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Road and Rail Infrastructure V

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PRACTICAL DETERMINATION OF GAP-ACCEPTANCE PARAMETERS ON ROUNDABOUTS

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Abstract

Roundabouts have various benefits in terms of safety and capacity issues that are worldwide recognized. Capacity analysis, which is very often key factor in the decision-making process between different types of intersection, can be performed with the empirical regression or gap-acceptance based models. The second model is more suitable for different locations because it depends only on two parameters: critical gap and follow-up headway. This paper presents practical determination of these two parameters on single and two-lane roundabouts in Bosnia and Herzegovina. Study like this was made for the first time in Bosnia and Herzegovina and have high importance for accurate capacity evaluation in local conditions.

Keywords: roundabouts, gap-acceptance parameters, critical gap, follow-up headway, MLM

1 Introduction

Capacity calculation of roundabouts can be performed with different models. Two main groups of these models are empirical regression and gap-acceptance based models. Empirical regression models have been created by the observation of traffic flows on built roundabouts and express capacity in the function of different traffic and geometric characteristics. Their limitation is that they often reflect only local conditions and are not applicable to other sites that are not covered by research. In addition, they require significant time for data collection. On the other hand, gap-acceptance based models use different statistical probability functions and fully theoretical approach for capacity evaluation of one roundabout approach. The application of these models requires the knowledge of two parameters; critical gap and follow-up headway. Using these two parameters, it is possible to reliably describe the behavior of drivers on unsignalized intersections, including roundabouts. Their determination does not require observation of traffic in the peak period, as in the case of empirical regression models, but it can also be time-consuming process and requires a large amount of data collected.

2 Gap-acceptance parameters

In process of determination of gap-acceptance parameters it is necessary to know and distinguish several of the following terms. The gap is defined as the time difference between two successive vehicles passing through the same reference point in a roundabout. Reference point is often chosen as point where vehicles in circular lanes of roundabout are in conflict with vehicles that are trying to get into roundabout, i.e. waiting at the entry. If the vehicle arrives on the stop line of roundabout approach after the gap has begun, the rest of this gap is called "lag". National Cooperative Highway Research Program (NCHRP) Report 572 defines "lag" as "the time from the arrival of the entering vehicle at the roundabout entry to the arrival of the next conflicting vehicle; this time is essentially a portion of the actual gap" [1].

Based on definition of gap, the critical gap is defined as minimum gap the driver will accept to enter the roundabout. Direct and empirical determination of critical gap is not possible. Theoretically, the gap accepted by the driver is greater than or equal to the critical gap, while the rejected gap is usually smaller than critical gap. Accepted and rejected gaps can be measured on the field, and estimation of the critical gap is based on that values. Follow-up headway is defined as the time difference between two successive vehicles using the same approach (or lane) and the same gap to enter the roundabout.

2.1 Methods for practical determination of gap-acceptance parameters

Estimation of critical gap is very complex procedure, mostly due to these two reasons:
- Heterogeneity of drivers – drivers are not equal; different drivers accept different gaps,
- Critical gap varies depending on traffic conditions.

The heterogeneity of drivers implies that the critical gap is not a unique value, but a distribution. There are frequent situations in which drivers accept a smaller gap, even though they have previously rejected the larger. As the number of rejected gaps is greater, or the longer the driver is spending waiting for the opportunity to enter the roundabout, this increases the likelihood of accepting a smaller gaps. Drivers who manifest this type of behavior are referred to as inconsistent drivers. Assuming that drivers are consistent in their behavior, or in the selection of a gap, suggests that a critical gap is the point at which the likelihood of acceptance or rejection of the gap is approximately equal.
Numerous methods have been developed and proposed to estimate critical gaps, based on data collected at selected locations, or on the basis of measured rejected and accepted gaps. In the early 1950s, Raff proposed a method for determining the critical gap value. Critical gap is determined as number at intersection point of cumulative distribution functions of accepted and rejected lags [2]. Miller (1972) explained the statistical and numerical meaning of this value, which did not mathematically match the definition of a critical gap, emphasizing that the value is sensitive to the volume of traffic [2]. Other researchers suggested methods similar to the logit procedure. Although these methods gave the distribution of accepted gaps, the critical gap was nevertheless chosen only as simple average of the accepted gaps.
In 1973, Siegloch developed a linear regression technique that uses data on gaps in steady flow conditions to evaluate the value of the critical gap and follow-up time. This method records the i-th gap with the size of ti and the number of vehicles Ni that have accepted that gap. Furthermore, all data are categorized according to the number of accepted vehicles. An average gap is calculated within each category. The result is a set of average gaps and the number of accepted vehicles. As a final step, the average gap is formed as a linear function that depends on the number of accepted vehicles. The value of the critical gap is defined as y coordinate of the intersection point of previously defined function and the curve representing the follow-up time. Although the method is very direct and gives relatively good estimates, this method was applied only in situations where the steady flow state occurred at a minor approaches.
The methods described earlier do not provide a physical and mathematical relationship between the observed data of the critical gap value. As different researches noted that the value of the critical gap depends on the driver, more comprehensive methods for estimating the distribution of the critical gap have been developed.
Assuming the negative exponential distribution of all gaps within the major stream and statistical independency between consecutive gaps, Ashworth (1968) proved that the probit procedure gives a shifted normal distribution over the expected distribution of the gaps. As a result, the probit method correction was made. Miller tested this procedure and showed that if the gamma distribution is accompanied by a critical gap, the correction is still applicable.

