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Road and Rail Infrastructure III

Stjepan Lakušić – EDITOR

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

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EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

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DETERMINATION OF THE EFFECT OF INTERSECTION CONTROL MODE ON VEHICLE DELAY TIMES

Jan Hradil, Michal Uhlik, Tomas Havlicek
Czech Technical University in Prague, Faculty of Civil Engineering,
Department of Road Structures, Czech Republic

Abstract

The article deals with the determination of the effect of intersection control modes on vehicle delay times, or with the differences arising from the use of different control modes of traffic lights at low traffic volumes. It describes the methods used in the Czech Republic, and makes a brief comparison with neighbouring countries.In the second part of the article, vehicle delay times on traffic lights are determined using different methodologies and compared with reality. The HCM methodology (method of recording queue lengths in firmly fixed steps) was used and compared with the TP 235 Czech methodology for the calculation of delays and the method of direct measurement of each vehicle delay by a stopwatch. The results are in good agreement; considerable differences occur only in cases where more complex movements are involved (left turn in combination with giving priority to straight direction traffic). Furthermore, based on traffic surveys, vehicle delay times were determined and compared in the mode with traffic lights on (i.e. TL) and after switching over to different TL control modes at low traffic volumes. Different traffic movements at the intersection were monitored at multiple locations for verification and comparison purposes. Based on the results, it is evident that in terms of delay times, any active TL mode used at low traffic volumes is rather counterproductive. Also, environmental impacts (CO_2 emissions, CO, NO_x) tend to grow in the active TL mode. The article also presents the analysis of several model examples using micro analysis software and quantifies the above parameters. The last part brings the initial design of conditions under which TL switching off may be applied. Basic design and traffic engineering characteristics are identified and their effect on the TL control mode is described.

Keywords: traffic lights, HCM, intersection control mode, vehicle delay, environmental impacts

1 Introduction

Delay times of vehicles at intersections represent one of the principal criteria manifesting the traffic quality level in the Czech Republic. Delays at intersections controlled by traffic lights (TL) naturally depend on the control mode (CM) used, and at low traffic volumes, they may cause indignation on the part of drivers who are waiting for the free signal at an “empty” intersection, although they would pass across the intersection without a significant delay in the case of uncontrolled intersection operation. While in peak hours, TL at intersections should be preset to maximize their capacity, at low traffic volumes their setting should significantly differ, so that the cycle is not too long and vehicle delay times are minimized.

1.1 Intersection control modes used in the Czech Republic

There are numerous approaches to traffic control during low demand periods applied both in the Czech Republic and worldwide. They mostly involve uncontrolled traffic or different modes of vehicle actuated signal control, where the traffic signal controller reacts to the arrival of vehicles from different directions assigning accordingly the green light signal. The issue of the operating times of TL has been a controversial topic discussed among traffic experts not only in the Czech Republic, but also abroad, for decades. There are basically two groups of opinions. One group is composed of the proponents of continuous TL operation without exceptions, who prioritize a greater clarity and safety of the TL controlled intersection. Their opponents, on the contrary, prefer differentiated operation of individual TL according to local traffic conditions as a better solution for many reasons.
Different approaches to continuous traffic control using TL in the Czech Republic are evident from the following data coming from four largest cities in the country. (from 3% of continuously controlled intersections in Ostrava to 85% in Prague). Different approaches to the operating times of TL provide numerous opportunities for traffic surveys focusing on the comparison of delay times under different traffic conditions (traffic volumes, traffic control modes).

1.2 Intersection control modes used abroad

The views on traffic control during low demand periods also differ in foreign countries depending on the locality. In Germany, similar diametrical differences among individual cities may be found as in the Czech Republic. Overall, we may summarize them saying that the control mode significantly depends on the age of the used technology. With abilities of modern TL technology the necessity of alternative TL modes tends to lessen.

2 Traffic surveys

2.1 Methods of vehicle delay determination

Three different methods were used to determine the delay times of vehicles at an intersection within the scope of TAČR – TA03030046 project. The HCM method is based on observing the length of vehicle queues at the approach to an intersection in time steps which subsequently serves for deriving the average delay of vehicles. The results are processed using simple relationships that are not the subject of this article and can be found in HCM [2]. For accuraccy improvement 30 minutes interval was used as opposed to the recommendation mentioned in HCM (15 minutes).
The second method is measuring the delay of each vehicle separately with a stopwatch which records the moment when a vehicle stops and the moment when it passes a stop line. This method is considered the most accurate of all.
The third method is the calculation of the delay based on the Czech TP 235 methodology [3]. This methodology was compiled as the average of numerous measurements made at different intersections, mostly in situations approaching the capacity limits of entries to intersections.

2.2 Comparison of methods for identifying vehicle delays

Several intersections situated in different cities (Prague, Brno, Ostrava and Olomouc) were selected for the assessment of the informative value of the results of delay times identified by a traffic survey based on the HCM methodology [2]. The results are compared in Table 1.

