Retraction Notice

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☐ Some of the authors:
☐ Editor with hints from
  O Journal owner (publisher)
  O Institution:
  X Reader:
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Date initiative is launched: 2016-06-16

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Editor guiding this retraction: Tschangho John Kim (EiC, JTTs)

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Estimation of Critical Gap of U-Turns Road in Turkey

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Abstract

The estimation of critical gap is an important traffic parameter and this is useful to estimate the capacity of U-turning vehicles at uncontrolled median openings. In this study critical gap is estimated by four different methods by collecting data at seven median openings in Turkey. An unconventional method of critical gap estimation using the merging time of the U-turning vehicle is proposed. The merging time to clear the conflict area at uncontrolled median opening was calculated from field data and this time is utilized to estimate the critical gap for different categories of vehicle.

Keywords

U-Turn, Critical Gap, Median Openings, Heterogeneous Traffic, Capacity

1. Introduction

The U-turn movement at median openings is highly complex and risky compared with turning movements at intersections, firstly because of the high speed and traffic volume and secondly because the turning vehicle has to make a reverse movement. The turning vehicle must wait and then turn under low speed conditions in the face of oncoming traffic and may need to accelerate rapidly to achieve the speed of the traffic stream. A critical gap is a significant factor in gap acceptance behavior and also for estimation of the capacity of U-turns at uncontrolled median openings [1]. Raff and Hart defined critical gap as the size of the gap whose number of accepted gaps shorter than it is equal to the number of rejected gaps longer than it [2]. The Highway Capacity Manual (HCM) defined critical gap as the median time headway between two successive vehicles in the major street traffic stream that is accepted by a driver in a subject movement who intends to cross or merge with the major street flow [3]. HCM modified the definition and stated that the critical headway is the minimum time interval between the front bumpers of two successive vehicles in the major traffic stream that will allow the entry of one

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minor-street vehicle [4]. The present study is an attempt to estimate the critical gap of U-turns and also to access the effect of opposing traffic on the critical gap for different categories of vehicle.

2. Literature Review

Pant and Balakrishnan developed a binary-logit model for predicting accepted or rejected gaps at two-way stop-controlled (TWSC) intersections on rural areas [5]. Hamed *et al.* studied various factors affecting the gap acceptance for left-turn maneuvers at urban T-intersections [6]. Gattis and Low used different methods to calculate the critical gap at intersections [7]. Tian *et al.* investigated various factors affecting the critical gap and follow-up time [8]. Davis and Swenson developed logit model for assessing the drivers' left turn gap acceptance and inferred the probability of a driver accepting a gap of a given duration increased as the speed of the oncoming vehicle increased [9]. Wu developed an innovative and robust method for the estimation of the critical gap at un-signalized intersections [10]. Ashalatha and Chandra criticized the incapability of the existing methods for critical gap estimation under highly heterogeneous traffic conditions [11].

In this case some authors [12] calculated critical pedestrian estimation with queuing model and this model inspired that new concept that critical gap estimation. They developed a new concept for critical gap estimation by assessing the clearing behavior of vehicles. The author concluded that the proposed method provides realistic estimation of critical gap and provide accurate result in estimating the entry capacity in traffic condition prevailing in Turkey.

3. Methods for Critical Gap Estimation

Critical gap models are an important parameter to study the gap acceptance behavior of human movement [13]. As human movement, critical gap cannot be directly measured in the field. Its value differs from driver to driver, from time to time. The review of literature revealed that, among all the different methods, modified Raff method, maximum likelihood method, and macroscopic probability equilibrium method produced the best results.

3.1. Modified Raff Method

The earliest method for the estimation critical gap was proposed by Raff and Hart and this method has been used in many countries because of its simplicity [2]. The modified raff method involves the observed distribution function of accepted gaps $F_a(t)$ and rejected gaps $F_r(t)$. When the sum cumulative probabilities of accepted gaps and rejected gaps are equal to 1.0, then a gap of length t is equal to critical gap t_c. Mathematical the expression for critical gap is presented below:

$$F_a(t) = 1 - F_r(t). \quad (1)$$

The cumulative frequency distribution curves of accepted and rejected gaps are plotted and the intersection of the two curves gives the critical gap.

