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ORIGINAL SCIENTIFIC PAPER

The Research Into the Influence of Non-Resident Drivers on the Critical Headway and Follow-Up Headway at an Unsignalised Intersection

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Abstract: The input parameters in the procedure for calculating the minor movement capacity of the unsignalised intersection are the values of conflict flow, critical haedway and follow-up headway. The conflict flow value is established in exact measuring, on the basis of flow values on approaches and their distribution by driving directions. On the other hand, the values of the critical headway and the follow-up headway are the parameters which depend on the estimate and the behaviour of the drivers doing the minor movement. On account of that, these parameter values depend on different factors and influences, therefore, they are not identical at all intersections. In the procedures for calculating the capacity of two-way stop controlled inersections, the values of critical headway and follow-up headway are given as recommendations. Some of the methods for capacity calculations, such as Highway Capacity Manual, recommend the research on these parameter values in local conditions, considering different influences. This paper presents the results of the research into the influence of non-resident drivers on the features and values of critical headway and follow-up headway, and thereby on the intersection capacity as well.

Keywords: unsignalised intersection, capacity, driver behaviour, non-resident drivers, critical headway.

INTRODUCTION

Two-way stop controlled (TWSC) intersections (unsignalised intersections) are the most common form of road and street crossings in a road network. Traffic at these intersections is regulated by priority signs, and according to the signalization, manoeuvres can be classified as major and minor ones. The capacity of an unsignalised intersection is calculated partially, on the basis of the capacity of minor movements on intersection approaches. The capacity of minor movement is most affected by the character of the observed manoeuvre, as well as by the values of conflict flow, critical headway (t_c) and follow-up headway (t_f). The conflict flow value is determined in the calculation on the basis of the values of approach flows and traffic features of the approach, that is, the distribution of approach flows by driving directions [1].

The critical headway of vehicles is defined as the minimum interval in the main flow which enables the minor movement being carried out. The follow-up headway represents the period from the moment of minor movement performing for the vehicle first positioned in the line on the minor approach, to the following vehicle coming to the position of the first vehicle [2]. Values of the both stated parameters depend on different factors and on the behaviour of the drivers who create the traffic flow on the minor approach. In procedures for calculating the capacity of unsignalised intersections, local measuring is advised in order to establish the influence of different local factors, which is not identical in all environments, through the determined values of critical headway and follow-up headway. In calculating the capacity of roads and intersections, different factors are considered for explaining the influences of traffic flow features. In the procedure for road capacity calculation, the influence of driver characteristics is also taken into account. The basic conditions for a highway flow include a driver population primarily consisting of commuters.

Studies have shown that resident (commuters) and non-resident (non-commuters) drivers do not demonstrate the same characteristics. Thus, the fact that resident and non-resident drivers take part in traffic significantly influences the features of traffic flow and road capacity. Taking into consideration previously stated facts, it can be assumed that driver characteristics also influence the intersection capacity, since the behaviour of resident and non-resident drivers significantly differ. Taking into account input parameter features for calculating the capacity of unsignalised intersections, it can be assumed that the presence of resident and non-resident drivers on minor approaches influences the values of critical headway and follow-up headway. As the influence of driver behaviour and driver characteristics has been experimentally confirmed at signalised intersections [3], as well as at roundabouts [4], it is expected that the influence of behaviour of different driver groups will also be confirmed at the TWSC intersection.

In a situation when the size of traffic flow parameters is measured within operational analysis, it can be considered that the influence of driver characteristics have been taking into account. However, in a situation when the project analysis of the capacity and service level of the unsignalised intersection is performed, the influence of driver characteristics, according to existing methods, cannot be valorised in any way. Considering the recommended values of driver population factor in procedures for analysing road capacity, it can be assumed that driver characteristics can significantly influence the capacity and service level of the unsignalised intersection.

In this paper, the analysis of values of accepted critical headways and follow-up headways with resident and non-resident drivers has been completed, within more consecutive local measurements, to determine whether driver characteristics can influence the capacity of an unsignalised intersection (TWSC intersection).

