Clearance speed study for intergreen time determination

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Abstract. Intergreen is the period between ends of a green period of one phase and the beginning of a green period of the next phase at signalized intersections. Its determination requires data which are in relation of geometrical parameters of junctions and that of dynamic parameters of the entering in and passing through the crossroads vehicles. One of them is clearance speed of a last passing vehicle of a phase which is necessary to calculate its clearance time. The present study aims to determine values of clearance speed for straight ahead and turning vehicles and find a relations between them and curves radii, slope of the road etc. The study use field data bring at three traffic lights junctions in Sofia city. The obtained results and the conclusions reached would be used in intergreen time determination for phasing design optimization at these junction and the other one in the same condition includes clearance distance and curves radii of turning flows.

1. Introduction

Intergreen periods are very important for traffic safety in cases of crossing a traffic light junction. In the international scientific community, the *inter-green* time is defined as the time between the end of green of one stream and the onset of green of a conflicting stream [1]. They are secure the necessary time last passing car of a flow of a stage to leave conflict zone whit first entered cars of a flow in next stage, which will cross or merge the way of first one.

These times are parts of time-spacing diagram of signalized intersections. There are various methods to calculate their duration around the world. Main of them is German method [2] that is applied in many countries all over the world directly or in some modifications or supplements. Intergreen calculation principles in Germany, United States of America, Switzerland, Austria, France and some other country are reviewed by Wolfermann in [1].

In Bulgaria intergreen times are calculated according German model with Austrian acceptances in accordance in (1). Differences are in that the value cannot be less than three seconds (Austrian models says less than four seconds recommended). Intergreen time in Bulgaria may be adjusted for special local situation, if justifiable as permitted by the Swiss model [1].

$$t_{ig} = t_y + t_c - t_e + t_{ad}, s \qquad (1)$$

Where t_{ig} is intergreen time, s

t_y – Amber after green signal (its value is equal to 3 s, normatively defined);

t_c – Clearance time, s

t_e – Entrance time, s

t_{ad} – Additional time by the specialists view, s

$$t_c = \frac{L_c + L_v}{V_c}, s \qquad (2)$$

Where L_c is clearance distance of last departure car of a phase, m
L_v – Vehicle length, m
V_c – Clearance speed, ms^{-1}.

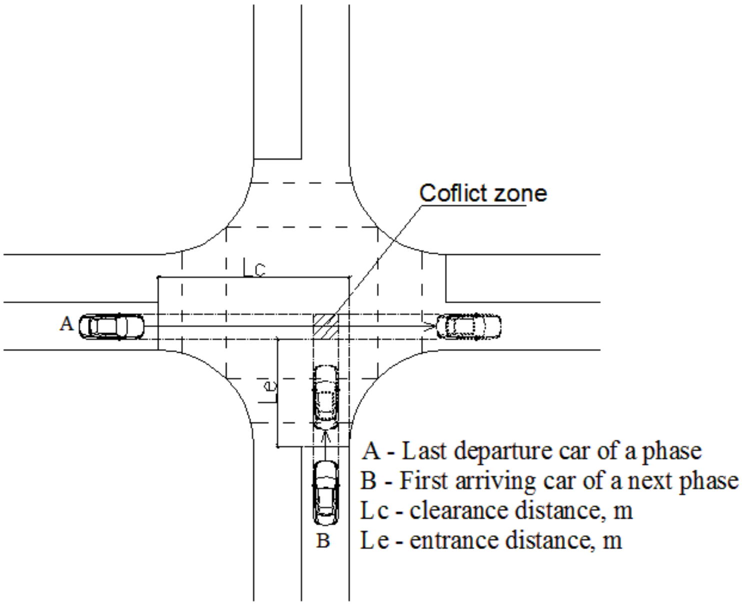

Figure 1. Clearance distance and entrance distance for the timing of intergreen periods.

A part of necessary data for intergreen time determination is a clearance speed in accordance of equation (2). This is the speed of last passing car of a departure flow (Figure 1). This paper gives the value of that speed which are result of field study in Sofia city.