3.2. Maximum Likelihood Method

This microscopic model assumes the log-normal distribution of accepted and maximum rejected gaps [14]. In this method, only the accepted gap and the maximum rejected gap of each vehicle are considered pair wise [15]. For one individual U-turning vehicle, one accepted gap (a_i) and one corresponding the maximum rejected gap (r_i) are considered. This method assumes that the U-turning drivers are consistent drivers. It means that each driver will reject every gap smaller than the critical gap and will accept the first gap larger than the critical gap.

$$\prod_{i=1}^{n}\left[F(a_i) - F(r_i)\right] \quad (2)$$

where,

a_i = the logarithm of the gap accepted by the ith driver,

r_i = the logarithm of the maximum gap rejected by the ith driver,

$r_i = 0$, if no gap was rejected,

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$f(\,)$ and $F(\,)$ are the probability density function and cumulative distribution function for the normal distribution respectively.

The logarithm, L, of this likelihood is

$$L=\sum_{i=1}^{n}\ln\left[F(a_i)-F(r_i)\right]. \tag{3}$$

The maximum likelihood estimators, μ and σ^2, are solutions when the partial derivative of Equations (4) and (5) are equal to zero. They can be simplified as follows

$$\sum_{i=1}^{n}\frac{f(r_i)-f(a_i)}{F(a_i)-F(r_i)}=0 \tag{4}$$

$$\sum_{i=1}^{n}\frac{(r_i-\mu)f(r_i)-(a_i-\mu)f(a_i)}{F(a_i)-F(r_i)}=0. \tag{5}$$

By iterating the Equations (4) & (5) to zero, the value of t_c is determined by using the Equation (6).

$$t_c=\mathrm{e}^{\mu+0.5\sigma^2}. \tag{6}$$

The variance in critical gap can be calculated as follows:

$$s^2=t_c^2\left(\mathrm{e}^{\sigma^2}-1\right). \tag{7}$$

3.3. Macroscopic Probability Equilibrium Method

Wu proposed this method which is based on probability equilibrium between accepted and rejected gaps [10]. The main advantage of this method is, it provides a true average of the critical headway, and it does not need any predefined distribution function of critical gap and assumptions related to the consistency and homogeneity of drivers whereas MLM needed predefined distribution function as well as these assumptions [16]. Wu explained the method as described below. Wu stated that "The equilibrium is established macroscopically from the cumulative distribution of the rejected and accepted gaps [10]. The observed probability that a gap of length t is accepted is $F_a(t)$ and that it is not-accepted is $1-F_a(t)$. The observed probability that a gap of length t is rejected is $F_r(t)$ and that it is not-rejected is $1-F_r(t)$. Generally, $F_r(t)\neq 1-F_a(t)$ and $1-F_r(t)\neq F_a(t)$ because an accepted gap in the major stream may not have the exact length of the actual critical gap.

$$\begin{cases}P_{r,tc}(t)=F_r(t)\cdot P_{r,tc}(t)+F_a(t)\cdot P_{a,tc}(t)\\ P_{a,tc}(t)=\left(1-F_a(t)\right)\cdot P_{r,tc}(t)+\left(1-F_r(t)\right)\cdot P_{a,tc}(t)\end{cases} \tag{8}$$

By solving the Equation (8) and substituting $P_{r,tc}(t)=F_{tc}(t)$ and $P_{a,tc}(t)=1-F_{tc}(t)$, the probability distribution function is stated as follows:

$$F_{tc}(t)=\frac{F_a(t)}{F_a(t)+1-F_r(t)}=1-\frac{1-F_r(t)}{F_a(t)+1-F_r(t)}. \tag{9}$$

The step by step procedure for the implementation of the method into an Excel spreadsheet is also explained by Wu [10].

4. Case Study

For the study on critical gap, data have been collected from seven different median opening on multilane divided urban roads in Turkey. The detailed geometry of the median openings and traffic composition of U-turning traffic stream is presented in **Table 1** and **Table 2** respectively. Videography technique was used to collect data from all the sites during both peak and off peak periods on various week days. Data were collected to cover all traffic volumes ranging from 1000 vph to 6000 vph.

Table 1. Geometry of different test sections.

Section No.	1	2	3	4	5	6	7
Width of median opening	20	15.7	19.8	14.8	20	20.3	20.1
Width of raised median	1.3	1.0	1.2	1.2	1.3	1.2	1.3
Width of carriageway	9.6	9.6	9.8	9.5	9.4	9.5	9.4

Table 2. Traffic composition at different sections.

