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Traffic volume and waiting time influence on gap acceptance of selected change direction U-turn opening

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ABSTRACT

The vehicles moving on change direction U-turn opening have to spend some time while the acceptable headway provided on conflicting main traffic flow. The present paper investigated the effect of waiting time and traffic volume increasing on gap acceptance behavior, critical gap limit, and U-turn capacity. The data were collected at selected change direction U-turn in Najaf city (center city of the Najaf governorate located approximately 160 km south of Baghdad, the capital of Iraq) within Najaf city highways network. The study concentrated on the passenger cars driver movement at change direction U-turn openings. The analysis approach depended on evaluating these parameters and their degree of influence on U-turn capacity is statistical analysis. statistical analysis established that, when waiting time fall in a range between 21- 30 sec, driver enforced to accept gap size less than that fall in the range of 11 to 20 sec at a confidence interval of 95%. On the other hand, there is a slightly different in mean gap acceptance between an interval of (1-10) and (11-20) sec) at the same confidence interval. Results showed the studied U- turn change direction median critical gap equal to 3.75 sec. and follow-up time was 1.1 seconds. According to Siegloch's formula the maximum capacity of 3273pcu/ hr. At level of confidence of 95%, the mean value of the highest wait time group interval is lower than the critical gap. Therefore, the studied change direction U-turn might be hazard location and it is important to control and manage at the median opening.

Keywords: Change direction U-turn opening, Critical gap, Delay, Gap acceptance, waiting time.

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1. Introduction

In any current nation, urban highways network has a high proportion of change direction U- turn facilities. Any vehicle in miner stream aims to inter the mainstream by using a U-turn facility, have to spend some time looking for a satisfy gap in the opposing through traffic flow, then take its movement to merge and complete its maneuver. The change direction U-turn movement takes in behavior, same as that in minor traffic stream at unsignalized intersections. This vehicle's behavior depends on the "gap acceptance process". Although The sight distance provided for change direction U-turn movement is sufficient, the moving vehicles request larger space and additional time in order to make the turning movement. According to hierarchy point of view, the change direction U-turn doesn't have a traffic priority, but driver decisions depend widely on their waiting time at it. When a driver spends longer waiting time, a normal reaction drivers will be more aggressive and as a result, he/she is obliged to accept the risk and move with the shorter gap.

Well design highway networks depend on U-turning openings as the main role in eliminating traffic congestion by providing access to change direction, or indirect median left turn. Alternatively, in some situations, the U-turn movement is completed by the allowance of making one left turn plus malty right turns at congested facilities or junctions. Otherwise, the drivers may change their driving route by turning to use other highway classes such as collectors or local roads instead. U-turn opening facility may be found on any highway classification, however, present highly, in urban arterials in signalized or un-signalized intersections, and mainly as change direction U-turn median.

current research deals with U-turn driver behavior, dedicated passenger car movement change direction U-turn on miner arterial in Najaf city in order. Other types of vehicles are ignored in order to eliminate the effects of their mechanical properties of gap acceptance. Research main aims can be listed as:

- Investigate traffic volume and waiting time effect on the accepted gap, the critical gap and whole capacity of a selected U-turn change direction,
- Define the effect of waiting time that cause safety worry.

At any U-turn facility, each turning vehicle's driver has to wait for a safe gap (in his/her point of view) known as the acceptable gap on opposing through traffic. As the selection of a large gap is sufficiently safe done, the driver begins to make a U-turning maneuver. Driver behavior in U-turning follows the same trend in minor approach gap acceptance at TWSC (two way stop controlled) intersection. However, change direction U- turn maneuver at highway is simplest than that at TWSC in terms of traffic components, but in terms of the maneuvering mechanism, change direction U-turn maneuver is more complicated.

The "waiting time" in the current paper refers to a period of time that an arrival turning vehicle at change direction opening, spends waiting for the acceptable gap through the opposing traffic flow until begins its U-turning maneuver. The "rejected gap" represents the headway time between two following opposing vehicles that waiting at U- turn vehicle can't accept to implement its maneuver. The "accepted gap" is that head time when a U-turning vehicle can complete turning maneuver. While the turning vehicle is waiting for an accepted gap, may encounter one or malty gap that can't satisfy it to complete the desired movement, each one of these gaps is rejected gap, but there is only one gap accepted. In the case of the first gap is an accepted gap, there are no rejected gaps. Usually, the current control measures depended on highways are traffic signals and existing of policeman at the U-turn facility. In peak periods, it was necessary to merge with conflicting traffic volume for U-turning vehicles safely and within the capacity.

