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PROCEDURE FOR SAFE DISTANCE DETERMINATION FOR MINOR MOVEMENT ACCOMPLISHING AT UNSIGNALIZED INTERSECTIONS

ABSTRACT

A minor movement performed at unsignalized intersections is one of the most complex and most difficult actions in traffic. Drivers performing a minor movement make decisions based on the estimation of movement parameters of vehicles in the major street. A driver's estimation depends on subjective estimation of the distance between vehicles in the major street and the gap which exists between them, that is, the time gap in the conflicting flow which is suitable for accomplishing a minor movement. The possibilities of estimation are sometimes limited due to complex traffic conditions, as well as the limited driver's view. When, during doing a minor movement, a traffic accident happens, in most cases the cause of the accident is the failure to give right-of-way. But, in case when a vehicle from the major street moves at a speed above the limited one, based on the existing analytical procedures, it is impossible to determine the extent of their responsibility. This paper shows the procedure for safe distance determination, necessary for accomplishing a minor movement, as well as the procedure of establishing the driver's omission, depending on the movement regime and traffic conditions at unsignalized intersections.

KEY WORDS

unsignalized intersection, minor movement, critical gap, safe distance

1. INTRODUCTION

Intersections at which the traffic is regulated by traffic signs are in the European countries, as well as in many other countries the most common type of intersections in the road network. In our region the most common type of intersections are TWSC (*two way stop–controlled*), although in the world it could be AWSC (*all way stop-controlled*) intersections. Usually, those are 4-leg or 3-leg intersections at which there is one way designated as the major – priority street, and the other is designated as a minor road by legal authority decision. The data about traffic accidents at priority intersections and causes of their occurrence are different. It should be noted that in some countries there are no precise statistics about traffic accidents. In the USA about 5,800,000 traffic accidents happen every year, out of which about 984,000 happen at unsignalized intersections or nearby. From the total number of accidents at unsignalized intersections it was determined that in about 70% of all accidents, the basic omission is failure to give right-of-way from a minor street, which is about 12% of all traffic accidents [1]. According to a research in small towns in Croatia, where the traffic at intersections is regulated mostly by traffic signs, using the example of Nova Gradiška, during a period of 7 years it was determined that not giving right-of-way is the cause of about 14% of traffic accidents [2].

Drivers on the minor street at unsignalized intersections are exposed to an increased risk because they often have to follow a complex traffic situation, make decisions and accomplish the necessary minor movements. The period or the interval that drivers from a minor street take for making a minor move-

ment is called a critical gap [3]. Drivers who drive on the major street have no reason to change the way of their movement approaching the intersection, and their following distance is in the function of speed [6]. For this reason, the number of suitable time gaps, or intervals that are greater or equal to a critical gap, beside the size of the flow on the major street, depends on the speed of vehicles in the major street. The number and possibility of critical gaps occurrence can be influenced by the closeness of nearby intersections at which traffic is regulated by light signals, that is, progression factor [7]. The size of the critical gap depends on many factors, and the best way for its right determination is by carrying out local measurements [7].

In order to make a minor movement, the drivers on minor streets are forced to estimate free time gaps suitable for a desired movement completion, or critical gaps, by observing the distance and gaps between vehicles in conflicting flows. For that reason, not giving right-of-way could be characterized as the wrong estimation of the critical gap. Because of the absolute priority of flows which are at higher level in the hierarchy, making some of movements from minor streets demands special drivers' attention. Causes of wrong estimation of the critical gap size could be carelessness, insufficient knowledge and skill, insufficient psychophysical abilities, reduction of psychophysical abilities due to alcohol or drug use, or to some other mistakes from the driver's personal field.

However, bad estimation of the critical gap size in which it is possible to make a minor movement safely, could be caused by behaviour, that is, drivers' mistakes on the major streets. Also, wrong estimation of the gap in the major street can be caused by unfavourable road characteristics (insufficient view distance, curves, severe side slope, bad geometry of intersection, etc...), inadequate regulative measures as well as other drivers' mistakes, which are not directly involved in the traffic accident (wrongly parked vehicles, stopping at places where this is forbidden, wrong moves by pedestrians or cyclists). Usually, drivers who drive along a minor street are not aware that they are on the street which has no priority of movement, so, for reducing a possible mistake of not giving right-of-way, location, visibility and recognition of a traffic sign are of vital importance [5].

It is considered that a vehicle entering from a minor street performed well if it did not disrupt the right-of-way of vehicles on the major street, and if drivers of those vehicles did not have to change the regime of their movement. However, there is often the case that right-of-way is treated as an absolute right, by means of which the principle of priority loses its basic meaning, that is, the right in traffic which means respecting all norms of behaviour by all traffic participants [4].