Table 1 Delay values comparison

Location			Delay tw [s/veh]		
City	**Intersection**	**Mv.***	**HCM**	**Watch**	**TP235**
Praha	Nárožní – Pod hranicí	^›	7.6	5.4	7.4
Praha	Nárožní – Pod hranicí	‹	27.6	24.9	26.7
Praha	Patočkova – Pod Královkou	‹	25.4	24.3	25.8
Praha	Plzeňská – Jeremiášova	‹	27.0	23.3	9.0
Ostrava	Novinářská – Hornopolní	^›	27.9	29.4	29.0
Ostrava	Českobratrská – Sokolská	‹	47.6	50.9	38.0
Brno	Osová – Jihlavská	‹	37.6	44.5	44.1
Olomouc	Hodolanská – Tovární	‹	46.3	47.9	50.5
* Mv. – Intersection movement					

The comparison of eight Czech intersections clearly shows that the HCM-based methodology very well corresponds to the actual delay of vehicles measured with a stopwatch. Comparing the delays calculated on the basis of the TP 235 methodology against the delays measured with a stopwatch, we may also conclude that the methodology is in fairly good correspondence with reality (stopwatch). The exception is measurement No. 4 where the deviation is significant. This is caused by the fact that it is the only approach in the table with the left turn on a separate turn lane being also affected by the opposite direction (oncoming vehicles travel in the same phase). These issues were not elaborated in the Czech TP 235 methodology in an optimum way.

2.3 Comparison of delays in different control modes

Several measurements at intersections controlled by different modes in night hours than during the day was conducted. Due to the extensive amount of data thus obtained, only some selected measurements arre presented in this article.

2.3.1 Fixed control mode vs. flashing yellow control mode

One main and one minor approach were monitored at an intersection in Kladno. Both approaches share a common transfer lane for all directions; the intersection is controlled by a fixed programme with a cycle length of 60 seconds in the daytime, and at 9 p.m. it is switched to the flashing yellow control mode. The delay was measured using the proven HCM-based method from 7:00 p.m. to 9:00 p.m. and with a stopwatch in the flashing yellow mode from 9:00 p.m. to 10:00 p.m. (for the reason of lower traffic volumes). The column Iappr. expresses the vehicle volumes at the monitored approach, while the column Iinters. expresses the total vehicle volumes at all approaches to the intersection.
It is evident from Table 2 that switching this intersection to the flashing yellow control mode was suitably selected. Vehicle delays are smoothly reduced down to minimum values.

Table 2 Survey results – fixed CM vs. flashing yellow CM

City/Inters./Approach	Delay t_w [s/veh]	$I_{appr.}$ [veh/h]	$I_{inters.}$ [veh/h]	Control mode
Kladno Pražská-Unhošťská main approach	9.6	354	1096	fixed
	12.7	268	932	
	9.9	212	686	
	7.5	150	478	
	0.8	116	458	flashing yellow
Kladno Pražská-Unhošťská minor approach	21.9	248	1096	fixed
	21.9	266	932	
	18.6	160	686	
	15.3	118	478	
	13.4	118	458	
	6.3	86	378	flashing yellow

2.3.2 Vehicle actuated control mode vs. flashing yellow control mode

This control procedure is applied at many intersections in the city of Plzeň and at some intersections in Prague. The measurements were always performed 2 hours before switching modes and one hour after switching modes. The delay was measured using the proven HCM method in the actuated mode and with a stopwatch in the flashing yellow mode. It should be noted that the actuated control rates may have varied at the monitored intersections, and the control cycles were also different in length.

It is evident from Table 3 that the vehicle actuated control is not able to provide a substantial reduction in vehicle delay times at low traffic volumes either. After switching to the flashing yellow mode, the delay of vehicles at the monitored approaches sharply decreases at all intersections suggesting that the control had already been inefficient in terms of delays before the mode was switched over.

Table 3 Survey results – actuated CM vs. flashing yellow CM

City/Intersection/Approach	Delay t_w [s/veh]	$I_{appr.}$ [veh/h]	$I_{inters.}$ [veh/h]	Control mode
Plzeň Strnadova-Slovanská minor approach	26.9	108	1394	actuated
	18.6	110	1198	
	23.6	64	1010	
	23.7	62	728	
	9.1	32	646	flashing yellow
	3.8	26	420	
Plzeň Koperníkova-Tylova minor approach	16.1	308	754	actuated
	15.2	210	602	
	19.7	192	612	
	16.2	166	488	
	9.8	108	440	flashing yellow
	8.7	118	358	

2.3.3 Vehicle actuated programme vs. all-red control mode

This control procedure is applied at numerous intersections in Prague and it was also monitored at one intersection in České Budějovice. The measurements were always conducted in the same way as in the previous case. Table 4 clearly shows that if appropriately designed, the all-red control mode may reduce the delay times at an intersection compared to the vehicle actuated control mode. It was, however, identified at the monitored intersections that the majority of vehicles had to stop or at least brake before the intersection as detection devices were not adequately positioned. Although some experts point out the safety factor and the fact that this mode may reduce vehicle speeds in municipalities, it would be interesting to get some feedback from citizens living in the vicinity of such intersections related particularly to noise emisions due to decelerating and accelerating vehicles.