Many research was investigating U-turn openings performance, capacity, and degree of hazards. Some solutions presented in almost these researches are focused on using right-turns- U-turns (RTUT) instead of direct left-turns (DLT) movement, such as (1); (2); (3); (4).

Earlier, U-turn median opening capacity was considered by Al-Masaeid (5) in Jordan by identifying the affected factors that were evaluated statistically. Analysis results showed a significant correlation of opposing through traffic with delay time. On the other hand, the critical gap is highly affected by opposing traffic speed and average total delay. Regression analysis conducted an empirical model of U-turn capacity in addition to the gap acceptance model. Both models verified and gave reasonable results. The same approach for estimation of U-turn capacity was carried out by other researchers like (6)& (7). Liu et al. (8) investigated un-signalized intersections critical gap assessment from characteristic of gaps acceptance and rejected. The main funds of the current study, that critical gap size and U-turn capacity highly depend on geometric design of intersection especially the median width. In other words, U-turn capacity increased with a wider median. According to HCM 2000, gap acceptance model is recommended for estimating U-turn potential capacity for TWSC. Also, the gap acceptance model can give realistic U-turn movement capacity as compared with data collected from the field, (6).

TWSC intersections are widely taken in almost gap acceptance researches. Many factors studied and investigated their effect on the size of the accepted gap likes delay time, gap length, opposing traffic flow rate, volume, speed, and effect of directional movement of turning vehicle on gap acceptance (9). Results exhibited that accepted gap length was significantly affected directly by queue length and time or waiting time length. When waiting time increases, the driver’s frustration increases and need his/her best capability for estimation the sufficient gap size to accept it. The same assumption was studied by Pollatschek et al. (10), in developing gap acceptance behavior decision model. The model evidence that the long waiting time makes driver ready to accept shorter gap regardless of movement hazardously.

Driver ability according to age group and different condition time of day effect on gap acceptance complimented meaningfully variances in gap acceptance, Yan et al. (11). Longer gap sizes appear more suitable for the old age group more than the mid and younger group. Furthermore, longer gap accepted by a female driver more than a male driver. Major stream Speed effect also taken in research; results showed that higher speed was pushing the driver to take a risk by accepting shorter gaps. Un- protected left turn phase and gap acceptance in U-turn at signalized intersections studied in terms of driver behavior influenced by restricted sight distance, Yan and Radwan (12). Because of limited data collected from the no-queued conditions, U-turn critical gap analysis by the logistic regression model. Critical gap and follow-up time are the essential of any gap acceptance model, (13). There are different methods depending in the evaluated the critical gap, mainly depending on regression analysis data collected from the field, such as "Siegloch's method", Brilon et al. (14). The degree of saturation widely effects on gap acceptance model estimation. U-turn capacity can be estimated for un-saturated flow situations by the maximum likelihood method and Siegloch’s method, (7).

Current research explores wait time and opposing traffic volume on gap acceptance in change direction U-turn median openings. Traffic movement at a U-turn mid-block opening at the Kufa–Najaf highway in front of the University of Kufa campus main gate was recorded by videotape. Waiting time, gap size, accepted, rejected gap, and traffic volume have been collected from video recorded in the laboratory. Statistical analysis and Siegloch’s method depend on the critical gap, average follow up time, and capacity model evaluation. In order to evaluate safety insurance, the mean accepted gap is compared with an estimated critical gap. Although, vehicles classify into three general types (passenger car, truck and buses, and motorcycle), this paper concentrated on passenger cars only.

2. Methodology

2.1. Site characteristics and data collection

Change direction U-turn median opening facility selected in Najaf- Kufa minor arterial taken in this study as a source of data depended in evaluation critical gap and U-turn capacity shown in figure 1.

