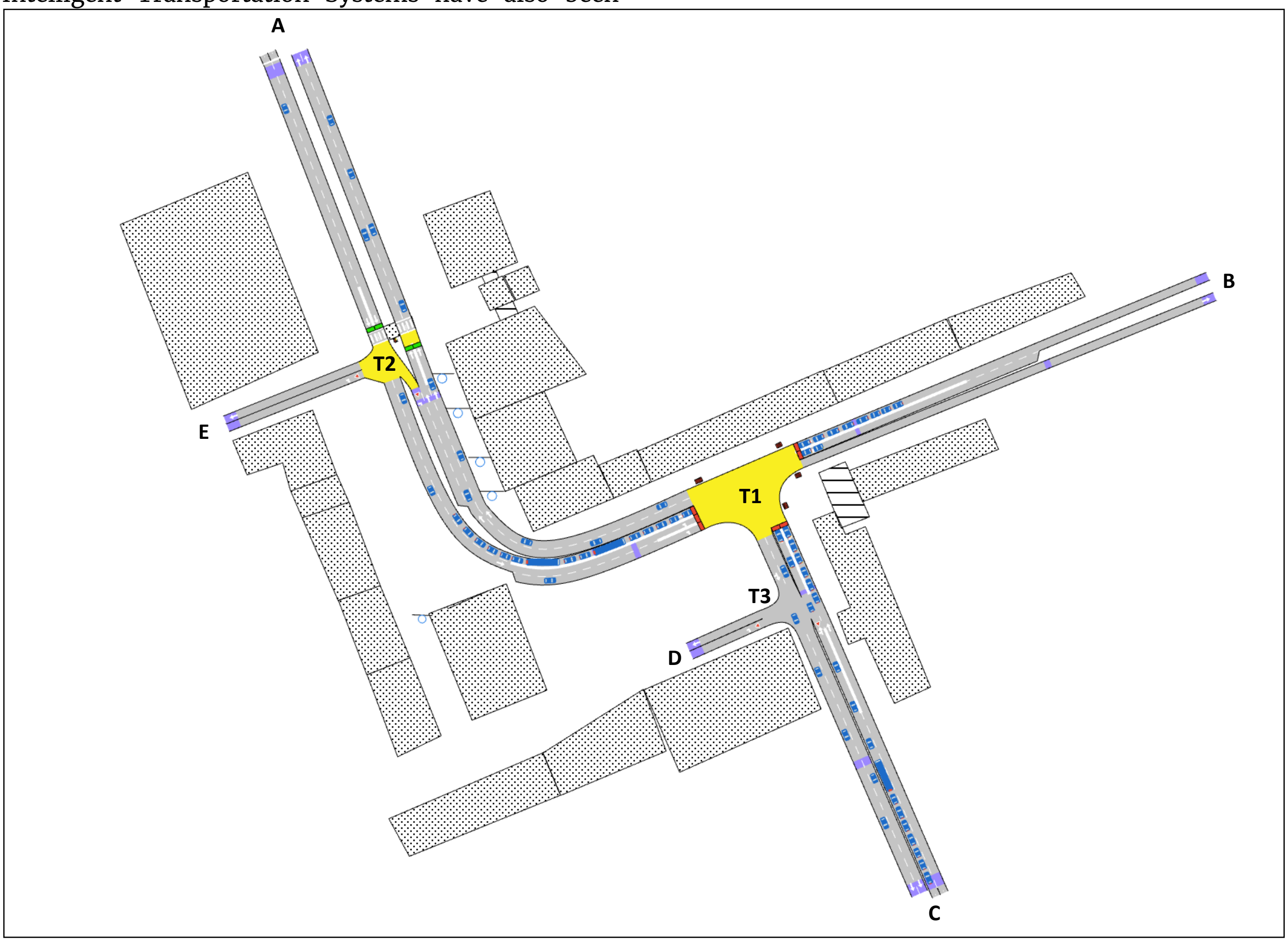

Figure 1. The illustrative screenshot from the road traffic simulation within the frame of the tool Aimsun.

