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Road traffic modelling and development of a specific traffic light control system

Dian Dzhibarov
Faculty of Computer Sciences and Automation
Technical University of Varna
Varna, Bulgaria
djibarov@tu-varna.bg

Ivan Grigorov
Faculty of Computer Sciences and Automation
Technical University of Varna
Varna, Bulgaria
ivan_grogorov@tu-varna.bg

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***Abstract*— The present paper is designed to give a sharper focus on the development of a traffic signal control system for a particular intersection. The study sets forth to examine the movements of vehicles, pedestrians and other types of traffic participants on their approaching, stopping and passing through a traffic-light regulated intersection. Accomplished is a critical examination and made is a road traffic model of a given intersection zone in order to help reduce traffic obstructions and congestion. Singled out, accordingly, are the respective traffic indicators along with some traffic flow dependencies and determined, subsequently, are the quantitative values of the key intersection performance indicators. Established is the criterion of optimality and refined are the algorithms to optimize the relevant length of the phases and the traffic signal cycles at the intersection area. Proposed, further, is a concrete solution for a definite traffic light control system.**

Keywords*— *analysis of traffic flows, detection of cars and pedestrians, traffic light system, traffic-light signal controlling

I. Introduction

The traffic light intersection systems, in the cities of the Republic of Bulgaria, operate with a fixed cycle lengths and phase sequences regardless of the traffic flow parameters. This causes both congestion and emergencies, in addition to the poor intersection capacity utilization. In such cases, there is strong possibility of prolonged waiting time for the vehicles and a waste of time for the pedestrians waiting at the curb to cross safely, an increase in the fuel consumption and the amount of harmful emissions released into the atmosphere.

Determined, thus, against such a background, is the choice of the object and subject of the present research:

• the object of the study is a light-signal control subsystem, namely, the feature – management of intersections controlled by traffic signals in the city of Varna and in particular the intersection between Slivnitsa Blvd. and Otets Paisiy Str. (Fig.1).

• the subject of the study are the processes of entering, waiting and passing through traffic-light -controlled intersections.

Road traffic is a complex and dynamic process and is explored as such. Expressed by the means of mathematics, the motion is a function of four variables - coordinates in space (x, y, z) and time (t).

Main traffic indicators:

When determining the key traffic indicators, different authors address that issue from different perspectives in terms of the objectives set. The traffic on the roads is expressed as a set of:

• transport flows;

• pedestrian flows;

• throughput capacity (of the signalized intersection);

• conflict points and obstructions;

• road traffic accidents.

When planning, organizing and controlling traffic, optimal solutions are sought to comply with the requirements for the traffic and pedestrian flows, the intersection throughput and various obstructions and blockages at the junctions.

In [3, 6] the intensity is considered as the number of vehicles passing through a given road section per unit of time. It can be measured for a given road lane, traffic or road direction as well as for a shorter time interval (minutes, seconds) depending on the intended objectives.

In [4, 5, 6] account has been taken of the importance of the composition of the transport flow as one of its main characteristics. It is a reflection of the percentage of the different types of vehicles in a given flow and has its impact on the mode and safety of the traffic, the load, the speed of movement, the types of maneuvers, junction visibility, and others. It also has its repercussions upon the optimal solution of issues related to the proper planning, organization, arrangement, guidance and control of traffic; problems regarding the computation of the throughput value of the specific road network, the estimated traffic intensity, the length of the traffic signal cycle, etc.

Two methods of research are primarily employed: manual and automated. The manual counting is conducted by an observer, while the automatic one-by detection devices positioned at specific points of the street network. There are authors [1, 2] who have introduced another method – traffic enforcement camera footage. This takes into account not only the number of the vehicles but the number of occupants as well. Moreover, this is a method that provides for the estimations of the speed of movement, the intervals between the vehicles themselves (spatial and temporal), the queue length, emergent obstructions, as well as assessment and prediction of dangerous situations and road traffic accidents.