PREVIOUS RESEARCH STUDIES

The procedures used today for the calculation of unsignalised intersection capacity are based on gap acceptance theory. This theory is based on the assumption that vehicles will pass through the intersection when the interval between vehicles in the conflict flow, a higher priority flow, is bigger than the minimum – critical headway. Gap acceptance theory was developed in the second half of the previous century. On the basis of gap acceptance theory, different models have been developed, like [5] and [6], which represent the basis of engineering procedures for capacity calculation. In engineer practice in the world, the most commonly used edition of manuals for the calculation of capacity and roads is *Highway Capacity Manual – HCM*. In the 1985 edition of this manual, the stated models were implemented as the basis of the procedure for calculating the capacity of unsignalised intersections. According to this method, firstly the potential capacity for each minor movement is calculated, and then, the capacity of the approach and finally the capacity of the whole intersection [7]. According to the *HCM* [2,8] the potential capacity of minor movements is calculated by the relation based on *Harder's* model [5].

The direct application of the *HCM* procedure for the capacity calculation of unsignalised intersections, with the recommended values of input parameters sometimes does not provide objective results [9]. The experience of many countries has shown that it is very useful to make corrections of input parameter values in the existing procedures for capacity calculations, that is, to adjust the recommended values of parameters to the results of the research [10]. In many procedures for calculating the capacity of unsignalised intersections, it is emphasized that field research results have been used [2,8,11,12,13]. Critical headways and follow-up headways are performed by the reaction of the drivers steering the vehicles in the traffic flow. Since mentality, habits and behaviour of drivers in the local environment differ in relation to the research conditions, on the basis of which recommendations have been given, it can be assumed that the values of critical headways and follow-up headways are not the same for all intersections. For that reason, many research studies have been carried out in the world, related to different factors which influence the values of critical headway for the minor movement and follow-up headway for the minor movement. The research studies have been performed in several directions: research into the influence of limited speed, the type of traffic signalization, the complexity of movement, local surroundings and the position of the intersection, the intersection geometry, traffic flow structure, etc.

The research studies in Sweden have shown that there is a difference of almost 40% in critical headway values, depending on the type of traffic signs and speed limit [14]. The complexity of the movement affects the observation span and driver's decision-making, which provokes the bigger delay from the start. All that causes higher values of critical headway and follow-up headway [12,13,15]. Some research studies have shown that their values are influenced by the characteristics of the local environment, such as the size of the town where the studied intersection is situated [10]. Influences of intersection geometry and traffic flow structure in *HCM* have been considered since the 2000 edition [8], which was also established in some previous research studies of this subject [16].

DEFINING THE AIM AND THE BACKGROUND OF THE RESEARCH

According *to the Highway Capacity Manual 2016 – HCM 2016* [2], the potential capacity of the minor movement is given in the following Equation (1):

$$C_{p,x} = V_{c,x} \frac{e^{-V_{c,x} \cdot t_{c,x}/3600}}{1 - e^{-V_{c,x} \cdot t_{f,x}/3600}} \quad (1)$$

where:
$C_{p,x}$ – potential capacity of movement x (veh/h)
$V_{c,x}$ – conflicting flow rate for movement x (veh/h)
$t_{c,x}$ – critical headway for minor movement x (s)
$t_{f,x}$ – follow-up headway for minor movement x (s)

As it can be seen from the previous Equation (1), the potential capacity of the minor movement, and thereby the unsignalised intersection capacity, is affected by the value of the conflict flow. The value of the conflict flow is determined in the calculation for each minor movement by the established procedure, on the basis of the traffic flow value on intersection approaches and on the basis of flow distribution by driving directions. No additional factors can influence the conflict flow value or, through it, the intersection capacity.

Taking into consideration the fact that the conflict flow value is precisely determined in calculations, it ensues that the values of critical headway and follow-up headway, through the potential capacity value, directly influence the practical capacity of an unsignalised intersection, i.e. capacity in real existing conditions. These parameter values are usually given in the form of recommendations, in accordance with the intersection geometry. Values of critical headway and follow-up headway are always given on the basis of real research within the standards and traffic regulations and social environment where the traffic is happening. In *HCM 6*, it has been emphasized that the value of critical headway for the minor movement and follow-up headway for the minor movement in some cases can have some other values as well, hence, field measurements are recommended.