Najaf- Kufa minor arterial is six lanes divided highway, 3- lanes in each direction. On & off- street parking, over-pass in two locations, many change direction U-turn in addition to access in both directions are existing at this highway. according to data collected from percent of passenger cars is 92% of total vehicles making U-turn maneuvers, so the study taking only passenger cars, as mentioned earlier. The field survey included collecting data for three normal workdays (minimum of 4 hrs each day), during daytime from 7 AM. to 3 PM depending on the amount of video data recorded for gap acceptance investigation. The recording period is defined in terms of one-hour duration, divided into two recording periods containing two break times. The observations’ location set in distance ranges from 30 m to 90 m upstream of the mid-block U-turn opening, depending on the space available for observation purposes, (15). Each selected daytime must be clear of traffic breakdowns, such as congestion, traffic flow breakdown, collisions, or severe weather conditions, to prevent the effects of these parameters. A simple software program called EVENT written with C-language, (16), provides a system for data counting and enables digital counting for available gaps manually in addition to Microsoft Excel. Each vehicle aimed to turn should be stopped or at least reduced its speed has a waiting time, No. of vehicle in the queue (if present), rejected gap, accepted gap, and the number of vehicles follow up turning vehicle. It is important to mention that traffic flow should be unsaturated. This condition is essential to prevent driver enforcement behavior and insure normal gap acceptance of driver behavior. Furthermore, all data was collected without the presence of traffic police or any other movement control.

Figure 1. Location of study

2.2. Data analysis

Statistical analysis method depends on collected data analysis. Two approaches had been used in data analysis, individual data point, and interval data. The data characteristics were explained and shown statistically in a descriptive way. Level of confidence interval selected in current study was 95% (i.e., significance level= 5%).

2.3. Critical gap estimation

Normally, vehicles before turning, they have to wait for an adequate gap (accepted gap size) in opposing flow. The gap size should be long enough to permit turning vehicles to move safely and merge with the main traffic flow. As mentioned earlier, the method of U-turn capacity model estimation provides equitable capacity values established on Al-Masaeid (5) and (6). All data collected had been classified according to their value as parameters of critical gap estimation, which refer to gap size, time wait, and follow-up time. "Siegloch's method" depended on critical gap estimation, which is regression analysis, (17).

For each vehicle that comes from a minor road, try to encroach into a major road refer to (n), n=1 in case of no queuing in the minor stream. Mainstream gap denoted by t may be rejected or accepted gap. The value of n will be zero in case of a rejected gap. Average gap acceptance is calculated in case there is a number of vehicles n accepted gaps. Linear regression analysis was fitted for average gap acceptance as a function of vehicle numbers. Graphical representation of gap size t as the independent variable with a number of vehicles n as the dependent variable, normally, gives zero-gap factor t0 from intercept with X-axis. While follow-up time tf was the slope of the regression line. On the other side, critical gap tc can be found from the following equation:

$$t_c = t_0 + 0.5 t_f \tag{1}$$

2.4. Models of U-turn capacity

The capacity model of U-turn established by two methods basically related to gap acceptance models. The first method is Siegloch's formula, (5) that adviced by HCM 1994, the second method is Harder's model, (6) that presented in HCM 2000. The following equations represent "Siegloch's formula" and Harder's models, respectively:

$$c = (3600/t_f)\, e^{-(q/3600)(t_c - 0.5\, t_f)} \tag{2}$$

$$c = q\left[\frac{e^{-(q/3600)(t_c)}}{1 - e^{-(q/3600)(t_f)}}\right] \tag{3}$$

c= U-turn capacity (pcu/hr), q= opposing flow in major stream (pcu/hr), t_c= critical gap (sec.), t_f= follow up time (sec.)

3. Results and discussion

gap acceptance and Waiting time are the main critical gap parameters collected from videotape recorded. There are some collected data discarded such as that case when two or more vehicles turned together and merged with the main traffic flow stream because these vehicles accepted the same gap size. Other types of data discarded, that when turning vehicle enforced the traffic flow in the major stream to provide suitable gap, in other words, when vehicles in major stream enforced to slow down the speed or stop. According to the research aims, data filtering, the collected data mainly represent the waiting time, accepted gap, and follow-up time.