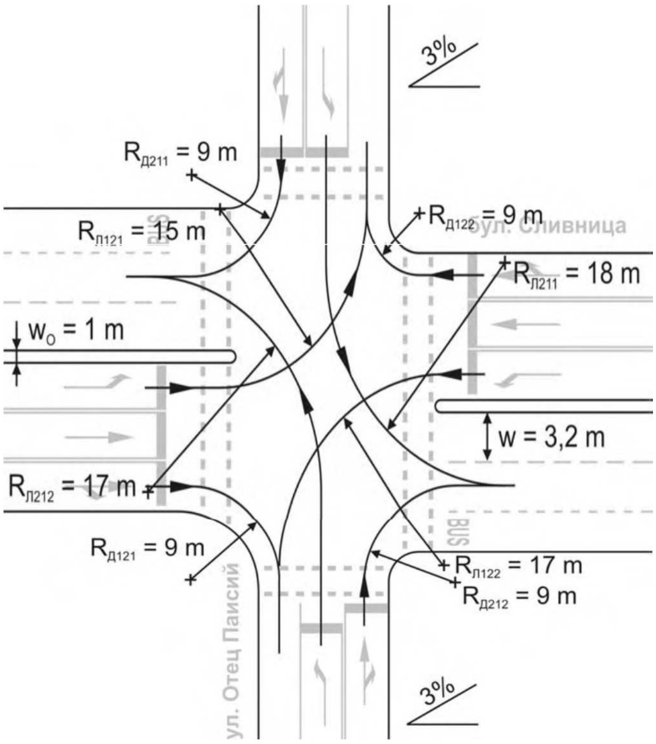

Fig.1 The main parameters of the intersection between Slivnitsa Blvd. and Otets Paisiy Str. – Varna

- Width of the lanes: 3,20 m;
- Width of the traffic islands: 1,0 m;
- Radii of right-turning lanes: 9,0 m;
- Radii of left-turning lanes: 15, 17 and 18 m;
- South/north gradient: 3%;
- Length of left-turning lanes from the major road: for 6 vehicles;
- Length of left-turning lanes from the secondary road: for 4 vehicles;

II. Selection and Survey of Key Traffic Indicators in the Zone of a Specific Signalized Intersection

A. *With a fixed cycle length and the phase sequence, regardless of the parameters of transport flows.*

According to Appendix №28 to Art. 56a of Ordinance №17 as of 2001 of the Ministry of Regional Development and Public Works for the regulation of the traffic through signal-controlled roads, estimation of the intermediate periods of time, the transition intervals, the signals giving the right of passage and the cycle of the permanent road traffic signal installations shall be carried out as described in the relevant methodology.

Derived are the following dependencies with respect to time:

- intermediate periods of time allowing for the vehicles and pedestrians to clear the lanes of traffic in the conflict zone of the signal-controlled intersections;

- for the oncoming vehicles approaching the stop line at the end of green signal giving right of way;

- for the vehicles or pedestrians to free up the zone of conflict:

-for a departing vehicle to approach the conflict zone at the beginning of the next green signal giving right of way;

The length of the signals granting permission for the different traffic and pedestrian flows to proceed is determined by their intensity. The coefficients of vehicle conversion into passenger cars are reported in Table 1 and are consistent with the Ordinance 2/2004 related to the planning and design of communication and transport systems in urbanized areas.

TABLE I. COEFFICIENT OF MV CONVERSION TO PASSENGER CARS

№ in sequential order	Type of motor vehicle (MV)	Coefficient of conversion to pc
1.	Passenger vehicles with a gross vehicle weight of up to 800 kg., minibuses with up to 12 seats	1,0
2.	Bicycles, mopeds	0,3
3.	Motorcycles	0,5
4.	Heavy-duty vehicles with permissible maximum weight of up to 5t.	2,0
5.	Buses or trolleybuses	3,0
6.	Articulated buses / trolleybuses	3,5

Estimated are the saturation flow rates S^i for each phase and every entry to the given signalized intersection, where w is the corresponding phase width at the entrance.

Obtained are the correction coefficients to reference conditions: for longitudinal gradient prior to the stop line – K_i; for the traffic conditions K_c – good, moderate and poor; for turning traffic flows – K_t;
The final value of the saturation flow rate is defined as:

$$S=S^i.K_i.K_c.K_t\ [E/h] \tag{1}$$

Example of a conflict zone clearance:

For vehicles: When leaving at a speed up to the maximum speed permitted $V_{l,a} = V_{мax,a} = 50\ km/h$:

$$T_{v,a}=3,6\frac{Il,a+Ia}{Vl,a} = 3,6\,\frac{Il,a+6}{50}\ [sec] \tag{2}$$

where I_a is the length of the passenger vehicle[m].

for pedestrians – freeing up at a speed of $Vl,p=1,2\sim1,5$ $[m/s]$

The vehicle 's waiting time during the first signal cycle of the traffic light system T_n depends on the number of the vehicles left in the queue Q, the maximum number of vehicles that can pass through a green traffic light Ggr, the number of incoming vehicles during the green - Agr and red – Ar signals, as well as the length of the green - tgr and red – tr signals:

$$Tn = (Q - Ggr) * tc + Agr * \left(\frac{tgr}{2} + tr\right) + Ar * \frac{tr}{2}\,[sec] \tag{3}$$

The vehicles' waiting time after the first traffic light cycle, up to the moment of their passage T_m, depends on the number of cycles N of the traffic light system, through which the remaining vehicles will have to wait for their turn to pass:

$$Tm = \sum_{n=2}^{N}(Q + Agr + Ar - Ggr * n) * tc\ [\text{sec}] \tag{4}$$

To acquire the final value of the green signals, calculated is the sum of the waiting periods of time for the individual flows of the entire intersection. The optimal solution is the minimum of the obtained values T_{wmin} for various possible combinations of the length of the cycle.