Section No.	Approaching through traffic volume	U-turning traffic volume							
		CAR	2W	3W	SUV	LCV	HV	Others	Total
1	4416	153	492	213	36	24	6	18	942
2	4380	170	552	72	80	30	12	8	924
3	5876	103	647	72	30	12	6	12	882
4	5521	15	178	23	4	2	-	-	222
5	5858	36	108	12	3	1	-	-	160
6	4857	43	139	20	14	5	2	1	224
7	4736	287	700	343	92	94	23	66	1605

*All the values are in vph (vehicles per hour).

Lag was measured as the time interval between the arrival of a U-turning vehicle at line AB (**Figure 1**) and the arrival of the next (first) approaching through vehicle on the upstream end of Inafoga (line BC). The line BC is considered as the reference line for the estimation of the gap. The merging time (MT) of a U-turning vehicle was measured from the time the rear bumper passed over the line AB to the time the rear bumper crossed the merging line AD.

5. Data Analysis

The extracted data were analyzed with the three methods described in Section 3. The review of earlier research revealed that with the increase of major stream volume or minor stream vehicle delay, drivers tend to seek smaller gaps [6] [8] [17]. Therefore, this aspect is also studied and presented below.

The procedure explained previously has been utilized to find the critical gap for different categories of vehicle. In this study the lag acceptance data are also considered for the estimation of critical gap. The accepted and rejected gaps have been binned into a time interval of 0.3 s. The cumulative distribution curves of accepted and largest rejected gaps for a particular category of vehicle at a particular approaching through traffic volume are plotted. **Figure 2** shows the cumulative distribution curve of accepted and rejected gaps for cars when the approaching through traffic volume is in the range of 3500 to 4000 vph. The intersection point of the two curves is reported as the critical gap.

The critical gap was calculated for other three categories of vehicle at various approaching through traffic volume level and is tabulated in **Table 3**. The variation in the critical gap values with traffic volume is shown in **Figure 3**. The variation in critical gap is attributed to the wide disparity in static and dynamic features of the vehicles. The critical gap of 2W is found to be minimum among all the category of vehicle. The critical gap for 2W is the least due to the narrow dimension and peculiar driving attitude of the drivers.

The observation in the values of **Table 3** reveals that, the critical gap values decrease with an increase in the approaching through traffic volume. The trend is shown in **Figure 3**.

In maximum likelihood method, accepted and maximum rejected gap for each U-turning driver has been used. The driver who has accepted a gap smaller than the one, which they have previously rejected have been considered as an inconsistent driver and those data have been discarded from the analysis. Equations (4) and (5) were iterated simultaneously for estimation of likelihood parameters. The calculated critical gap values at different

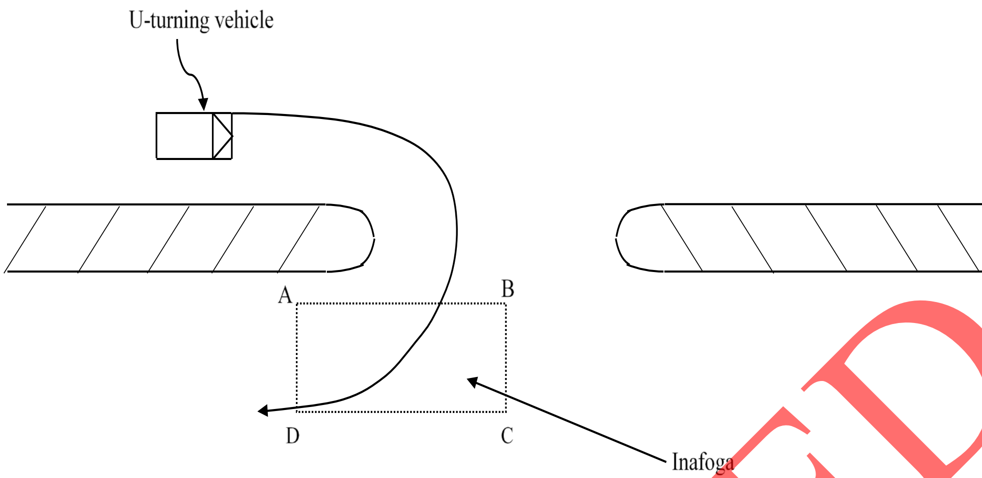

Figure 1. Schematic representation of influence area for gap acceptance for U-turn movement.