As shown in Chapter 2, the previous research studies have implied that the values of critical headway for the minor movement and follow-up headway for the minor movement are affected by different factors.

In traffic flow theory, it is known that traffic flow participants who use the same section every day behave differently in relation to the drivers who use the same section occasionally, rarely or for the first time. These facts related to driver behaviour are considered in calculations of road capacity. The research studies of this subject have shown that capacities for recreational traffic can be up to 20 percent lower than for commuter traffic on highways and 10 to 15 percent on the freeways. If this possible effect of driver population is taken into account, locally derived data should be obtained and used carefully, according to the methodology. The influence of driver characteristics on road capacity is expressed by the value of Driver Population Factor [2,8].

The aim of the research is to determine whether driver characteristics influence unsignalised intersection capacity on the basis of local measurement results, that is, whether there is a difference between the value of headway for the minor movement and follow-up headway for the minor movement with resident and non-resident drivers.

At unsignalised intersections, drivers individually estimate the traffic situation, which means that the values of critical headway and follow-up headway while performing the desired movement are 'determined' by the drivers, on the basis of their habits, previous knowledge, skills and the features of the vehicle they are driving. For that reason, it can be assumed that the value of critical headway for the minor movement and follow-up headway for the minor movement depend on driver characteristics. Considering these facts, the main hypothesis of this paper is that values of critical headway for the minor movement and follow-up headway for the minor movement are higher with non-resident drivers.

Non-resident drivers appear in higher percentage on transit directions and in tourist regions, where these drivers often represent the majority of driver population in periods of holidays. Therefore, calculation of priority intersection capacity with recommended values of input parameters can provide unreal results. All these can influence the wrong estimate of measures which are to be taken in order to improve a service level.

THE RESEARCH METHODOLOGY

The measurement of the values of critical headway for the minor movement and follow-up headway for the minor movement of vehicles is a relatively simple procedure. The local measurement of these parameters have been carried out in the world since last century but they have to be carefully considered. For the measurement it is necessary that, on the minor approach, there are conditions of the saturation flow, i.e. there is a queue, and on the main road direction, in certain periods, there are conditions for time gap occurrence which enable the minor movement being performed. The occurrence of a queue, i.e. a line of vehicles on the minor approach, is an obligatory and necessary assumption for determining the follow-up headway. On the other hand, in order to carry out the measurement of critical headway, it is necessary that, at the moment of measurement, there are conditions on the main approach similar to those of the saturation flow. For that reason, there are rarely conditions for the simultaneous measuring of both critical headway and follow-up headway at the same intersection. The occurrence of any disturbance of minor or the main flow while doing the measurements is not allowed [4,10].

Restrictions regarding possibilities for measuring the follow-up headway occur when the traffic flow intensity is low on the minor approach, as well as in the situation when the flow is very intensive on the main road direction, and for these reasons it is not possible to perform two consecutive movements from the minor approach. On the other hand, while measuring the critical headway, the restrictions occur when the traffic flow intensity is low on the main approach, since, at that time, two consecutive movements from the minor approach are performed very often. Thus, favourable conditions for direct measurement of critical headway and follow-up headway on the minor flow are not always practically feasible during the whole research period [4].

In order to determine the influence of non-resident drivers on the values of the parameters t_c and t_f, and thus on the capacity of TWSC intersections, the parameters t_c and t_f were measured in such a way as to eliminate the possibility of commercial vehicle impact on the values of parameters t_c and t_f when performing the minor manoeuvre by resident and non-resident drivers. For that reason, the values of the parameters t_c and t_f were considered in the analysis only if a passenger car was performing the minor movement, and if all the vehicles in relation to which the measurement was performed were also passenger cars. The homogeneous traffic flow composed exclusively of passenger cars has proven to be a good method for processing data and determining the influence of the diversity of particular groups of drivers (resident and non-resident drivers) on the capacity of unsignalised intersections [4].

For the research needs, the measuring of the critical headway and follow-up headway of vehicles was carried out in the town of Bijeljina, situated in the northeast of Bosnia and Herzegovina (Figure 1). The measuring was performed at the four-forked intersection of the streets Miloša Obilića – Solunska (44°45’38.9”N 19°12’46.3”E), situated in the town centre. At the both of minor approaches in Solunska Street there is the traffic sign YIELD.

