ISSN: 0975-766X
CODEN: IJPTFI
Available Online through ***Research Article***
www.ijptonline.com

DETERMINATION OF THE ADAPTATION OF TRAFFIC LIGHT CONTROL TO THE CHANGING STRUCTURE OF TRAFFIC FLOW

Ivan Alekseevich Novikov, Anastasiia Gennadievna Shevtsova, Andrei Aleksandrovich Katunin
Belgorod State Technological
University named after V.G. Shukhov, Russia, 308012, Belgorod, Kostyukova Str., 46.

Received on 25-10-2016 *Accepted on 02-11-2016*

Abstract.

This paper deals with the analysis of existing approaches to the determination of road capacity by using forced control. This value is characterized by the maximum amount of conventional cars, which overcome the cross-section of the roadway at enabling signal of traffic light. We have determined the ways of development in the field of traffic management, overviewed various studies aimed at the calculation of the amount of road capacity, and explained the concept of conditional vehicle for its determination. We have considered the principles of determining the fundamental values for choosing an optimal traffic control regime. We have reviewed the heterogeneity of the composition of the traffic flow and the different classification systems of the main types of vehicles. We have determined the composition of the traffic flow, taking into account the heterogeneity of passenger cars according to West-European classification. We have suggested an equation of relationship between the composition of traffic flow and the capacity of a controlled intersection, which allows developing a mathematical model for the calculation of the optimal duration of the control regime for traffic flows.

Keywords: Road capacity, controlled intersection, traffic light, traffic management, traffic flow composition.

Introduction

One of the main indicators characterizing the efficiency of road operation is its capacity, estimated by the maximum possible number of vehicles passing through a certain road section in a unit of time. A special attention is paid to the investigation of this value both in the evaluation of proposed activities, and for the calculation of the existing schemes of traffic management. When assessing the effectiveness of forced management at the intersections, namely traffic light control, road capacity of the intersections is calculated with the use of such concepts as "saturation flow", which is a fundamental characteristic in the analysis and design of a controlled intersection.

Due to a rather wide variety of cars that make up the bulk of the traffic flow in any city, region, state and country, we have identified the main objective of the study - reduction of loss of time for road users due to the rational management of traffic lights. This paper includes one of the objectives of the study performed - a theoretical substantiation of the relationship of design parameters of passenger vehicles and the road capacity under traffic light control.

F. Webster was one of the first describing value of saturation flow in his writings [1]. He defined the basic parameters during traffic light operation and precisely specified the saturation flow in his model, defining it as car crossing, which would be ended if there was a continuous queue of vehicles, and they had a 100% duration of the green cycle (Figure 1). The Webster's basic model was later used by A. Miller [2], A. Clayton [3], J. Wardrop [4], B. Cobbe [5], and B. Greenshields [6].

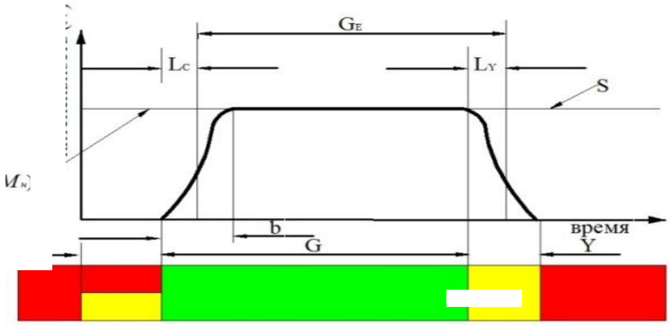

Figure 1 – "Webster's model" parameters, the initial process of signal controlled traffic:

G – green light duration;*Y* - yellow light duration;*ra* – duration of the combination of red and yellow lights; *Ge* – effective duration of green light; *LC* – start time losses; *LY* – a part of yellow light at the end of phase used for movement; M_H – saturation flow; *b* – the time interval from switching the enabling signal until the saturation flow.

The analysis of Webster's model (Figure 1) shows that the saturation flow depends on the traffic intensity, which is primarily determined by the cars that form it, so the calculation is mainly performed with the use of constant value obtained in the course of research and analytical studies.

According to research conducted in Washington, the current practice is focused on 2000 cars/hour at green signal at an intersection as the theoretical limit for the controlled intersection. In practice, this value ranges from 1500 to 1800 units/h and is typically used for the planning and design.

Methods

Considering the traffic process at the controlled intersections, it is obvious that the saturation flow value is defined as the duration of the movement with intervals and the delays at enabling signal and its switching to a block signal.