Various (analytical) methods are used in the field of traffic engineering to create signal plans that are suitable for road traffic control. These methods always take into account selected characteristics of the relevant traffic flows, which include, for example, current intensities between defined points (origins and destinations), vehicle composition of these flows, etc. An example of a method that is often used to design signal plans is the so-called saturated flow method. (Webster, 1958; Webster et al, 1966; Cheng et al, 2003; Zakariya et al, 2016).

Traffic control at an intersection can be of two types. *Fixed* (static) *control* is always fixed for a given period of time (e.g. for rush hour), while a specific signal plan is always used, which does not take into account the changing intensities of traffic flows in real time. It is assumed a constant intensity of vehicle flows with only long-term changes. The operational and technical costs of carrying out fixed traffic control are not relatively high.

The principle of *dynamic control* (applying flexible switching between different signal plans) is to adapt to traffic so that even short-term fluctuations in traffic intensity affect the control (Yanguang, 2012; Rida et. al., 2020). A dynamic way of traffic control requires higher technical costs (than in the case of fixed traffic control) with regard to the processing of data that reflect the current traffic. The number of required measuring points corresponds to the number of controlled traffic lanes, while the measurement and interrogation intervals are short (in the order of seconds).

4. Simulation testing of road traffic

After designing specific variants/scenarios of road traffic control (reflecting the given features of traffic flows), it is then possible to advantageously use the verification of these variants using computer simulation. Relevant simulation investigations, which apply a sufficient number of replications for individual simulation experiments, provide detailed operational characteristics (regarding the traffic performed) within many different parts of the investigated network.

After evaluating the results of individual simulation experiments (examining different variants of traffic control), the respective variants can be compared in terms of their operational properties. Variants showing good quality of operation (considering account the given optimization criteria) then represent suitable candidates for deployment in real operation.

5. Case study

For the purpose of demonstrating a simulation testing of different traffic control scenarios within light-controlled intersections, a small-scale case study was processed.

The case study presents the examination of road traffic in a smaller city (a limited segment of the road network in the city of Pardubice in the Czech Republic was examined – Fig. 1).

Relevant experiments were performed using the simulation tool Aimsun (Barcelo et al, 2005). The aim of the research was to assess the traffic variants applying different signal plans for the traffic control, especially within the central intersection. Variants were evaluated and appropriate recommendations were formulated. This study represents a loose continuation of the earlier work: (Křivka, 2010).

In accordance with the requirements of the city council, only fixed (static) control was checked, as the city does not plan to install sensors (measuring points) to detect the current traffic situation.

5.1. Road infrastructure specification

The investigated system (Fig. 1) includes one central light-controlled T-intersection (T1), two smaller T-intersections (T2, T3) and also parts of adjacent roads (A, B, C, D, E).

The mentioned roads can be characterized as follows: A – the four-lane road, B – two-lane road, C – four-lane road, D – two-lane road within a smaller street, E - two-lane road on a shopping street.

Table 1. The metric characteristics of the roads.

Communication ID	The length
Road A (interconnected with T2)	106 m
Road B (interconnected with T1)	158 m
Road C (interconnected with T3)	104 m
Road D (interconnected with T3)	36 m
Road E (interconnected with T2)	51 m
Connecting road **T1-T2**	150 m
Connecting road **T1-T3**	20 m

The intersections have the following properties: T1 – the main isolated light-controlled intersection, T2 – a smaller intersection with the light-controlled pedestrian crossing (the pedestrians utilize a relevant button in order to indicate their request to cross the road A), T3 – a smaller intersection interconnecting the roads C and D.

The metric characteristics of the infrastructure are specified within the Table 1.

All T-intersections represent three-armed equilateral intersections whose arms have the following lengths: 20 m (T1), 7 m (T2) and 7 m (T3).

5.2. Traffic flows in rush hour

In the case study, the road traffic was monitored at peak hours (3-4 p.m.). OD matrices (specifying the rates of individual traffic flows) were obtained on the basis of conducting our own traffic survey and subsequently performing expert predictions of increasing the intensities of selected traffic flows for the period 2020+ (Tables 2-3).