In literature which analyses traffic accidents there are no defined procedures for establishing the values of necessary gaps for accomplishing safe minor movements, that is, entering from a minor street regarding traffic conditions. The gap between vehicles on the major street which would allow accomplishing a safe minor movement, calculated on the basis of the critical gap size and permitted speed on the major street, makes it possible to have an objective analysis of mistakes committed by traffic accident participants.

2. ROAD AND TRAFFIC CHARACTERISTICS OF UNSIGNALIZED INTERSECTION APPROACHES

At 4-leg and 3-leg intersections which are unsignalized intersections of TWSC type there are two characteristic types of approaches which differ in regard to traffic regulation type and traffic conditions:

- *minor street approach* - secondary street approach where vehicles are obliged to give right-of-way to vehicles on the major street, and
- *major street approach* or the main street where vehicles have the right-of-way regarding vehicles on the minor street. Also, vehicles which turn left from the major street are obliged to give right-of-way to vehicles passing through from the opposite direction.

For traffic regulation on minor street approaches at unsignalized intersections these traffic signs are used:

- B-1"GIVE WAY" or "YIELD" and
- B-2 "STOP"

The length of approach to an intersection and its configuration have the greatest influence on traffic conditions at unsignalized intersections. In order to improve traffic safety, especially on rural roads, the speed on the major street is limited. The length of approach is defined as the distance from a placed traffic sign for speed limit to the point of entering the intersection. Starting from half-distance of the approach, looking toward the centre of the intersection, there is usually a road widening for at least one traffic lane in order to compensate for the difference in capacity between the previous section and the approach [8]. This widened part of the road is called the entry leg and its function is to allow drivers to change lanes for a desired movement of passing through the intersection or making turns. The entry legs, in real condition, are not usually widened, so that vehicles from the last part of approach make queues preparing to make the wanted movements, and during this, they obstruct each other. For this reason, the length of the entry leg is half of the approach length. Entry leg configuration is defined as the number of traffic lanes and their purpose in order to place the vehicles regarding their direction.

The method of traffic regulation on the minor and major street approaches is the basic traffic characteristic of unsignalized intersections, based on the gener-

al rule by which vehicles on the major street have the right-of-way, and cars on a minor street have to give right-of-way to vehicles which are on the major street. At unsignalized intersections the right-of-way is determined by the following hierarchy [3], [7]:

R1 *"Highest priority"* movements or manoeuvres are movement through traffic on the major street, and right turn from the major street. Vehicles from all other streets are obliged to give right-of-way to vehicles which are on the major street, and make through movement or right turn movement.

R2 Movements in this rank are called movements of *"lower priority"* or *"simple secondary movement"* and those are left turn from the major street and right turn from the minor street. Movements from this rank have to give right-of-way to the highest priority movements – movement through and right turn from the opposite direction, but they have the right-of-way regarding the vehicles from all other streams.

R3 This rank is called "*Complex secondary movement*" which is through traffic movement from a minor street, and it is in conflict with the highest, and lower priority movements (both through movements from the major street, one right turn, and both left turns from the major street). This movement is complex because it is necessary to give right-of-way respecting the relative priority between the highest and lower priority movements.

R4 This movement is called *"The most complex secondary movement"* which is left turn from a minor street because vehicles have to give right-of-way to all movements on the major street – the highest and lower priority movements (both through and both left turn movements), respecting their relative priority. Besides, this movement is in conflict with simple and complex secondary movements (right turn and through movement from the opposite direction on minor street approaches). Drivers carrying out this movement have to pay attention to relative priority between the highest and the lower movements on a minor street.

3. PARAMETERS OF VEHICLE MOVEMENTS AT UNSIGNALIZED INTERSECTION APPROACHES

Vehicle movements at unsignalized intersection approaches during common use of intersection centre are characterized by many factors, out of which the most important is the vehicle speed, the acceleration at the start, follow-up time and critical gap. The speed of a vehicle on the major street has a very important role for defining of other parameters, as well as in the process of omissions defining in case of a traffic accident at an unsignalized intersection. Due to complex traffic conditions, the speed on the major streets is often limited to values lower than on the road section before the intersection [4]. Speed reducing on the major street is almost always applied to intersection approaches outside populated places. The necessary driver's view length at the intersection zone, or the so-called sight distance triangle, depends on the vehicle speed value on the major street [9].