The work by B. Greenshields is widely known in this area [6]. He found that the first car enters the intersection after 3.8 seconds after green light turns on, and that the next cars start moving 3.1; 2.7 and 2.2 seconds after the previous vehicle. All the cars following the fifth one entered the intersection with an average interval of 2.1 seconds. The studied process of traffic corresponds to the saturation flow value of 1,714 U/h.

The instructions for the study of controlled intersections developed in Washington [7] defines “the basic flow" as 1,500 U/h in a 12-foot traffic lane (3.66 meters) per hour of enabling signal, or 1,250 U/h in a 10-foot traffic lane (3.03 m). These basic values are applied to the continuous traffic flows entering the intersection at an interval of 2.4 seconds for lanes of 3.66 m wide and 2.9 seconds for lanes of 3.03 m wide.

R. Bartle, V. Skoro and D.L. Gerlough [8], following a procedure similar to that used by B. Greenshields, examined the starting delays and intervals of the crossing at 13 intersections in Los Angeles, resulting in the average time interval for all traffic lanes ranged from 0.95 to 1.63, with a saturation flow equal to 2,208 U/h.

D. Capelle, and C. Pinnell [9] in their studies found that all vehicles, moving right after the second car, were moving at intervals of 2.1 seconds on average, and the saturation flow value was 1,714 U/h.

W. Assmus [10] investigated the intersections with two specially allocated lanes for turning left and defined the average interval as the time between the third and the last vehicle in the queue; according to his studies, the saturation flow value ranges from 1,540 U/h to 1,600 U/h.

R. Carstens [11] measured the traffic range for the fifth and the subsequent vehicle with an average of 2.3 and obtained a value of saturation flow equal to 1,572 U/h.

D. Berry [12] measures the saturation flow at 16 commuter intersections and gets different values depending on the type of traffic and lane width. This helps him identifying the dependence of change of the studied lane on the approach width and type of traffic.

Studying the relationship between the projected signal and the movement with an interval, G. King and M. Wilkinson [13] recorded the crossing intervals of passenger cars at 39 intersections and concluded about the initial reduction of motion interval caused by the increasing position in the queue, which then leveled at about 2.2 second, and at the fifth position results in the saturation flow value equal to 1,636 U/h.

W. Kunzman [14] investigated the controlled intersections in Orange County, California, and determined the dependence of traffic interval on the number of cars waiting for the enabling signal, and received saturation flow values for forward and left turn movements.

In the case where the saturation flow value cannot be measured in-situ, the value of "ideal saturation flow" is applied with the use of correction factors that modify it in accordance with typical local conditions. The Highway Capacity Manual [16] considers the saturation flow equal to 1,800 U/h, as "ideal", used in combination with the correction factors. Saturation flow $M_н$ in the specific road conditions is determined by the formula:

$$M_н = M_o \cdot N \cdot f_W \cdot f_{HV} \cdot f_G \cdot f_P \cdot f_{BB} \cdot f_A \cdot f_{RT} \cdot f_{LT} \quad (1)$$

where M_o – ideal saturation flow, taken for 1,800 U/h; N – number of traffic lanes, f_W – lane width factor; f_{HV} – heavy vehicles factor; f_G – longitudinal gradient factor; f_P – parked vehicles factor; f_{BB} – bus barrier factor, f_A – area type factor; f_{RT} – right turn factor; f_{LT}- left turn factor [19].

Average calculated values for ideal conditions, when the intersection has no longitudinal gradient, the influence of the heavy vehicles, buses and parked cars is absent or minimal, as well as the performance of the right and left turn occurs without interference, make up, in the American controlled intersections capacity manual [20], 1,900 U/h, in German - 2,000 U/h [21].

Levashev A.G. defined in his study [22] a "perfect saturation flow" as 1,904 U/h.

Kremenets Iu.A., Pecherskii M.P., Afanasiev M.B. [23] calculate the saturation flow value for the straight forward movement on the road without a longitudinal gradient by a formula that associates this figure with the width of the traffic lane:

$$M_н = 525 \cdot B_{ПЧ} \quad (2)$$

where $Mн$ – saturation flow, U/h; $Bпч$ – traffic lane width, m.

A literature review on the study of the saturation flow revealed a variety of methods and approaches used to define it; the generalized analysis of the saturation flow studies is shown in Table 1.

Table 1 – The generalized analysis of the saturation flow study.