From recorded video, totally 454 observations were collected, and accepted gaps are 214 observations from them used for analysis. Figure 2 shows the gap acceptance relationships versus waiting time. As obvious from figure 2, the accepted gaps range was varied relative to the small waiting time. On the other hand, long waiting times cause a narrow range of accepted gaps, especially waiting times exceeding 15 seconds. The main tendency of gap acceptance noticeably shows when the driver was facing a relatively long waiting time, he/ she attend to accept a shorter gap.

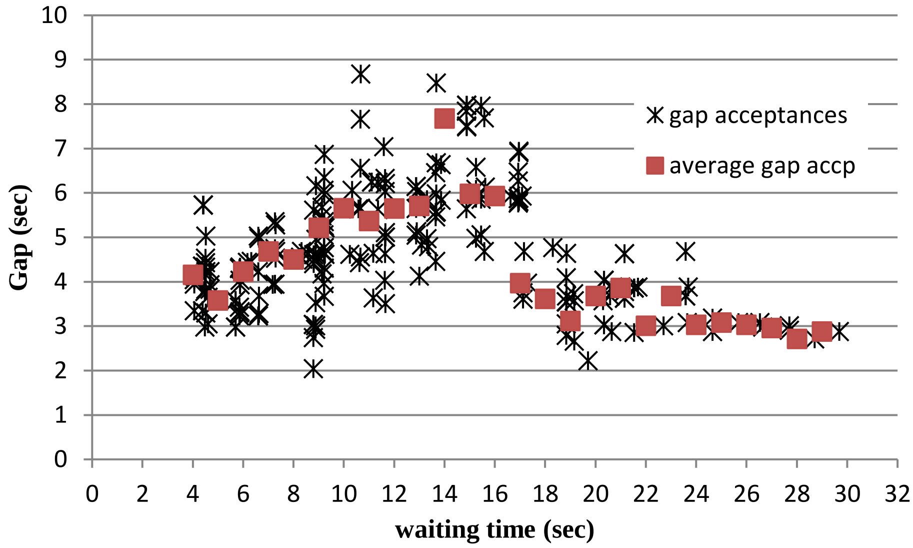

Figure 2. Waiting time verses accepted gap for turning vehicle

In order to explore the relationship between waiting time and accepted gap, a correlation test had been done. Test results show Pearson correlation was -0.0997, this value of Pearson correlation indicates an intermediate relationship between parameters. It is well known that the Pearson correlation's negative value represents the inverse correlation between these parameters (i.e., longer waiting time mean relatively shorter gap acceptance). Other outcomes of correlation test are p-value= 0.0196< level of significance of 0.20. In other words, significance at 80% level interval of the one-tailed statistical significance obtained from the negative correlation.

Acceptance gap observations are rearranged in form of waiting time intervals, this arrangement is necessary for the investigation of waiting time relationships with gap acceptance that indicate normal distribution by parametric statistical tests. The data interval length was selected to be 10 seconds. So, the whole data is divided into three intervals group of waiting time. These groups were defined on 10- sec intervals. The first group cover waiting time up to 10 seconds, the second group was the interval of waiting time between 11-20 seconds, finally the third one of the waiting times between 21-30 seconds. Each group has a normal distribution at the 95% confidence interval according to W-test, that is a base statistical consideration analysis of the data arrangement previously. Average accepted gaps for each waiting time are essential to eliminate the range of data scattering. Consequently, for each waiting time value, there is only a unique gap acceptance value. Normality test at 95% confidence interval (p value> 0.05) should be satisfied for each data group. The accepted gap statistical numerical results showed in table 1. While figure 3 illustrates the ranges and mean values of gap acceptance for each waiting time interval group.

Other important observation, that the same trend of waiting time increase on accepted gap size. In other words, with a longer waiting time, there is a slight decrease in the mean accepted gap. This behavior us obvious strongly when waiting time is longer than 20 sec. other essential drivers' behavior observed from gap parameters was their tendency to accept a gap of approximately 4 seconds to complete the turning maneuver. In addition to that, when wait time extends for other seconds, drivers always tend to accept gap size equal or less than previously rejected.