Vehicle acceleration during start sequence from minor streets when the vehicle starts moving toward the centre of the intersection is a very important vehicle movement characteristic, because the time that the vehicle spends in the middle of the intersection depends directly on vehicle acceleration. This parameter is conditioned by the vehicle dynamic characteristics and traffic conditions on the approach, as well as the manner of driving. The follow-up time for the vehicles in the minor street is the time needed for the second vehicle on the approach to get to the sight view point, after the first vehicle in a queue has made its movement. This parameter is very important in the procedures of approach capacity calculation and minor movements, but it has no direct influence on the safety of the main road traffic.

The critical gap is the most complex parameter at an unsignalized intersection and it represents the time in the major street which is sufficient for drivers on the minor street to make their minor movement safely. This interval depends on many factors, but in all researches which have been done so far, the type of movement was the main spotted factor [10].

Drivers from the minor approach estimate the critical gap based on the distance of vehicles in the major street and compare it with the time that they evaluate as necessary to provide the desired movement. If their estimation is such that the time needed to execute the desired movement is less than the size of the critical gap, they will make the desired movement, and if the time is shorter, that is, if it takes more than the size of the critical gap, the drivers from the minor approach mainly await the next opportunity [11]. For this reason, knowing the size of the critical gap is of crucial importance for defining the required distance for safe minor movement accomplishing at unsignalized intersections.

4. DEFINING CRITICAL GAP VALUES

Knowing the value of the critical gap in the major street is important not only for the analysis of capacity at unsignalized intersections, but it is also important for defining the required distance for vehicles from the minor flow to enter the intersection and accomplish the minor movement safely.

Research of the critical gap size began in the late 1940s in the United States, and so far they have been

carried out in most countries. Recommendations about the size of the critical gap are mostly given in relation to the type of minor movement, although there were researches done including other influences. In most of the recommendations it is stated that the size of the critical interval depends on the observance of certain specific characteristics of the environment in which the research was done. The real value of the critical gap mostly depends on the psychological characteristics of drivers, or on their individual perception of the situation as well as on training and driving experience. The environmental influences, as well as gender and age, cannot be excluded [14]. The size of a city can also affect the size of the critical gap because of different driving techniques and habits of the drivers [12]. The speed and the type of a traffic sign on a minor street may also have an impact on the critical gap as shown in a research which was conducted in the Scandinavian countries [13]. Beside all the mentioned above, the number of lanes in the major street also affects the critical gap size as well as the type of the vehicle that carries out the movement. In practice, the most commonly used recommendations on the size of the critical gap are given in the Highway Capacity Manual. According to these recommendations [7], the critical interval succession is calculated as follows:

$$t_{c,x} = t_{c,base} + t_{c,HV} \cdot PHV + t_{c,G} - t_{c,T} - t_{3,,LT} \quad (1)$$

where:

- $t_{c,x}$ – critical gap for movement x,
- $t_{c,base}$ – base critical gap,
- $t_{c,HV}$ – adjustment factor for heavy vehicles (1.0 for two-lane major streets and 2.0 for four-lane major streets),
- PHV – proportion of heavy vehicles for minor movement,
- G – percent grade divided by 100,
- $t_{c,G}$ – adjustment factor for grade for heavy vehicles (0.1 for movement right from minor street, and 0.2 for movements through and left on minor street),
- $t_{c,T}$ – adjustment factor for each part of a two-stage gap acceptance process (1.0 for the first or the second stage; 0.0 if there is only one stage),
- $t_{3,,LT}$ – adjustment factor for intersection geometry (0.7 for minor-street left-turn movement at three-leg intersection; 0.0 otherwise).

The precise values of the critical gap size for a specific intersection can only be determined by the local measurements and research, because only in this way all the factors that have an impact on the critical gap can be covered.

It is known that the intersections geometry or its environment can affect the behaviour of drivers, which directly affects the value of the critical gap. The results of conducted research show that the values of critical gaps can be significantly different, indicating the need for permanent research. *Table 1* provides results of some researches which were carried out to define the size of the critical gap in a variety of conditions.

Table 1 - Some recommendations for critical gap value depending on the traffic sign type and character of manoeuvre [12]

Method/year	Sign type	Critical gap (s)			
		left major	right minor	through minor	left minor
HCM/1985	II–1	5.0	5.0	5.5	6.0
HCM/1985	II–2	5.0	5.5	6.0	6.5
HCM/1994	II–2	5.0	5.5	6.0	6.5
Finland/1997	II–1	4.0	4.0	5.0	5.5
Finland /1997	II–2	–	5.0	6.0	6.3
DanKap/1999	II–1	5.5	5.5	6.0	7.0
DanKap/1999	II–2	-	6.5	7.0	8.0
SNRA/2001	II–1	4.8	5.0	5.1	5.3
SNRA/2001	II–2	6.7	7.5	7.6	7.8
Finland/2004	II–1	5.9	6.1	–	6.4

Table 1 shows that the critical gaps depend on the location of the measurement and the type of controls on the minor street.