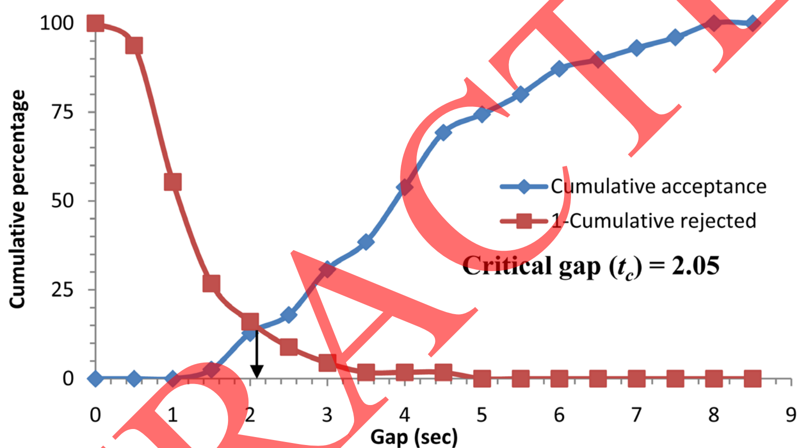

Figure 2. Distribution functions of accepted gaps and rejected lags and gaps.

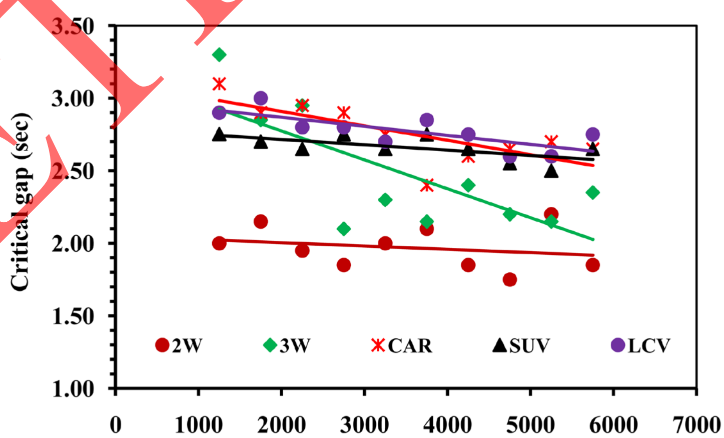

Figure 3. Effect of approaching through traffic volume on critical gap estimated by modified Raff method.

traffic volume are given in **Table 4** and shown in **Figure 4**.

This method is based on the equilibrium probability of the rejected and accepted headways. It does not require the predefined distribution function of the critical headways, or assumptions about the consistency or the homogeneity of drivers and the result of the analysis is presented in **Table 5** and shown in **Figure 5**.

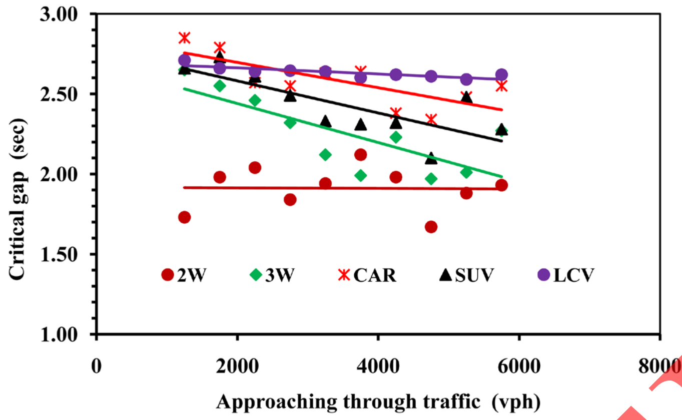

Figure 4. Effect of approaching through traffic volume on critical gap estimated by maximum likelihood method.

