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Effect of Waiting Time on Gap Acceptance Characteristics of Change Direction U-Turn Opening

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ABSTRACT

This paper investigated the effect of some traffic factors such as waiting time and traffic volume increasing on gap acceptance characteristics i.e., driver's behavior, limits of gap acceptance, critical gap, and the facility capacity. The current study depends on real field data collected at selected change direction U-turn within Najaf city highways network (center city of the Najaf governorate located approximately 160 km south of Baghdad, the capital of Iraq). The study focused on the passenger cars and minibus drivers maneuvering at change direction U-turn opening as the primary case study. The statistical analysis approach depended on evaluating traffic factors selected as parameters and their degree of influence on U-turn capacity. The results of statistical analysis established that firstly, waiting time range between 21 - 30 sec, lead driver to enforce opposing direction traffic flow to accept gap size less than that when waiting time fall in the range of 11 to 20 sec at a confidence interval of 95% for a passenger car. While, minibus shows results higher than passenger car by approximately 20%. Secondly, there is a slightly different mean gap acceptance between an interval of (1-10) and (11-20) sec) for both types of vehicles at the same confidence interval. On the other hand, 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 3273 pcu/hr. Other results show that the highest wait time group interval (when taken as the mean value) is lower than the critical gap. The main recommendation obtained due to the hazard of studied change direction U-turn is the importance of control and management it.

1. INTRODUCTION

Any urban highway network has to contain a proportion of change direction U-turn facilities. A vehicle on a usual trip may need to change the direction of driving by using a U-turn facility. In order to achieve this movement, the driver has to occupy some time figuring out a satisfying gap in the opposing traffic flow, then initiate its movement to join and complete its change direction maneuver. The driver behavior in changing direction U-turn movement takes same that in minor traffic stream at unsignalized intersections. This driver's behavior depends on the "gap acceptance procedure". Although the change direction U-turn movement provided sufficient sight distance, the moving vehicles need larger space and further time length in order to complete their turning movement. According to the hierarchical point of view, changing direction U-turn doesn't have a traffic priority, but driver decisions of turn widely depend on their waiting time before moving. As a driver spends a longer waiting time, normal drivers' reactions will be more aggressive and as a result, he/she is gratified to accept the risk and enforce opposing traffic and move with the shorter gap.

Adequate design of highway intersections depends 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 sometimes may need to change their driving way by maneuvering to use other highway classes such as collectors or local roads in order to complete their trip either in a short time or more safety. U-turn opening facilities may be found on any highway classification, however, they present in high proportion, in urban arterials, signalized or un-signalized intersections, and mainly as change direction median openings.

The current study contracts U-turn driver behavior, dedicated passenger car, and minibus movement change direction U-turn on miner arterial in Najaf city. Other types of vehicles are ignored in order to eliminate the effects of their mechanical properties on gap acceptance. The main aims of the current study can be itemized as:

(1) Investigate waiting time effect on the accepted gap, the critical gap, and whole U-turn change direction capacity;

(2) Figuring out safety worries by defining the effect of waiting time on aggressive driver behaviors.

Normally, in each turning U-turn facility, the vehicle's driver has to wait for a safe gap (in his/her point of view) recognized as the acceptable gap enough to merge with opposing through traffic. As the provided gap is large it will be sufficiently safe done, the driver takes 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, the change direction

U-turn maneuver at the highway is simplest than that at TWSC in terms of traffic components, but in terms of the maneuvering mechanism, the change direction U-turn maneuver is more complicated.

In this study, the “accepted gap” is the headway time when a U-turning vehicle can complete a turning maneuver. The “rejected gap” represents the headway time between two following opposing vehicles that waiting at a U-turn vehicle can't accept to implement its maneuver. The “waiting time” refers to a time period that an arrival turning vehicle at a U-turn spends waiting for the acceptable gap through the opposing traffic flow until begins its U-turning maneuver. While the turning vehicle is waiting for an accepted gap, a 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 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 policemen at the U-turn facility. During peak periods, it was necessary to merge with conflicting traffic volumes for U-turning vehicles safely and within their capacity.