The YIELD sign is a traffic sign used as the primary means of establishing a hierarchical structure, i.e. enhancing the legal superiority of one traffic flow over another, in poorly congested locations, where most traffic can cross an intersection without stopping. In terms of capacity, there are no major differences between the intersections with two approaches controlled by STOP and YIELD signs. In locations controlled by the sign YIELD, where the traffic congestion is high, practically every vehicle on the bypass approaches controlled by the sign YIELD will stop in particular because of the stop control. For this reason, the capacity at the intersection controlled by the sign YIELD can be observed as it is an intersection where two approaches are controlled by the sign STOP [10].

Figure 1. The Studied Intersection

The research was carried out using a digital video camera in July and August, 2018. The recordings were later on analysed in video players used for measuring parameters of the flow in real time. The results were statistically processed in the Microsoft Excel software (Table 1 and Table 2).

Table 1. Collected Values of The Sample for the Critical Headway (t_c)

Manoeuvre	Resident Drivers	Non-Resident Drivers	Total
Left from major	111	30	141
Right from minor	101	21	122
Through on minor	82	24	106
Left from minor	88	29	117
Total	382	104	486

Table 2. Collected Values of The Sample for the Follow-up Headway (t_f)

Manoeuvre	Resident Drivers	Non-Resident Drivers	Total
Left from major	193	45	238
Right from minor	161	38	199
Through on minor	89	29	118
Left from minor	93	26	119
Total	536	138	674

In Figure 2, a typical manoeuvre, recorded by a video camera, is shown. The town of Bijeljina has been chosen for the research because of the fact that in the research period there is a higher number of drivers who spend their time in this town only several times a year. Namely, a significant number of Bijeljina residents are temporarily working in European states, and they could easily be identified by registration plates (Figure 2).

Figure 2. The Minor Movement Performed by a Vehicle Steered by a Non-resident Driver

RESEARCH RESULTS

Within the framework of this research, 486 values of critical headway and 674 values of follow-up headway (Table 1 and Table 2) were recorded when performing the minor movement (left from major, right from minor, through on minor and left from minor). The results of critical headway measured values are given in Table 3.

Table 3. Measured Values of Critical Headway (t_c) at the Studied Intersection

Manoeuvre	HCM 6	Local measurement				Percentage of non-resident drivers
		Mean value	Resident drivers	Non-resident drivers	Difference non-resident –resident	
Left from major	4.1	4.63	4.43	5.37	0.94	21.28 %
Right from minor	6.2	5.62	5.44	6.49	1.05	17.21 %
Through on minor	6.5	6.15	5.96	6.79	0.83	22.64 %
Left from minor	7.1	5.92	5.71	6.57	0.86	24.79 %

Results of follow-up headway measured values are given in Table 4.

Table 4. Measured Values of Follow-up Headway (t_f) at the Studied Intersection

Manoeuvre	HCM 6	Local measurement				Percentage of non-resident drivers
		Mean value	Resident drivers	Non-resident drivers	Difference non-resident - resident	
Left from major	2.2	2.91	2.86	3.13	0.27	18.91 %
Right from minor	3.3	3.31	3.24	3.63	0.39	19.09 %
Through on minor	4.0	3.76	3.66	4.09	0.43	24.58 %
Left from minor	3.5	3.64	3.57	3.91	0.34	21.85 %

In the previous tables (Table 3 and Table 4), the basic values of critical headway for the minor movement and follow-up headway for the minor movement are given, recommended in *HCM 6* for the TWSC intersections. Additionally, the same tables show the values obtained in the research, where the values for resident and non-resident drivers have been separated.

DISCUSSION

The research results have confirmed the importance of local measurements of the critical headway for the minor movement and follow-up headway for the minor movement. Based on the results given in Table 3 and Table 4, graphically shown in Figure 3 and Figure 4, it can be concluded that the values of the measured parameters of critical headway and follow-up headway deviate from those recommended in *HCM*, which implies that it is useful to perform local measurements. The largest deviations from the recommended values given in *HCM 6*, for the parameter t_c are regarding minor movement - manoeuvre "left from minor" (1.18s), while for the parameter t_f, the largest deviations of local measurements from the recommended values given in *HCM 6* are recorded when performing the minor movement – "left from major" manoeuvre (0.71s).