In our region, for the capacity of road parts and street network, HCM methodology has been commonly used.

5. MODEL FOR DETERMINING THE REQUIRED DISTANCE FOR PERFORMING SAFE MINOR MOVEMENT

In cases where vehicles coming from the minor and the major street were involved in the traffic accident, mostly without further checks, failure to give right-of-way was spotted as the cause of the accident of the vehicle from the minor street. These conclusions are often based just on the fact that one of the parties of the accident began moving from the minor street without detailed time-space analysis of the whole accident. Often, the vehicles on the major street move exceeding the speed limit, and in that way mislead the drivers on the minor street to make a wrong conclusion about the size of the critical gap and ability to carry out their movements safely. If the place of collision and speed of participants of a traffic accident are known, using the classical procedures it is very easy to determine the distance from the vehicle on the major street to the point of collision at the moment when the vehicle started performing a minor street movement. Comparing the calculated distance of the vehicle on the major street from the conflict point, the distance

which allows minor movement to be performed safely, when the vehicle from the major street moves at the allowed speed, the participant's omission at an unsignalized intersection can be easily defined.

For procedures of the real traffic accident analysis at unsignalized intersections and determining omissions of the accident participants, the size of the safe distance according to the speed limit on the major street and those of the drivers from the minor streets considered safe enough for minor movement performance, have to be defined.

The critical gap is the time taken for a safe minor movement completion by a minor street vehicle. The driver estimates the distance from the minor approach to the conflicting vehicle, that is, to the vehicle which potentially endangers its movement. This distance is functionally related to the critical gap. If the conflicting vehicle, moving at the speed up to the speed limit, covers the distance in a time period which is longer or the same as the critical gap, then the minor approach driver can objectively conclude that the manoeuvre can be completely safely accomplished.

In this situation there is no need for the driver on the major street to change the regime and the speed of his movement. If the driver from the minor street starts his movement in a situation where the arrival time of vehicles from the conflicting major street moving at the speed limit is less than the critical gap size, this means that the driver on the major street needs to change the movement regime, either to start slowing down or braking. This would mean that the driver from the minor street started to make the movement conditionally safely. For this reason it is necessary to define the distance from which the driver on the major street could avoid the accident by changing the regime of movement within the comfortable deceleration, as well as the limiting distance which did not allow the driver from the major street to avoid the accident by forced braking.

On the basis of the size of the critical gap a minimal safe distance of vehicles in the main flow moving at the speed limit can be defined. Safe distance represents the function of its speed and determined critical gap:

$$L_s = t_{c,x} \cdot V_a \tag{2}$$

where:

V_a – the allowed speed on the major street.

For any vehicle entering from a minor street, when the vehicle from the major street is located at a distance greater than the minimally safe one, it would mean that one of the causes of the accident was vehicle speed on the major street. On the other hand, every turn of vehicles from a minor street when the vehicle in the major street is located at a distance smaller than minimally safe, not giving right-of-way and its omission causes dangerous traffic situation. For avoiding the accident in this situation, it is necessary that the driver on the major street undertakes certain avoiding activities. It is not necessary that the vehicle stops before the point of contact. Instead of stopping, it has to "spend" the critical gap by slowing down. In this interval, the vehicle from the minor street needs to complete the movement. In real conditions this situation occurs relatively frequently, especially where there is intense traffic on the major street. By using classical analytical methods it is possible to define the relationship for the calculation of the distance that allows the performance of a minor movement by changing the regime of movement and slowing down on the major street.

In case when it is

$$(b_c \cdot t_{c,x}) < \left(V_a - \frac{b_c \cdot t_3}{2}\right)$$

the following relation can be used:

$$S_c = V_a \cdot t_r + \frac{\left(v_a - \frac{b_c \cdot t_3}{2}\right)^2 - \left(\left(v_a - \frac{b_c \cdot t_3}{2}\right) - (b_c \cdot t_{c,x})\right)^2}{2 \cdot b_c} \tag{3}$$

where:

S_c – safe distance,

b_c – deceleration ($2.5\ m/s^2$),

t_3 – time of deceleration increase,

t_r – reaction time of vehicle-driver system.

In case when

$$(b_c \cdot t_{c,x}) > \left(V_a - \frac{b_c \cdot t_3}{2}\right)$$

the following relation can be used:

$$S_c = V_a \cdot t_r + \frac{\left(v_a - \frac{b_c \cdot t_3}{2}\right)^2}{2 \cdot b_c} \tag{4}$$

The time of deceleration increase and reaction time of vehicle-driver system depend on the vehicle type and it is taken for every category of vehicle.