Table 1. Accepted gap data statistic results

No. group	Time* Wait	N	Max.*	Min.*	Mean*	SD*	Q1*	Q2*	Q3*
1	1-10	91	6.87	2.84	4.30	0.918	3.58	4.33	4.77
2	11-20	88	8.68	2.22	5.51	1.366	4.63	5.66	6.25
3	21-30	35	4.68	2.71	3.52	0.540	3.01	3.63	3.88
Sum.	1- 30	215	8.68	2.04	4.44	1.318	3.68	4.50	5.65

Note: n = No. of Data, Min/Max = Minimum/Maximum, SD = Standard Deviation, Q1, Q2, &Q3 = 1st, 2nd, &3rd Quartile * Units are seconds.

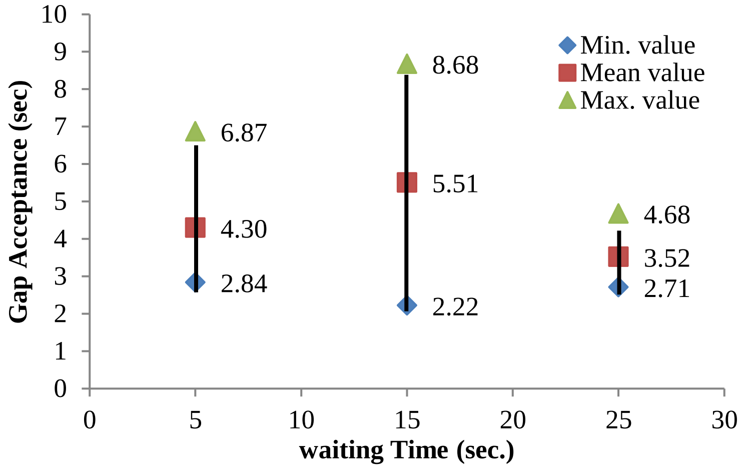

Figure 3. Gap acceptance for waiting time interval groups

The variations between mean accepted gap in the three intervals of waiting time had been conducted statistically. The principle of a hypothesis test is the mean accepted gaps of the last group interval, in this study last group interval represents waiting time interval 21-30 seconds. The statistical test hypothesis was shown below in some detail:

Null Hypothesis H_0: $\mu i = \mu 10$

Alternative Hypothesis H1: $\mu i > \mu 10$

The waiting time interval groups were i = 1, 2, 3

For comparison purposes, two sample t- test had been conducted. Table 2 illustrates the two-sample t-test, at a confidence interval equal 95%. The differences in sample variances between group intervals were checked by Levene's test results. Furthermore, the values of the two-sample t-test in table 2 are corrected and conducted properly.

From statistical analysis has been established that significantly, when waiting time fall in the third group interval (i.e., between 21- 30), driver enforced to accept a gap size less than that for the second group interval (i.e., between 11- 20) at a confidence interval of 95%. On the other hand, there is a slightly different in mean gap acceptance between the first and second group intervals (i.e., between (1-10) and (11-20)) at the 95% confidence interval.

The main element in the current study is critical gap parameters. As mentioned earlier, Siegloch's method was dependent on finding the critical gap. The data collected for the critical gap parameters determination are in queue conditions of turning traffic.

Gap sizes are plotted in scatter pattern versus U-turn turning vehicles number, also the average gap size is presented in, linear regression line of these data shown in figure 4. It is obvious in figure 4, according to Siegloch's method, and application of equation 1 gave the X-axis intercept equaled to 3.2 seconds that is the zero-gap parameter, t0. Reciprocal of the slope which is follow up time (tf,) was 1.1 seconds. Finally, The critical gap, tc = t0 + 0.5tf = 3.75 seconds.

Table 2 Comparisons of two means based on the means of Group 3.

Group Interval	(1-10 sec.)	(11-20 sec.)	(21-30 sec.)
Difference in Variances (Levene's Test)	Insignificant (No Variance)	Insignificant (No Variance)	Insignificant (No Variance)
Difference in Means (One-tailed t-Test)	Significant (p-value= 0.0091)	Significant (p-value= 0.0063)	Insignificant (p-value= 0.052)

Note: level of significance= 5%. - level of significance 10% for The difference in means.