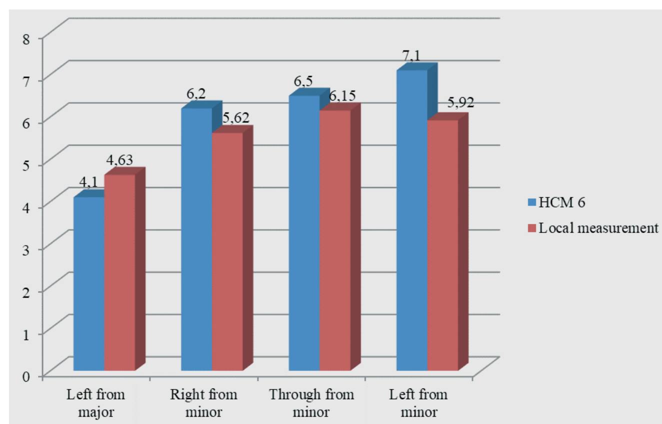

Figure 3. The Ratio of the Recommended Values of Critical Headway (t_c) for the Minor Movement to The Values Determined in Local Measurements

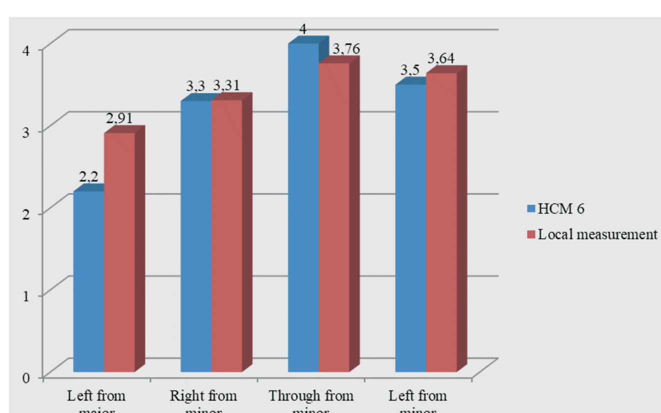

Figure 4. The Ratio of the Recommended Values of Follow-up Headway (t_f) for the Minor Movement to the Values Determined in Local Measurements

It is important to emphasize that the results of the analysis have provided that non-resident drivers use higher values of critical headway and follow-up headway to perform the minor movement, i.e. they need more time to make a decision and perform the minor movement than non-resident drivers. Consequently, the participation of non-resident drivers in a traffic flow directly leads to a decrease in capacity for each minor movement, and thus a decrease in capacity of the entire intersection. As it can be seen in Figure 5 and Figure 6, there are clear differences between the critical headway and follow-up headway accepted by resident drivers on the one hand and non-resident drivers on the other.

Resident drivers use less critical headways and follow-up headways when performing the minor movement, i.e. they respond faster and more explosively. The research has shown that, regarding the minor movement "right from minor", the largest difference in measured values of critical headway for resident and non-resident drivers is 1.05s, while the smallest difference in measured values of critical headway for resident and non-resident drivers is 0.83s recorded for the minor movement "through on minor". The conclusion based on the result analysis of the measured values of the critical headway is that non-resident drivers, for performing minor movements, use the critical headways in the major flow, which are by about 1.0s higher than the interval used by resident drivers.

On the other hand, the differences in the measured values of follow-up headway for resident and non-resident drivers range from 0.27s to 0.43s, with certain deviations depending on the type of minor movement. The conclusion based on the result analysis of the measured values of the follow-up headway is that non-resident drivers require averagely 0.3 – 0.4 seconds more than resident drivers for consecutive joining the major flow.

Obviously, habits, behaviour, customs, and different regulations influence non-resident drivers to use larger critical headways and follow-up headways to perform the minor manoeuvre.

Having analysed the established values of parameters, it can be concluded that non-resident drivers, while performing the minor movement create higher values of critical headway for the minor movement and follow-up headway for the minor movement than resident drivers for all movements, as it can be seen in Figure 5 and Figure 6. This is a scientific confirmation that the participation of the examined groups of drivers significantly influences the capacity of TWSC intersection.