2. Prerequisites and means for solving the problem

The applied values of clearance speed of a car in case of intergreen time determination varies in all over the world despite the similar approaches and adoptions in question in different countries. Austria applies 10 ms^{-1} for clearance speed of a car turning in curve radius smaller and 20 meters and 7 ms^{-1} of a car turning in curve radius smaller and 10 meters. Germany used values are 10 ms^{-1} for straight ahead moving and 7 ms^{-1} for turning cars. Also applied a value of 5 ms^{-1} of a car turning in curve radius smaller and 10 meters [3]. Retzko and Boltze in [2] were applied maximum value for clearance speed equal to the speed limit at an intersection. The minimum value they were considered 23 fts^{-1} (approximately equal to 7 ms^{-1}). Also they were assumed for vehicles that pass small curves clearance speed 16.4 fts^{-1} (approximately equal to 5 ms^{-1}) for R<49,2 ft (about 15 meters). Keshuang and etc. in [4] were determined free flow speed of right-turn traffic (6.60 to 8.00 ms^{-1}) and the shock-wave speed for the discharge flow of right-turn traffic (about 5 ms^{-1}). Guberinic in [5] assumed the speed of the vehicles leaving the conflict areas in range of 25-30 kmh^{-1} (6.9-8.3 ms^{-1}) independent of their directions. They were not explained about curves radii of the observation. Other scientists in this relation were not used clearance speed to determinate intergreen time. They were used specific values for yellow and all-red periods of different phases of time-spacing diagram of signalized intersections [6]. These values depend of designed speed and the distance in meters measured from the departure stop line to the furthest point of conflict with vehicles or pedestrians in the next or subsequent phase, taking into account the longest distance of any straight or turning movement within the phase.

In aims of study presented in this paper research was conducted at three traffic light junctions in the Bulgaria capital – Sofia city. The junction are formed by crossing the one of main boulevard “St Kliment Ohridski” whit “Osmi dekemvri” street (junction “T”), “Traycho Stanoev” street (junction “U”) and

“”Dr G. M. Dimitrov” boulevard (junction “D”), located in Darvenica district (Figure 2). Schemes of the crossroads are shown in Figure 3, Figure 4 and Figure 5.

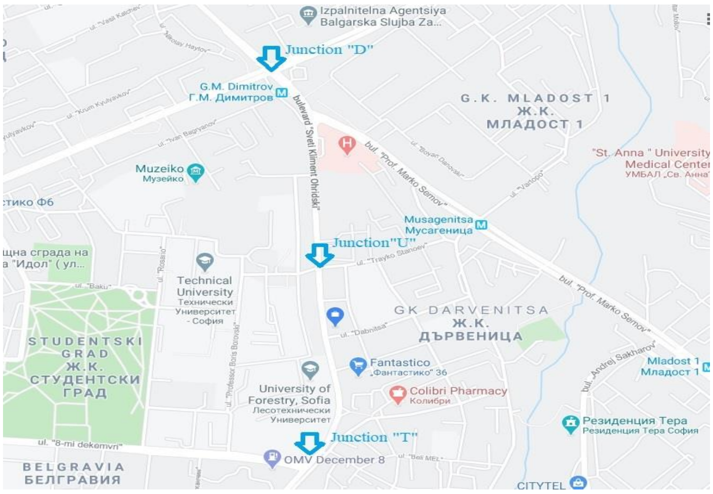

Figure 2. Location of observed junction.

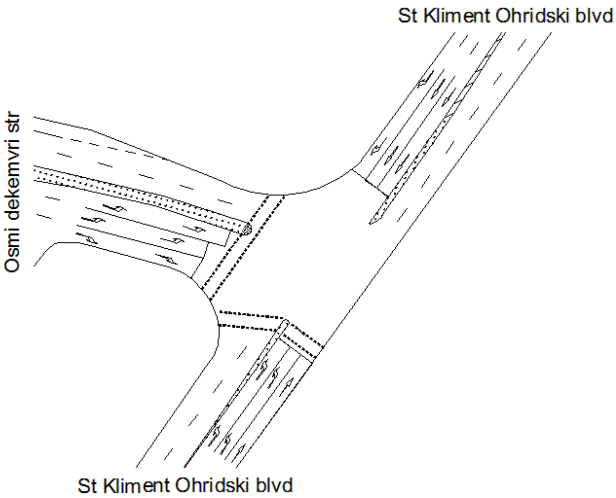

Figure 3. Scheme of junction “T”.

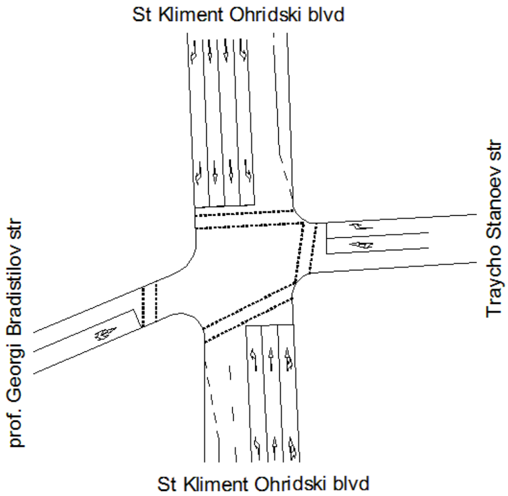

Figure 4. Scheme of junction “U”.