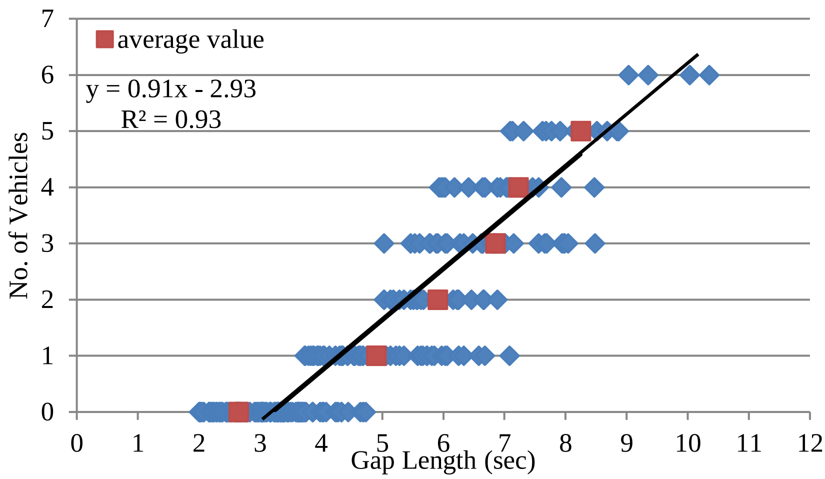

Figure 4. Critical gap parameter estimation based on Siegloch's method

This result complies with other previous investigation dealing with gap acceptance behavior of TWSC intersections and midblock U- turn median. One of this research (9) considered capacity and delay time characteristics and established that delay time value affects accepted gap size. In other research, (10) revealed that duration of wait time increases driver's tolerance risk. The main conclusion of this research is the higher value of waiting time, reduces the gap acceptance size. Sam gap acceptance process proofed in this study that focuses on change direction U-turn opening. Although, U- turn is a different transport facility but yield a longer waiting time might implement driver to accept shorter gap size.

It is expected that when waiting time is extended for a long time, I will be reasons for traffic accident at change direction U- turn facility, it can be evidently noticed through the driver enforcement behavior. The probable critical gap (*tc* = 3.75) is compared with the mean accepted gap for long waiting time statistically. At 95% level of confidence, highest wait time group interval mean value is lower than the critical gap. Therefore, the studied change direction U-turn might be hazard location and it is important to take some other investigation. The critical gap parameters widely depend on location characteristics and vary from place to place. As an example, the critical gap for turning movement on six-lane streets is 5.6 sec. while the follow-up time is 2.3 sec. in the USA (7), while, in Bangkok, Thailand, the critical gap was 4.3 sec. while the follow-up time was 3.4 sec.

U-turn capacity can be found as a function of opposing traffic flow according to "Siegloch's formula" and the "Harder's model" in terms of *c*, capacity of turning movement (pcu/ hr), and *q*, major approach opposing flow rate (pcu/ hr), as shown in Equation (4) and (5), respectively.

$$c = 3273\, e^{-0.000889q} \tag{4}$$

$$c = q\,\frac{e^{-0.001049q}}{1-e^{-0.000307q}} \tag{5}$$

Siegloch's formula gives maximum U-turn capacity when no opposing traffic flow (c= 3273 pcu/hr). Furthermore, higher capacity can be found by Siegloch's formula as compared with that obtained from Harder's model, especially with higher opposing traffic.

4. Conclusions

The current paper explored driver behavior at change direction U- turn facility in terms of waiting time, gap acceptance, and opposing traffic flow, accomplished the following point:

- Driver gap acceptance is strongly affected by waiting time
- Negative Pearson correlation value certify inverse relationship between waiting time and gap size, peas Revers.
- Critical gap for the studied change direction U- turn equal to 3.75 sec, follow up time = 1.1 sec.
- Siegloch's method and Harder's model depended on the development of the studied change direction U- turn capacity model
- change direction U- turn capacity reflect inversely with opposing traffic flow.
- Although the model presented in this paper is not authorized because of limited field data, it is present a good bases for more investigation.
- The turning maneuver difficulty to follow fixed and limited model that is related to moving dependency on driver's own decision, regardless of vehicle characteristics.

Because of the complexity and risky of U-turn movement, it is highly recommended to put appropriate control system and traffic management on turning traffic for improving operation and increasing safety situation.

Declaration of competing interest

The authors declare that they have no any known financial or non-financial competing interests in any material discussed in this paper.

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