Table 4 Survey results – actuated CM vs. all-red CM

City/Intersection	Delay t_w [s/veh]	$I_{appr.}$ [veh/h]	$I_{inters.}$ [veh/h]	Control mode
Praha Jeremiášova-Radlická	10.7	90	576	actuated
	14.9	70	416	
	10.0	74	350	
	11.5	52	310	
	6.7	62	278	all-red*
	4.1	36	196	
České Budějovice Lidická-Mánesova	34.5	108	542	actuated
	27.0	96	506	
	29.1	84	614	
	26.9	58	294	
	7.0	48	174	all-red*

* all red CM has at all signal groups the red sign in basic state. When a request from one direction comes, it can be changed into the respective phase.

3 Results of traffic simulations

In addition to the impacts on delay times, alternative TL modes at low traffic volumes also affect the majority of relevant traffic engineering characteristics. Environmental impacts of an intersection were compared for the purposes of this article, namely the volumes of vehicle emissions that would differ for different control modes. These emissions were quantified using the Sidra Intersection 6 software. The model configuration used was a symmetrical crossroad with a left turn lane onto the main road and a branch length of 200 m (Fig. 1).

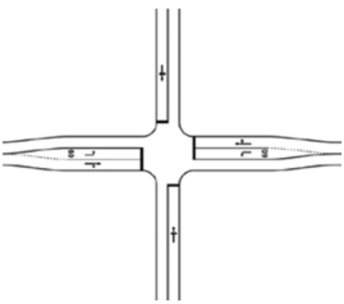

Figure 1 Model design of the evaluated intersection

Three basic control modes were evaluated, a fixed control model with a cycle time t=80 s, an actuated control mode and sign control (E-W major/N-S minor).
To see the effect of approach traffic volumes, two levels of approach traffic volumes were considered, 240 light vehicles+60 heavy vehicles and 600 light vehicles+120 heavy vehicles (for the whole intersection). The distribution into individual directions is uniform, i.e. the traffic loading scheme is also symmetrical for our purposes. The resulting values are presented in Table 5 and Table 6.

Table 5 Model results – 240 light veh/h+60 heavy veh/h

Control mode	Volumes $I_{inters.}$ [veh/h]	Ctrl. delay [s/veh]	Fuel [l/h]	CO_2 [kg/h]	CO [kg/h]	NO_X [kg/h]
TL-fixed	240+60	27.7	10.6	25.4	0.1	0.101
TL-actuated	240+60	13.6	9.7	23.4	0.1	0.096
Stop (2-way)	240+60	10.5	9.1	22.0	0.1	0.091

Table 6 Model results – 600 light veh/h+120 heavy veh/h

Control mode	Volumes $I_{inters.}$ [veh/h]	Ctrl. delay [s/veh]	Fuel [l/h]	CO_2 [kg/h]	CO [kg/h]	NO_X [kg/h]
TL-fixed	600+120	31.1	23.3	56.6	0.2	0.204
TL-actuated	600+120	14.5	21.4	51.3	0.1	0.193
Stop (2-way)	600+120	13.8	20.3	48.7	0.1	0.186

The results indicate the impact of the control mode used on both the expected delay times and the fuel consumption plus related modelled emissions. As it was assumed, this effect is the greatest for CO_2 emissions, which directly rely on the consumption and related vehicle delay times at an intersection. The CO values, however, are practically negligible (in terms of the total volume and its impact), while the drop in NO_x values is reduced by the fact that the volumes of NO_x emissions are only significant at higher speeds, i.e. their volumes in the area of intersections are not so noticeable. In terms of emissions, the difference between the fixed control mode and the stop (2-way) control mode is particularly evident. Here, the drop for CO_2 values is by up to 14%, while for NO_X values the drop is by up to 10% (Table 5, Table 6). Nevertheless, the decrease in delay times in this case is by up to 62% at low traffic volumes. For reference purposes, a simulation for loading with 1200 light vehicles+120 heavy vehicles was also performed which clearly shows that alternative modes of traffic control at intersections lose their effect with increasing approach traffic volumes.

4 Conclusion

As the above results and experience from abroad imply, alternative CMs are only usable under specific conditions which must be unambiguously defined and quantified. These are in particular:
· vehicle volumes and threshold values of switching to alternative CM modes;
· traffic significance of a particular road;
· width layout of individual branches;
· operation of public transport, pedestrian flows and their compositions;
· view parameters (vehicle/vehicle, vehicle/pedestrian);
· coordination of traffic lights;
· accident rates of a respective intersection;
· existing control system (fixed/actuated);
· used TL technology (classic light bulbs vs. LED technology);
· other atypical reasons (traffic calming TL, modifications for the blind, etc.).

The existing situation in the Czech Republic is rather chaotic. Due to the fact that there is no universal regulation specifying control modes, their application and impacts, different approaches are used in different towns. These procedures are frequently in contradiction with the basic traffic engineering knowledge being the cause of negative impacts in terms of both higher delay times and higher noise emissions and environmental burden. Therefore, a clear identification of the basic criteria, different control modes and their impacts on the road network is an indispensable fundamental priority for modern traffic engineering.

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