Source and conditions	Saturation flow value, U/h
B. Greenshields [6]	
one lane	1714
Traffic Performance at Urban Street Intersections (Washington) [7]	
intersection approach width	
3.05 m	1,250

3.66 m	1,500
R. Bartle, V. Skoro and D.L. Gerlough [8]	
one lane	2,208
D. Capelle and C. Pinnell [9]	
one lane	1714
F. Webster, B.M. Cobbe [5]	
intersection approach width	
3.05 m	1,850
3.66 m	1,900
W. Assmus [10]	
one lane	1,600
R. Carstens [11]	
one lane	1,572
D. Berry [12]	
intersection approach width	
3.05 m	1,733
3.66 m	1,736
G. King, and M. Wilkinson [13]	
one lane	1,636
W. Kunzman [14]	
one lane	1,672
D. Branston [15]	
intersection approach width	
2.98 m	1,757
3.29 m	1,767
3.60 m	1,771
4.39 m	2,050
Research of Department of Transportation (Washington) [16]	
one lane, 3.66 m wide	1,672
J. Sosin [17]	
one lane	1,895
Traffic Performance at Urban Street Intersections (Washington) [18]	
one lane	1,800
Highway Capacity Manual (Washington, USA) [20]	

one lane	1,900
Highway Capacity Manual (Cologne, Germany) [21]	
one lane	2,000
Levashev A.G. [22]	
one lane	1,904
KremenetsIu.A., PecherskiiM.P., AfanasievM.B. [23]	
intersection approach width	
3.0 m	1,850
3.3 m	1,875
3.6 m	1,950
4.2 m	2,075

Main Part.

According to the scientific and analytical review, the value of saturation flow varies significantly. It is measured on the ground or using an ideal or reference value obtained during the field research. The duration of the motion has been obtained for the conditional car, due to the diversity of this type of rolling stock, particularly characteristic of the current level of motorization. Today, there is a great variety of cars on the city roads, starting from *mini*, such as Smart (overall length - 2,500 mm.) and to *maxi*, for example, Toyota Tundra (overall length 5,800 mm) and, accordingly, the intermediate cars. Western European Classification is the most accurate for the rolling stock, classifying all passenger cars by the overall length (Table 2).

Table 2 – Western European Classification of passenger cars.

Class notation	Accepted class name	Approximate car length, mm
A	Ultra-small	up to 3,500
B	Small	from 3,500 to 3,900
C	Firs mid-sized	from 3,900 to 4,300
D	Second mid-sized	from 4,300 to 4,600
E	Large-sized	from 4,600 to 4,900
F	Luxury	over 4,900

Due to the difference in the design feature - overall length - the passenger cars will need a different time for passing a section of the roadway both in the case of controlled traffic with the help of traffic lights, and in the case of traffic in the priority direction without the use of forced control. The presence factors that reflect the share of each class of the car in general urban traffic, determined according to the following formula, help reflect the diversity of the basic structure of the city traffic - passenger cars, taking into account the Western European classifier:

$$k_A..k_F = \frac{\alpha_A..\alpha_F}{100\%} \quad (3)$$

where $k_A ... k_F$ – the presence factor of each class of the passenger car; $\alpha_A ... \alpha_F$ – the percentage of each class of the passenger car in traffic, obtained in a field study, %. Each city, region (state), the entire country will have its characteristic value of presence factors, which will depend on the level of profitability of the residents, eco-territorial location of the zone, the tax system, and many other micro- and macroeconomic indicators.

Conclusion

According to field studies of urban traffic flows, the values of the presence factors were determined, reflecting the composition of the urban traffic flows, on the example of the central area of the Federal District of the Russian Federation - Belgorod (Table 3).

Table 3 – The values of the presence factors for the urban traffic flows on the example of the central area of the Federal District of the Russian Federation - Belgorod

k_A	k_B	k_C	k_D	k_E	k_F
0.15	0.11	0.35	0.13	0.11	0.14

It is proposed to use the values of the presence factors in determining the road capacity at the traffic light regulation; we shall use a full-scale or calculation method to determine the travel length of each class of vehicle through the cross-section of the road according, and, using the resulting value, we will determine the unknown value [24, 25].

The obtained saturation flow values for different classes of passenger cars are reduced to a value, which depends on the proportion of the presence of each class of a car, determined by the presence factor in the general traffic flow, and is defined by the equation of relationship between the car design parameters and a road capacity of the controlled intersection:

$$M_н = M_{н\max A} * k_A + M_{н\max B} * k_B + ...M_{н\max n} * k_n \quad (4)$$

where $M_{нmaxA} ... M_{нmaxn}$– maximum saturation flow depending on the type of motion (straight, right turn, left turn) and the class of a passenger car, U/h; $k_A ... k_n$ - the presence factor that determines the percentage of each class of a passenger car in the general traffic flow; n - one of the six classes of cars according to Western European classifier.