Many researchers were investigating U-turn opening’s performance, capacity, and safety requirements. Some solutions presented in almost these researches are focused on using right-turns- U-turns (RTUT) instead of direct left-turns (DLT) movement [1-4].

Earlier, U-turn median opening capacity was considered by Al-Masaeid [5], in Jordan by categorizing some affected factors that had been evaluated statistically. Analysis results showed a significant correlation between opposing through traffic with delay time. Furthermore, the critical gap is highly affected by opposing traffic speed and average total delay. Empirical models of U-turn capacity and gap acceptance are obtained from regression analysis. Both models verified and gave reasonable results. The same approach for estimation of U-turn capacity was carried out [6, 7]. Liu et al. [8] studied un-signalized intersections critical gap assessment from characteristics of gaps acceptance and rejection. The main results of this research, are the critical gap size and U-turn capacity extremely depend on the intersection geometric design, especially the median width. In other words, U-turn capacity increases as the median are wider. According to the highway capacity manual (HCM 2000) [9], the gap acceptance model is recommended for estimating U-turn potential capacity for the TWSC intersection. Likewise, the gap acceptance model can give accurate U-turn capacity as compared with data collected from the field [8].

TWSC intersections are extensively taken as a model of analysis in almost gap acceptance research. Delay time, gap length, opposing traffic flow rate, volume, speed, and effect of directional movement of turning vehicle effect on the size of an accepted gap were studied and investigated [10]. Results exhibited that accepted gap length was significantly and directly affected by queue length and waiting time. When the waiting time becomes longer, the driver’s frustration increases and needs his/her best capability to estimate the sufficient gap size to accept it. A similar assumption was studied by Pollatschek et al. [11], in developing a model of gap acceptance behavior decision. The model indicates that the long waiting time engorged drivers to accept shorter gaps regardless of movement hazardously.

Driver ability according to age group and different time conditions of day affect gap acceptance complimented meaningfully variances in gap acceptance [12]. Longer gap sizes appear more suitable for the old age group than the mid and younger group. Furthermore, a longer gap acceptance by female drivers than male drivers. Major traffic flow speed effect also taken in research; results showed that higher speed was aggressively the driver to accept the risk of turning with 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 [13]. 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 essential for any gap acceptance model [14]. There are different methods depending on the evaluated the critical gap, mainly depending on regression analysis data collected from the field, such as "Siegloch's method", Brilon et al. [15]. The degree of saturation widely affects 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].

The aim of the present study is to highlight the effect of waiting time and opposing traffic volume on U-turn median openings gap acceptance. Traffic movement at a U-turn median 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, and rejected gap, have been collected from video recorded in the laboratory. Statistical analysis and Siegloch’s method depend on estimating the critical gap, average follow-up time, and capacity evaluation. In order to evaluate safety insurance, the mean accepted gap is compared with an estimated critical gap. Although, vehicles in counted traffic volume classify into three general types (passenger cars, trucks and buses, and motorcycles), this paper concentrated on passenger cars and minibuses only due to their higher percentage of traffic flow and mechanical properties.

2. METHODOLOGY

2.1 Site characteristics and data collection

Figure 1 shows the change direction U-turn median opening in Najaf- Kufa minor arterial taken in this study as a source of data depending on the evaluation critical gap and U-turn capacity.

Najaf- Kufa minor arterial is six lanes divided highway, three lanes in each direction with a total width of 11.2 meters (approximately 3.7 m each lane). Median width in about 2.5 m, each U-turn has a storage lane of 2 m width and 50 m length in both directions. All the highway section has a sidewalk in both sides. This section of highway contains on & off-street parking, over-pass in two locations, and many change direction U-turn, in addition, to access in both directions. according to data collected from percent of passenger cars is 92% and 40% of it is minibus of total vehicles making U-turn maneuvers. The field survey included collecting data for three normal workdays (minimum of 4 hrs each day), during the daytime from 7 AM. to 3 PM depending on the amount of video data recorded for gap acceptance investigation. In laboratory, the analysis counting period is defined in terms of one-hour duration, divided into two recording periods containing two break times. The observation’s location is set at distance ranging from 30 m to 90 m upstream of the mid-block U-turn opening, depending on the space available for observation purposes, Parker, and Zegeer [16]. 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 on driver's behaviour in gap accepted. A simple software program called EVENT written in C-language, Al-Neami [17], provides a system for data counting and enables digital counting for available gaps manually with the application of Microsoft Excel. Collected data comprehend each vehicle aimed to turn that should be stopped or at least reduced its speed, its waiting time, No. of vehicles in the queue (if present), rejected gaps, accepted gap, and the number of vehicles follow-up. It is important to mention that traffic flow should be unsaturated, due to it is essential to prevent driver enforcement behavior and insure normal gap acceptance of driver behavior. Furthermore, in order to ensure free driver decision on accepting or rejecting gap, normal turning speed, and safety conditions, all data was collected without the presence of traffic policemen or any other movement control.