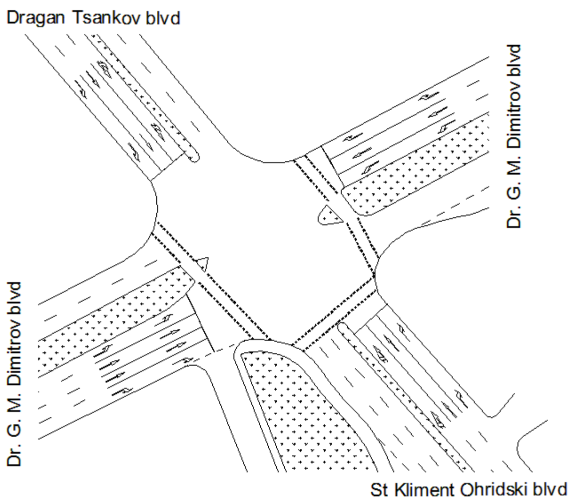

Figure 5. Scheme of junction “D”.

The research include determine clearance distance for every traffic flows cross the junctions and time to pass the distance from last clearing car of a departure flows of a stage. The purpose set require defining curves radii of turning flows wherefore also were measured. The data were obtained by hand measurement from video captured whit unmanned aerial vehicle known as a drone. Its type, principles of work and its opportunities were presented by Hristov, Damyanov, etc. in [7] and [8]. Usage of this type of aircrafts were described in detail in [9] and [10]. The authors were shown different applications of that technique which had been used in this study.

3. Results and discussion

For the purpose of the study traffic flows of each junction were indicated as shown in Figure 6 for junction "T", Figure 7 for junction "U" and Figure 8 for junction "D".

Necessary data about clearance distance, average time to pass the distance by flows, curves radii and result about average clearance speed by flows of each junction were presented in Table 1 for junction "T, Table 2 for junction "U" and Table 3 for junction "D".

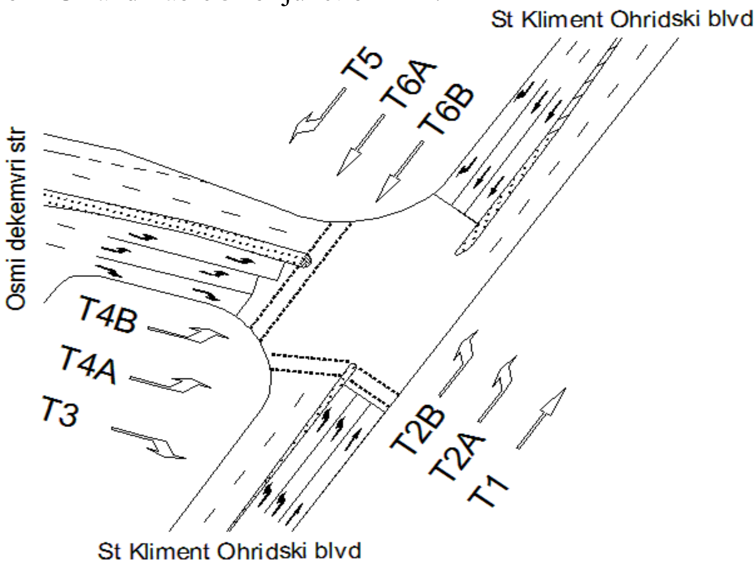

Figure 6. Traffic flows indication at junction "T".

Table 1. Necessary data and obtained results for junction "T".

Traffic flows	Passed distances, m	Turning radii, m	Average of last passed car		
			t, s	V, kmh^{-1}	V, ms^{-1}
T1	30	-	2.54	44.06	12.24
T2A	40	18	5.53	26.59	7.39
T2B	30	16	4.56	24.38	6.77
T3	17	12	3.18	19.78	5.49
T4A	40	37	5.45	28.14	7.82
T4B	31	33	4.68	24.92	6.92
T5	20	14	3.11	24.68	6.86
T6A	45	-	3.84	44.32	12.31
T6B	45	-	3.33	50.40	14.00

Results reading in Table 1 about junction "T" can see that the straight ahead flows run from 12.31 ms^{-1} to 14.00 ms^{-1} for last passing car of a departure flows. Last passing car of a turning flows had clearance speed from 5.49 ms^{-1} to 7.82 ms^{-1}. It is clear that the turning flows on minimum curve radius (12 m) had a minimum clearance speed at the junction. It gives an impression that the other turning flows had approximately equal values although a big differences of their curves radii. That can explain because the flows T4A and T4B despite of curves radii values have to decrease the speed at the end of passing which is determined of geometry of the crossroad.