Summary

The conducted practical research allowed us to determine that the traffic flow in the highly developed urban agglomeration consists of 80-90% of the passenger vehicles, differing from each other by their design parameters - overall length (from 2.5 m to 5.8 m).

Based on the theoretical studies the values of presence factors have been justified, reflecting the composition of the traffic flow at the regulated intersections, which are used in determining the level of adaptability of operating modes of a traffic light to the advanced characteristics of the traffic flow.

Acknowledgements

This paper has been prepared under a grant for research projects in priority areas of socio-economic development of the Belgorod region, Order No. 279 of October 22, 2015.

References

1. Webster, F., 1958. Traffic Signal Settings. London, England: Her Majesty's Stationery Office, pp: 156.
2. Miller, A., 1968. Australian Road Capacity Guide: Provisional Introduction and Signalized Intersections. Australian Road Research, pp: 132.
3. Clayton, A., 1940. Road Traffic Calculations. Journal of the Institution of Civil Engineers 16: 16-25.
4. Wardrop, J., 1952. Some Theoretical Aspects of Road Traffic Research. Proceeding of the Institution of Civil Engineers 1: 63-70.
5. Webster F., B.M. Cobbe, 1966. Traffic Signals. London, England: Her Majcsty's Stationery Office, pp: 231.
6. Greenshields, B., D. Schapiro and E.L. Ericksen, 1947. Traffic Performance at Urban Street Intersections. Technical Report No. 1 Yale Bureau of Highway Traffic: 12-24.
7. Highway Capacity Manual. TRB, Washington, DC, 1950. p. 1134
8. Bartle, R., V. Skoro and D.L. Gerlough, 1956. Starting Delay and Time Spacing of Vehicles Entering Signalized Intersections. Highway Research Board Bulletin, 2: 33-41.
9. Capelle, D., and C. Pinnell, 1961. Capacity Study of Signalized Diamond Interchanges». Highway Research Board Bulletin, 291: 1-25.
10. Assmus, W., 1970. Operational Performance of Exclusive Double Left-Turn Lanes. Evanston, IL: Northwestern University, pp: 57.
11. Carstens, R., 1971. Some Traffic Parameters at Signalized Intersections. Traffic Engineering, pp: 387.

12. Berry, D., 1974. Capacity and Quality of Service of Arterial Street lntersections, Research Report 30-1. College Station, TX: Texas Transportation Institution
13. King, G., and M. Wilkinson, 1976. Relationship of Signal Design to Discharge Headway, Approach Capacity, and Delay. Transportation Research Record 615: 37 – 44.
14. Kunzman, W., 1978. Another Look at Signalized Intersection Capacity. ITE Journal, 4: 12-15.
15. Branston D., 1979. Some factors affecting the capacity of signalized intersection. Traffic Eng. And Contr. V. 20, No 8-9: 390–396.
16. Transportation Research Board. Interim Materials on Highway Capacity, 1980.Circular 212.
17. Sosin J., 1980. Delays at inter sections controlled by fixed cycle traffic signals. Traffic Eng. And Contr., v.21, No5: 264–265.
18. SpecialReport209:HighwayCapacityManual.TRB, Washington, DC, 1985.pp. 516.
19. Levashev A.G., Mikhailov A.Iu., Golovnykh I.M. Engineering of controlled intersections: Study guide. Irkutsk: Publishing House of Irkutsk State Technical University, 2007.- 208 p.
20. Highway Capacity Manual. TRB, Washington, DC, 2000.: pp. 1134.
21. Handbuchfuerdie Bemessungvon Strassen verkehr sanlagen (HBS), 2002.ForshungsgesellschaftfuerStrassenundVerkehrswesen, Koeln, Januar.
22. Levashev A.G. Improving the efficiency of traffic management at regulated intersections: Author’s abstract of PhD in Engineering. Irkutsk: 2004. - 17 p.
23. Kremenets Iu.A., Pecherskii M.P., Afanasiev M.B. Technical means of traffic management. M.: Akademkniga, 2005. - 279 p.
24. Borovskoi A.E., Shevtsova A.G., 2013. Maximum lane capacity at a turning maneuver. Bulletin of Belgorod State Technological University named after V.G. Shukhov., 2: 188-191.
25. Borovskoi A.E., Shevtsova A.G., 2014. Study of the degree intersection saturation subject to the classification of passenger cars. Motor Transport Company,5: 51-53.