The method most commonly used to estimate the critical gap is the maximum likelihood method (MLM). According to this statistical method, for each vehicle the largest rejected gap tr and accepted gap ta are recorded. The probability that the critical gap is between tr and ta is expressed by using the logarithmic distribution of the critical gap.
The maximum likelihood method was first applied by Moran in estimating of critical lags. Miller and Pretty (1968) have applied this method to investigate behavior during overtaking. Troutbeck (1992) presented the iterative procedure for approximate solution of this method. Brillon (1999) concluded that the maximum likelihood method is the most accurate and robust method. Therefore, in this paper, MLM was used for estimating critical gap.
Equations (1) and (2) represent two essential equations for the maximal likelihood method. By solving this system of equations, estimation of mean and standard deviation of assumed distribution can be determined.

$$\sum_{i=1}^{N} \frac{f(t_r^i) - f(t_a^i)}{F(t_a^i) - F(t_r^i)} = 0 \tag{1}$$

$$\sum_{i=1}^{N} \frac{(t_o^i - \mu) f(t_r^i) - (t_a^i - \mu) f(t_a^i)}{F\left(t_a^i\right) - F(t_r^i)} = 0 \tag{2}$$

Where:
N – total number of drivers,
t_r^i – the largest rejected gap/lag of i-th driver (s),
t_a^i – accepted gap/lag of i-th driver (s),
f ( ) – assumed probability density function,
F ( ) – assumed cumulative density function,
μ – mean,
σ – standard deviation.

Estimating of follow-up time is much simpler than estimating a critical gap. Follow-up time can be directly measured on the field and unique value is obtained as simple average of collected values.

3 Data collection

Practical determination of gap-acceptance parameters was conducted on two roundabouts in city of Zenica, Bosnia and Herzegovina. First roundabout, called “Evropa” (Figure 1) is single-lane roundabout with four approaches. Second roundabout, called “Radakovo” (Figure 1) is two-lane roundabout with three single lane approaches, one two-lane approach and one bypass [3]. On single-lane roundabout data were collected with high-resolution video camera for four hours in one day, two in the morning and two in the afternoon (Figure 2). Two of the four approaches were examined [3].
On roundabout “Radakovo” we used stationary surveillance (police) camera with lower video quality. Due to bad weather conditions we were able to use only two hours of that video [3].
Using free video processing software Kinovea (Figure 2), we extracted three parameters: accepted and rejected gap for every vehicle and follow-up headway in case when more than one vehicle used the same gap. At the end, table with more than 895 sample (vehicles) on both roundabouts was made. In addition, “inconsistent” drivers have been identified, i.e. vehicles with the largest rejected gap larger than accepted, and these data have not been taken into account. Thanks to this, the premise of the maximum likelihood method that the behavior of drivers, or their selection of gaps, is consistent, i.e. logical, is satisfied. Log – normal distribution is selected as distribution of the critical gap

Figure 1 Analysed roundabouts (“Evropa” – left, “Radakovo” – right)

Figure 2 Video recording of single-lane roundabout “Evropa” and extracting gap values

Gaps are measured as the time between two successive conflicting events – vehicle on the approach of roundabout is on the stop line, and within the circular lanes, two successive vehicles pass over the conflict line. In the case of single-lane roundabout, there are no doubts as conflict vehicles are in one circular lane, while for a two-lane roundabout it is necessary to define what two successive events are.

Different situations are representing conflict for vehicles in different entry lanes. A vehicle in the left entry lane must cross outer lane of roundabout in order to enter inner lane, so both circular lanes are make conflict for this lane. Vehicles in right entry lane have primarily conflict with vehicles in outer circular lane, but also with vehicles in inner circular lane who tend to leave roundabout on next exit. These conflicting events are the reason for measuring the “combined” gaps on two-lane roundabout.

“Combined” gaps represent the time between crossings of two successive vehicles over the conflict line, when these two vehicles do not use the same circular lane (Figure 3).