In accordance with the above we can define three ways to perform a minor movement:

- safe,
- conditionally safe,
- unsafe.

Safe minor movement accomplishing means that the desired movement must be started at a distance from the nearest vehicle in the major street that allows completing the initiated operation without changing the movement regime of vehicles on the major street. Conditionally safe minor movement accomplishing means starting the movement at a distance from the vehicle in the major street, which allows avoidance of collision in case the driver of the vehicle from the major street changes the driving regime and slows down, or brakes slightly to avoid accident. Unsafe minor movement performance is every movement which was initiated when the distance from the vehicle in the major street was smaller than the previously calculated value of slowing down, or slight braking.

Table 2 shows the values of the required distance, for different values of allowed speed on the major street for base values of the critical gap size, according to the HCM 2000 for cars on a two-lane straight street [7].

Table 2 - Recommendations for the following distance size at a speed limit on a major street of 60km/h

Movement	Critical gap (s)	Safe distance (m)	Conditionally safe (m)	Unsafe (m)
Left from major	4.1	68	>63	<63
Right from minor	6.2	103	>71	<71
Through traffic on minor	6.5	108	>71	<71
Left from minor	7.1	118	>71	<71

The proposed procedure can be used for defining parameters by means of which it is possible to make a decision on which section of the unsignalized intersection there is need for speed limitation on the major street due to the impossibility of accomplishing the necessary safe distances.

6. CONCLUSION

Traffic conditions at unsignalized intersections are complicated and require drivers' special attention. Drivers from the minor streets use gaps or following intervals between vehicles on the major street to accomplish the desired minor movement. During the analyses of traffic accidents and reaching conclusions about the omissions of the traffic accident participants, it is necessary to perform accident analyses to determine when a driver from a minor street started their movement, and if the distance at which the vehicle from the major street was located could be regarded as safe. Only in this way conclusions can be made whether that vehicle which carried out the minor movement caused a dangerous traffic situation, or if vehicle on the major street was moving at the speed which can be considered as omission in a particular traffic situation. This paper shows the original procedure which enables determining the way the driver performed the minor manoeuvre. This procedure application makes it possible for every priority intersection and the current speed limit to determine the distance which enables safe integrating from the minor manoeuvre, conditionally safe distance and unsafe distance. If the minor manoeuvre is performed at conditionally safe or unsafe distance, the traffic accident can be avoided only in case of changing the movement mode of the vehicles in the priority traffic flow. The procedures which have dealt with the problem of minor manoeuvre performing so far have not treated this problem in the way as it is shown in this paper. The recommended procedure allows the implementation of the analysis depending on the size of the critical gap which, if it is possible, should be determined by the local measurements. Different factors can influence the value of the critical gap, thus, for determining safe distance for minor manoeuvre performing it is best to use local measurement data, which is especially underlined in this paper.

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ABSTRAKT

POSTUPAK UTVRĐIVANJA BEZBEDNOG RASTOJANJA ZA IZVOĐENJE SPOREDNOG MANEVRA NA PRIORITETNIM RASKRSNICAMA

Izvođenje nekog od sporednih manevara na prioritetnim raskrsnicama predstavlja jednu od najsloženijih i najkompleksnijih radnji u saobraćaju. Vozači koji vrše sporedni manevar donose odluke na osnovu procene parametara kretanja vozila u prioritetnim tokovima. Procena vozača zavisi od subjektivne procene rastojanja između vozila u glavnom toku i intervala sleđenja među njima, odnosno vremenske praznine u konfliktnom toku koja je pogodna za izvršenje sporednog manevra. Mogućnosti procene su ponekad ograničene zbog složenih uslova odvijanja saobraćaja, često i zbog ograničene preglednosti. Kada se prilikom izvođenja sporednog manevra dogodi saobraćajna nezgoda u većini slučajeva uzrok nezgode je neustupanje prava prvenstva. Međutim, u slučaju kada se vozilo iz prioritetnog toka kretalo većom brzinom od dozvoljene, na osnovu postojećih analitičkih postupaka nije moguće utvrditi stepen njihove odgovornosti. U ovom radu dat je postupak za utvrđivanje bezbednog rastojanja koji je potreban za izvođenje sporednog manevra i postupak za utvrđivanje propusta vozača u zavisnosti od režima kretanja i uslova odvijanja saobraćaja na prioritetnim raskrsnicama.

KLJUČNE REČI

prioritetna raskrsnica, sporedni manevar, kritični interval sleđenja, bezbedno rastojanje

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