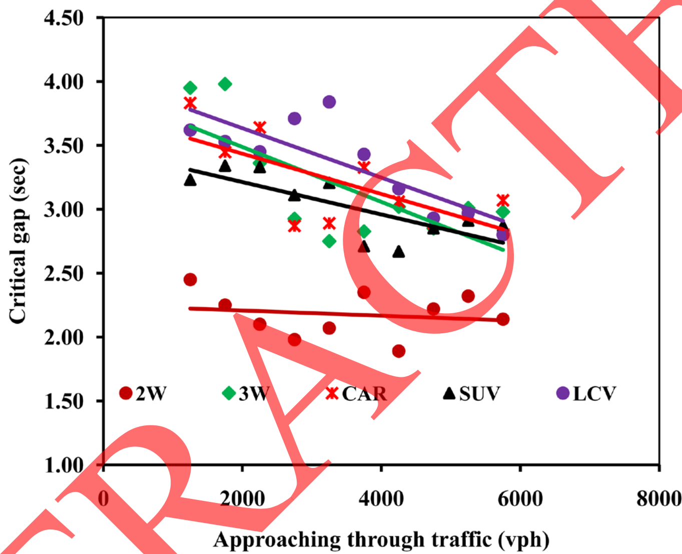

Figure 5. Effect of approaching through traffic volume on critical gap estimated by probability equilibrium method.

Table 3. Critical gap values by modified Raff method.

Approaching through traffic volume (vph)	Critical gap (sec)				
Range	2W	3W	Car	SUV	LCV
1000 - 1500	2.00	3.30	3.10	2.75	2.90
1500 - 2000	2.15	2.85	2.90	2.70	3.00
2000 - 2500	1.95	2.95	2.95	2.65	2.80
2500 - 3000	1.85	2.10	2.90	2.75	2.80
3000 - 3500	2.00	2.30	2.75	2.65	2.70
3500 - 4000	2.10	2.15	2.40	2.75	2.85
4000 - 4500	1.85	2.40	2.60	2.65	2.75
4500 - 5000	1.75	2.20	2.65	2.55	2.60
5000 - 5500	2.20	2.15	2.70	2.50	2.60
5500 - 6000	1.85	2.35	2.65	2.65	2.75

Table 4. Critical gap values by maximum likelihood method.

Approaching through traffic volume (vph)	Critical gap (sec)				
Range	2W	3W	Car	SUV	LCV
1000 - 1500	1.73	2.65	2.85	2.66	2.71
1500 - 2000	1.98	2.55	2.79	2.73	2.66
2000 - 2500	2.04	2.46	2.57	2.61	2.64
2500 - 3000	1.84	2.32	2.55	2.49	2.65
3000 - 3500	1.94	2.12	2.63	2.33	2.64
3500 - 4000	2.12	1.99	2.64	2.31	2.60
4000 - 4500	1.98	2.23	2.38	2.32	2.62
4500 - 5000	1.67	1.97	2.34	2.10	2.61
5000 - 5500	1.88	2.01	2.48	2.48	2.59
5500 - 6000	1.93	2.27	2.55	2.28	2.62

Table 5. Critical gap values by probability equilibrium method.

Approaching through traffic volume (vph)	Critical gap (sec)				
Range	2W	3W	Car	SUV	LCV
1000 - 1500	2.45	3.95	3.83	3.23	3.62
1500 - 2000	2.25	3.98	3.45	3.34	3.53
2000 - 2500	2.10	3.36	3.64	3.33	3.45
2500 - 3000	1.98	2.93	2.87	3.11	3.71
3000 - 3500	2.07	2.75	2.89	3.21	3.84
3500 - 4000	2.35	2.83	3.33	2.71	3.43
4000 - 4500	1.89	3.02	3.06	2.67	3.16
4500 - 5000	2.22	2.85	2.89	2.85	2.93
5000 - 5500	2.32	3.01	2.96	2.91	2.97
5500 - 6000	2.14	2.98	3.07	2.87	2.80

6. Conclusion

In this study, three different methods, namely: modified Raff, maximum likelihood, and macroscopic probability equilibrium are used for critical gap estimation. The estimated values are found to vary with category of vehicle and variation is attributed to the wide disparity in static and dynamic features of the vehicles. The critical gap values are estimated at the varying approaching through traffic volume and found to be slightly decreasing. This decreasing trend can be attributed to the fact that the pressure from increasing approaching through traffic flow results in drivers' waiting time. This makes the drivers frustrated and aggressive and compels the driver to accept a gap which was once rejected. Furthermore, the estimated critical values from the established methods are found to be very low. This can be attributed to the fundamental limitations of established critical gap estimation methods to address the peculiarity of mixed traffic.

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