Figure 1. The location of study

2.2 Data analysis

The statistical analysis approach depends on analyzing the collected data. Two approaches had been used in data analysis, individual data points, 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%).

2.2.1 Critical gap estimation

Normally, vehicles before turning have to wait for an adequate gap (accepted gap size) in opposing traffic 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 in Al-Masaeid [5], and Liu et al. [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 [18].

For each vehicle that aims to turn from one direction to another by using a U-turn opening, try to merge 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. According to Siegloch's method, graphical representation of gap size t as the independent variable with a number of vehicles n as the dependent variable. Normally, gap size gives zero-gap factor t_0 from intercept with X-axis. While follow-up time t_f was the slope of the regression line. On the other side, critical gap t_c can be found from the following equation:

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

2.2.2 Models of U-Turn capacity

U-turn capacity model established by two methods basically related to gap acceptance models. The first method is Siegloch's formula, [5] that was advised by HCM 1994 [19], the second method is Harder's model, [6] that presented in HCM 2000, [9]. The following equations represent "Siegloch's formula" and Harder's models, respectively:

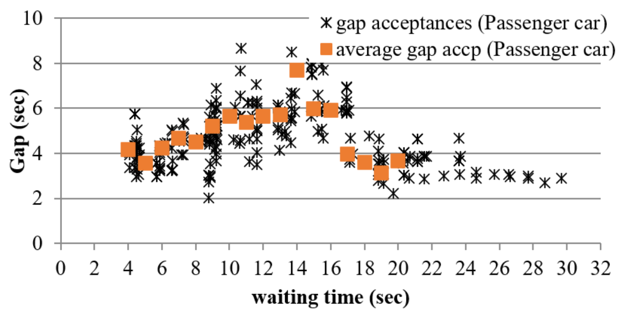
$$c = \left(3600/t_f\right)e^{-(q/3600)(t_c-0.5\,t_f)} \tag{2}$$

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

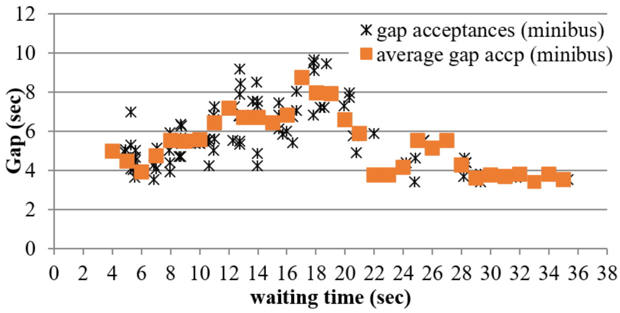
where, c=U-turn capacity (pcu/hr), q=opposing flow in major stream (pcu/hr), t_c=critical gap (sec.), t_f=follow up time (sec.).

3. RESULTS

Gap acceptance and Waiting time are the main factors in estimating critical gaps. There are some collected data neglected such as when two or more vehicles turned together and merged with the main traffic flow stream because these vehicles accepted the same gap size, or when turning vehicles enforced the opposing traffic flow to provide a suitable gap. In other words, when vehicles in a major stream are enforced to slow down their speed or stop. According to the research aims, the collected data mainly represents the waiting time, accepted gap, and follow-up time.