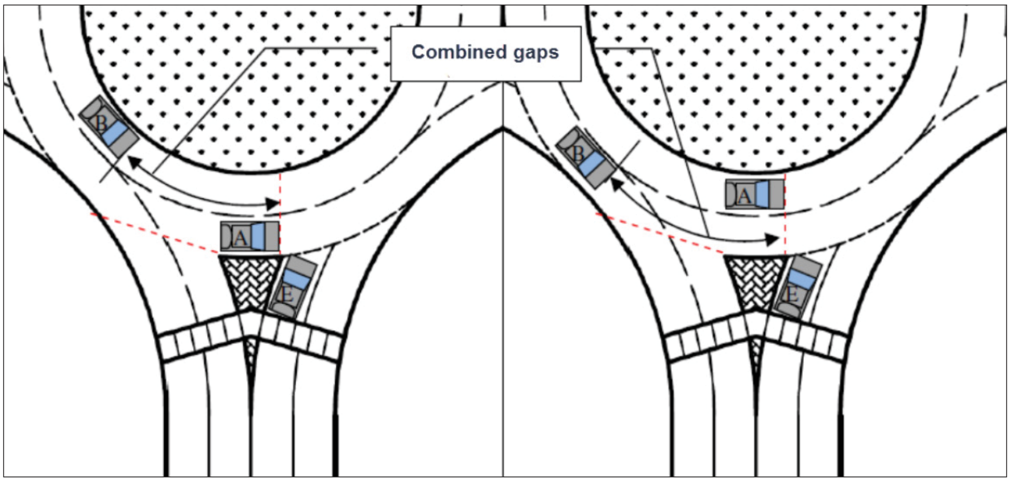

Figure 3 "Combined" gaps for two-lane roundabout [4]

Most of the existing researches on gap-acceptance parameters for two-lane roundabouts are presenting two sets of values, one for left entry lane and one for right entry lane. However, some of recently researches (i.e. [5]) suggest four sets of gap-acceptance parameters, depending on real conflict situations early described. This is especially important for applying of Hagring's formula for capacity (see [6], [7]). In this study, we also noticed the differences between these sets of gap-acceptance parameters, so critical gap and follow-up headway have been determined for every conflict situation.

4 Results

The results obtained, for both roundabouts, are shown in Tables 1 and 2. As it can be seen from Table 2, four sets of gap-acceptance parameters for two-lane roundabouts were obtained. For reasons given earlier, critical gaps for right entry lane on two-lane roundabout are much smaller than for left entry lane. However, those results must be verified with research on more existing roundabouts.

Table 1 Gap-acceptance parameters for single-lane roundabout

Single-lane roundabout "Evropa", Zenica	
Critical gap (t_c) (sec)	4,426
Follow-up headway (t_f) (sec)	3,670
Standard deviation (sec)	1,183
Sample (veh)	502
Inconsistent drivers	9

Table 2 Gap-acceptance parameters for two-lane roundabout

Two-lane roundabout "Radakovo", Zenica				
Approach lane	Left lane		Right lane	
Circular lane	Inside	Outside	Inside	Outside
Critical gap (tc) (sec)	3,95	3,95	3,07	2,65
Follow-up headway (t_f) (sec)	3,48	3,48	3,24	3,24
Standard deviation (sec)	1,072		1,011	0,971
Sample (veh)	204		101	88
Inconsistent drivers	13		4	5

Obtained results were compared with values from two most used methodologies and software (Tables 3 and 4), i.e. Highway Capacity Manual (HCM 2010) [8] and SIDRA Standard Model [9]. Also, we used values from the latest HCM edition (HCM6th Edition) from 2016. Detailed comparison of published studies on gap-acceptance parameters can be seen in [10].

Table 3 Comparison of gap-acceptance parameters for single-lane roundabout

Single-lane roundabout		
Study	**Critical gap (tc) (sec)**	**Follow-up headway (t_f) (sec)**
Zenica (2017)	4,426	3,670
HCM 2010	5,193	3,186
HCM 6th Edition	4,990	2,609
SIDRA Standard Model	4,50 (4,0 – 5,0)	2,50 (2,0 – 3,0)

Table 4 Comparison of gap-acceptance parameters for two-lane roundabout

Two-lane roundabout		
Study	**Critical gap (tc) (sec)**	**Follow-up headway (t_f) (sec)**
Zenica (2017) – left lane	3,946	3,480
Zenica (2017) – right lane	3,074 – inside	3,240
	2,646 – outside	3,240
HCM 2010 – left lane	4,113	3,186
HCM 2010 – left lane	4,293	3,186
HCM 6th Edition – left lane	4,320	2,536
HCM 6th Edition – right lane	4,650	2,667
SIDRA Standard Model	5,00 (4,5 – 5,5)	3,00 (2,5 – 3,5)

In compare to most used methodologies, gap-acceptance parameters from Bosnia and Herzegovina are very different. The bigger difference is in parameters for two-lane roundabouts due to presence of additional sets of them. Results clearly indicate the need to calibrate these models when used for capacity calculation. However, if all local gap-acceptance parameters are available, Hagring's equations for capacity are more suitable.

5 Conclusion

Gap-acceptance parameters represent key elements for capacity and level of service analysis on unsignalized intersections. Different sets of gap-acceptance parameters describe different behavior of drivers and the differences in driving practice between countries, so they cannot be constant and unique value. This study is of great importance for engineers in Bosnia and Herzegovina because for the first time critical gap and follow-up time have determined on local roundabouts.
Practical implementation of obtained gap-acceptance parameters for calibration of existing capacity methods (i.e. HCM 2010) or application in Hagring's capacity model, shows their real importance and necessity in analysis of roundabout operational performance.

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