The analysis shows increase of clearance speed of flow T6B compared with other straight flows. Its value is above 2.00 ms^{-1} from others. This cannot be explained by the junction geometry or traffic conditions furthermore there is a slope and flow was moving uphill. Obtained values show exceeding of speed limit about in 15% of cases.

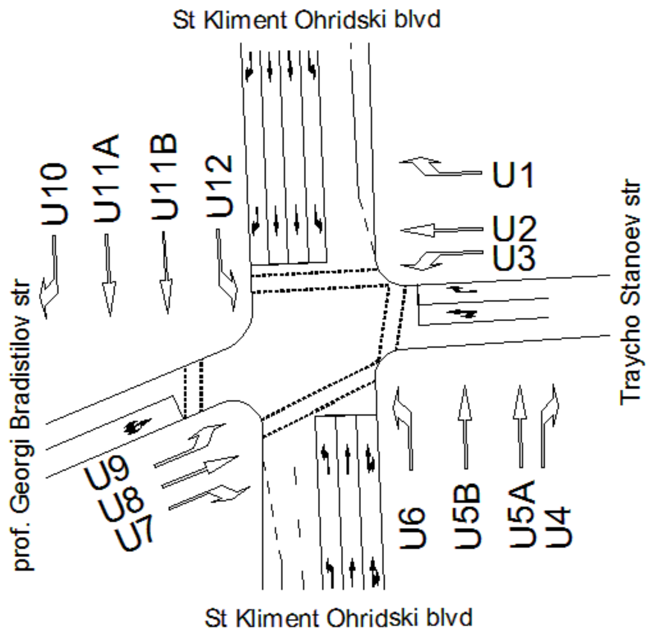

Figure 7. Traffic flows indication at junction "U".

Results about junction "U" show that the straight ahead flows had a speed from 6.43 ms^{-1} to 14.56 ms^{-1}. Flows U8 and U2 had a low speed in comparison with other straight flows. That explain with the conflict between flows U1, U2, U3, U7, U8 and U9 which runs in one phase. Approaches to the crossroad of these flows do not offer good visibility, straight ahead flows must to change their trajectory (it can be seen at Figure 4 and Figure 7) also contribute to decrease clearance speed of these flows. The same reasons are valid in the analysis of the speed when comparing flow U3 and U9 which had 10 meters higher curve radius but above 1.3 ms^{-1} lower clearance speed than flow U3.

Turning flows at this junction had a very various values for clearance speed. This is due to differences of curves radii of them. The analysis shows differences of clearance speed not only in different radii but in the equal values of this metric. For example flows U3 had about 1.2 ms^{-1} higher clearance speed than flow U12 which is had the same curve radius. It is the same at comparison about flow U1 and U4 which had above 1.00 ms^{-1} lower clearance speed than U1.

It gives an impression that the flow with minimum clearance speed are not that with minimum curve radius. This is flow U7 with curve radius 7 m and clearance speed of 4.91 ms^{-1}. Reason in this case is specific right turn conditioned of its geometry (approach, turn and exit condition).

Average clearance speed of last passing car of flow U11B was obtained like highest of observed ones. It value is above 3.00 ms^{-1} compared to flow U11A which is the same flow as regards to approach, traffic condition, direction and other conditions in relation for passing the junction of a car with this movement which is the same like situation about flow T6B at the junction "T". The values of the observed speed of flow U11B show exceeding the speed limit in about 30% of cases. This remains unexplained to the moment since it cannot be bound by the technical parameters of the intersection or traffic conditions.

Table 2. Necessary data and obtained results for junction "U".