Freight road transport was not considered for the monitored traffic, as a ban on the entry of lorries is applied in the center of the city.

Table 2. Origin-destination matrix (OD matrix) for private transport.

	B	D	C	A	Total
B	0	14	286	424	424
C	264	27	0	259	550
A	607	16	318	0	941
E	11	0	7	0	18
Total	882	57	611	683	2233

Table 3. Origin-destination matrix (OD matrix) for public transport.

	B	C	A	Total
B	0	1	1	2
A	3	0	0	3
C	3	0	0	3
Total	6	1	1	8

5.3. Signal plans for the central intersection

The saturation flow method was used to calculate the signal plans (Zakariya et al, 2016) for the control of the T1-intersection. Two different light signaling cycle lengths were proposed for this method (in accordance with recommendations from the field of traffic engineering): 100 s and 120 s.

Table 4. Parameterizations od simulation experiments.

Number of replications	100
Observed period of time (peak hour)	3-4 p.m.
Warming-up period	20 minutes
Simulation step (Aimsun)	0.75 s
Reaction time of drivers	1.50 s
Queue entry speed	1.00 m/s
Queue exit speed	4.00 m/s

Figure 2. The illustrative heat map (Aimsun) reflecting mean speeds of cars within the studied part of the urban road network.

5.4. Parameterization of simulation experiments

The simulation experiments were guided by two different scenarios: Sc100 and Sc120, which applied different signal plans to control the T1-intersection. These scenarios employed the cycle lengths given in section 5.3.

Each of these scenarios applied the same OD matrix. Both scenarios also used the parameterization of simulation experiments according to Table 4.

5.5. Verification and validation

The verification of the simulator was performed in the form of a visual inspection and data collection from the running of the simulation experiments, while the logical correctness of the simulation operation was approved. Available data from historical reality were used in the validation of the simulator (calibration model).

Historical intensities of individual traffic flows (obtained in the past through the relevant traffic survey) and information on average transit times of vehicles by individual segments of the transport network were available. The initial setting of the "Reaction time of drivers" parameter to 1.35 s showed unsatisfactory simulation results, which differed significantly from historical data.

Resetting the parameter to 1.5 s caused a change in the behavior of the model, which was subsequently evaluated as valid.

5.6. Evaluation of the results of simulation experiments

The results of simulations belonging to individual scenarios of experiments are described within the Table 5. In addition, an illustrative heat map reflecting mean speeds of cars is depicted in Fig.2.

The most important characteristics in terms of the focus of this case study are the traffic indicators: "Mean delay time" and "Mean stop time". This is in order to ensure the highest possible throughput of the T1-intersection for the forecasted intensities of traffic flows in the relevant part of the railway network.

From this point of view, the Sc100 scenario is better evaluated. The supportive indicators ("Total emission CO_2" and "Total emission NO_X") have very similar values.

Table 5. Results of simulation experiments.

	Sc100	**Sc120**
Mean delay time	107.0 s/km	116.0 s/km
Mean density	12.3 veh/km	12.8 veh/km
Total fuel consumption	119.0 l	118.0 l
Mean speed	22.8 km/h	22.7 km/h
Mean stop time	96.0 s/km	106.0 s/km
Total travel time	50.0 h	52.0 h
Total emission NO_X	0.2 g/veh	0.2 g
Total emission CO_2	131.3 g/veh	131.0 g/veh

Based on the above results, the application of measures according to the Sc100 scenario is recommended for the final implementation (i.e. the cycle length of the signal plan is 100 s).

6. Conclusions

Simulation-based testing of traffic at light-controlled intersections (reflecting variants of signal plans obtained from traffic engineering methods) represents a suitable evaluation method. The best evaluated variants (scenarios) are good candidates for implementation in real traffic. In addition, traffic simulations represent an appropriate environment for presenting relevant solutions to the investors (e.g., city councils.)

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