Finaly the calculated times are:

$T_{wgreen}=35s$

$T_{wyellow}=2\ s$

B. *With a flexible mode when specific phases of control are demanded.*

In such an event, the traffic light system operates with a minimum cycle formed by the phases that are not demanded and with a maximum cycle produced by all phases. The phases are demanded by inductive frames or presence detecting sensors placed at a distance of two to four meters prior to the stop line or by pressing a pedestrian crossing button.

The operation of the traffic light system is controlled by Siplus S7-412-2 PN programmable logic controller (PLC) with expansion modules SM421-32DE and SM422-32DA, power supply module PS407 10A, HMI panel KTP600 basic, and interfaces for connection of the selected controller - PROFINET and PROFIBUS (Fig.4).

Accomplished is a detailed state diagram (Fig.2), on the basis of which the selected controller (Fig.3) and panel are programmed in TiaPortal V.14 environment.

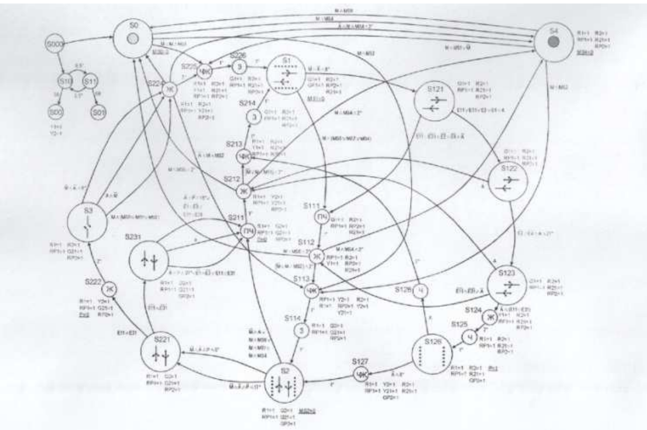

Fig.2. State diagram

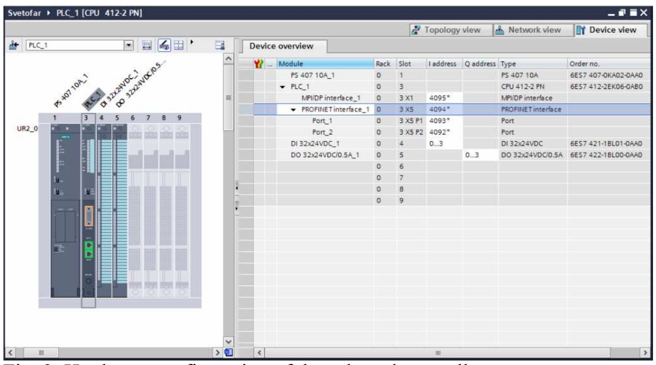

Fig. 3. Hardware configuration of the selected controller

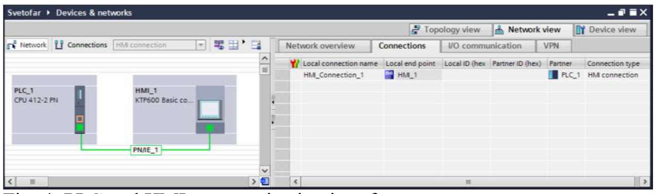

Fig. 4. PLC and HMI communication interface

III. Conclusions

Mathematical dependencies have been formulated to help determine the waiting periods of time for the transport flows at the surveyed intersection. Estimated, additionally, are the road traffic parameters with fixed cycle lengths and phase sequences, the lengths of the queues for each of the flows, and the intersection throughput. The same parameters have been analyzed in adaptive-signal mode of control allowing for the demand of specific phases, on account of the available measuring capabilities through various transport detectors– inductive frames or magnetic sensors embedded in the road surface paving material, microwave radars, passive infrared sensors, laser radars, acoustic sensors and video cameras. A comparative analysis of their advantages and disadvantages was subsequently carried out. All in all, the results achieved, through the algorithms that have been developed for the purposes of the present research and the adoption of an appropriate optimality criterion for improved passage of road traffic show a significant reduction in the fuel consumption, the amount of harmful emissions and the time of travelling.

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