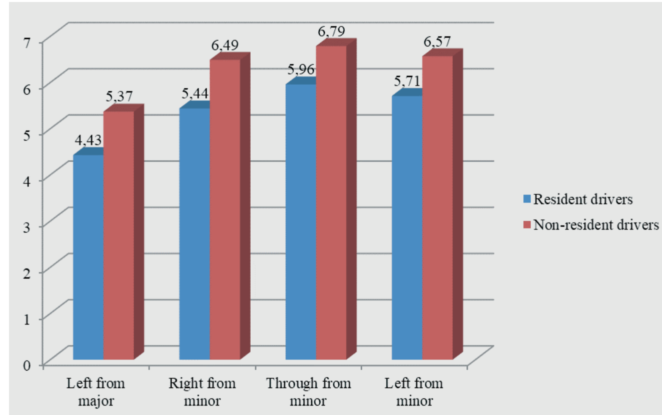

Figure 5. Parameter Values of Critical Headway (t_c) Obtained by Local Measurements for Resident and Non-resident Drivers, Depending on the Minor Movement

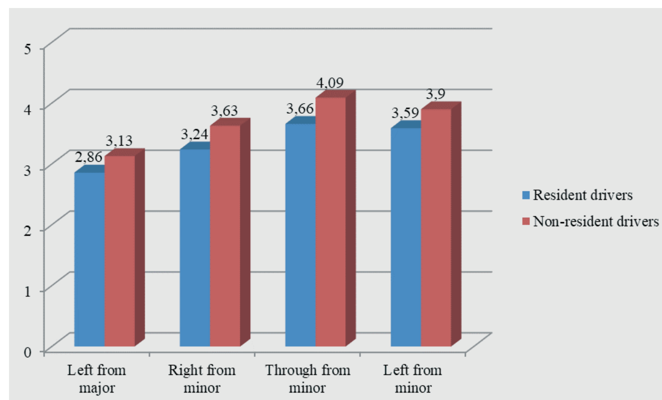

Figure 6. Parameter Values of Follow-up Headway (t_f) Obtained by Local Measurements for Resident and Non-resident Drivers, Depending on the Minor Movement

The research has completely confirmed the basic hypothesis that non-resident drivers create higher values of critical headway for the minor movement and follow-up headway for the minor movement. In further research studies, it would be necessary to study and establish the dependence on the participation of non-resident drivers in the traffic flow and the increase of critical headway values for the minor movement and follow-up headway values for the minor movement at two-way stop controlled intersections.

CONCLUSION

The previous research studies have shown that road capacity is significantly affected by driver characteristics and driver behaviour. The biggest difference in behaviour of resident (commuters) and non-resident (non-commuters) drivers has been noticed, hence, this influence is expressed as Driver Population Factor in the procedures for capacity calculation. In engineer procedures for capacity calculation of unsignalised intersections, the influence of driver characteristics and driver behaviour has not been valorised.

In previous research studies, it has been proved that the values of critical headway for the minor movement and follow-up headway for the minor movement are affected by different factors, therefore, it is useful to carry out local measurements. Within the framework of this paper, the influence of resident and non-resident drivers on the values of input parameters for calculating the capacity of unsignalised intersection has been analysed. In local measurements carried out in this research, non-resident drivers are the drivers at the intersections steering vehicles with foreign registration plates, since they only occasionally or very rarely use the intersection where the measurement has been performed.

As in many other previous research studies, it has been confirmed that there are certain deviations in parameter values determined in local measurements in relation to those recommended in *Highway Capacity Manual*.

The hypothesis that there is a difference in obtained values of critical headway for the minor movement and follow-up headway for the minor movement, with resident and non-resident drivers, has been completely confirmed. The research results have shown that non-resident drivers use higher values of critical headway and follow-up headway when performing the minor movement, leading to a decrease in the capacity of unsignalised intersection. The research into the influence of non-resident drivers on the capacity of unsignalised intersections should be performed in other locations as well, and these research results can be significant especially if capacity analysis is carried out in tourist regions.

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