Traffic flows	Passed distances, m	Turning radii, m	Average of last passed car		
			t, s	V, kmh^{-1}	V, ms^{-1}
U1	9	6	1.37	23.94	6.65
U2	38	-	4.58	33.07	9.19
U3	28	15	3.91	27.72	7.70
U4	13	6	2.42	19.61	5.45
U5A	22	-	2.06	42.71	11.87
U5B	22	-	1.94	42.11	11.70
U6	25	15	3.61	25.43	7.06
U7	18	7	3.80	17.69	4.91
U8	37	-	5.86	23.15	6.43
U9	36	25	6.03	22.89	6.36
U10	22	10	3.80	21.35	5.93
U11A	25	-	2.42	40.54	11.26
U11B	24	-	1.79	52.43	14.56
U12	16	15	2.93	19.96	5.55

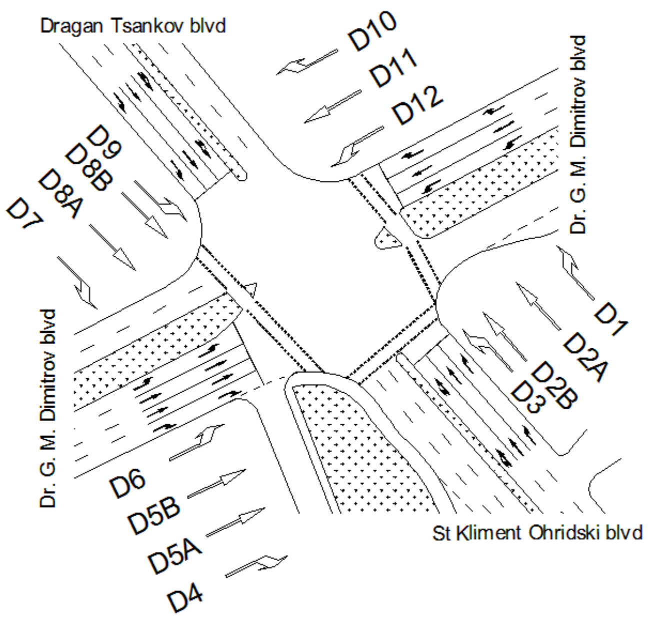

Figure 8. Traffic flows indication at junction "D".

Table 3. Necessary data and obtained results for junction "D".

Traffic flows	Passed distances, m	Turning radii, m	Average of last passed car		
			t, s	V, kmh^{-1}	V, ms^{-1}
D1	12	10	2.17	21.60	6.00
D2A	48	-	4.43	39.75	11.04
D2B	48	-	4.68	37.24	10.35
D3	50	37	5.20	35.26	9.79
D4	21	16	2.92	26.63	7.40
D5A	41	-	4.97	30.20	8.39
D5B	41	-	4.16	35.87	9.96
D6	38	30	5.14	27.50	7.64
D7	14	14	2.04	25.35	7.04
D8A	50	-	4.77	38.41	10.67
D8B	50	-	4.86	37.47	10.41
D9	48	38	4.95	35.14	9.76
D10	23	16	3.37	24.95	6.93
D11	40	-	3.66	39.91	11.09
D12	37	26	5.37	25.49	7.08

Shown results in Table 3 make clearly view of that the clearance speed of straight ahead flows are not much different from that of left turning flows (about 10 ms^{-1}). That can explain with their curves radii values which are than 30 meters expect the flow D12. Independently of his radius value (26 m) this flow have a behavior like flows with smaller curves radii. This is proven by his clearance speed (7.08 ms^{-1}) which is common for flows D7 of this intersection, U3, U6 of intersection "U" and others with curve radius about 15 meters that were been subject of the study.

It can be seen that the clearance speed of flows D5A and D5B is deferent form that of flow D12 although the flows D5A and D5B have a downhill slope. Similar is situation about approximately equal values for clearance speed of flows D2A, D2B, D8A and D8B, where the last two flows have large uphill slope. That show steadily driver behavior to keeping approximately constant speed in the same condition independently of road slope.

4. Conclusions

Presented study has given results about clearance speed used field data at three traffic light junction in Sofia city. Their analysis had shown that the clearance speed value depends on many factors which cannot be considered individually but always in the aggregate. That are the direction of the flow, curve radius in case of turning flow, traffic condition, organization, etc. The results showed the relation not so much between curves radii of the turning flows but between directions of turning. Was observed relation between left turn flows, right turn flows and straight flows. Study has shown speeds which were been above of speed limit at the area of junction. This result must not to be taken into account when specialists assumed clearance speed for more increase of traffic safety. It also turned out that the slope of the road does not affect in the clearance speed.

The conducted study gave grounds to determine the values of clearance speed as follows: straight ahead cars – 10 ms^{-1}; turning cars – 7 ms^{-1}; turning cars with curve radius smaller and 15 m – 5 ms^{-1}.

Author recommended these values be used in intergreen time determination with taking into account specific condition at a junction.

5. Acknowledgements

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