A-Data for passenger car



B-Data for minibus

Figure 2. Waiting time versus accepted gap for turning vehicle

From recorded video, total 454 observations were collected, and accepted gaps are 214 observations from them used for analysis for passenger cars and 94 data points for accepted minibus gaps. Figure 2 shows the gap acceptance relationships versus waiting time for passenger cars and minibus. 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. Same trend was taken by drivers of minibuses.

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, -0.0443 for passenger cars and minibus respectively. 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 means 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 was 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 at 10- sec intervals. The first group covered waiting time up to 10 seconds, the second group was the interval of waiting time between 11-20 seconds, and finally the third one of a waiting time between 21-30 seconds. Each group has a normal distribution at the 95% confidence interval according to the W-test, which 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.

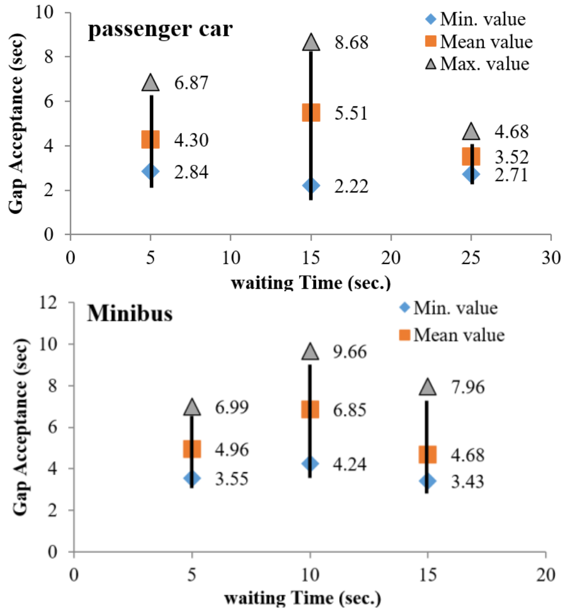


Figure 3. Gap acceptance for waiting time interval groups

Table 1. The accepted gap data statistic results

No. group	Time* Wait	n	Max.*	Min.*	Mean*	SD*	Q1*	Q2*	Q3*
				Passenger Car					
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
				Minibus data					
1	1-10	28	6.99	3.55	4.96	0.845	4.29	4.99	5.53
2	11-20	43	10.42	4.24	6.85	1.486	5.54	6.82	7.51
3	21-30	21	7.96	3.43	4.68	1.308	3.71	4.38	5.51
Sum.	1- 30	92	10.42	3.43	5.78	1.624	4.49	5.51	6.83

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

Another important observation is that the same trend of waiting time increases in accepted gap size. In other words, with a longer waiting time, there is a slight decrease in the mean accepted gap. This behavior is 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 to, or less than previously rejected.

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 H0: $\mu i = \mu 10$
Alternative Hypothesis H1: $\mu i > \mu 10$
The waiting time interval groups were i=1, 2, 3.

For comparison purposes, two sample t-tests had been conducted. Table 2 illustrates the two sample t-test, at confidence intervals 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. 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.

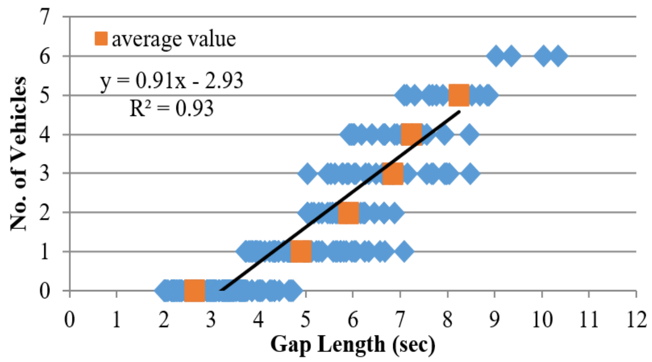


Figure 4. Critical gap parameter estimation based on Siegloch's method

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.

This result complies with other previous investigations dealing with the gap acceptance behavior of TWSC intersections and the midblock U-turn median. In one of these research Kyte et al. (1991) [10] considered capacity and delay time characteristics and established that delay time value affects accepted gap size. In other research, Pollatschek et al. (2002) [11] revealed that the duration of wait time increases the 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 is proofed in this study that focuses on change direction U-turn opening. Although, U-turn is a different transport facility but yields a longer waiting time might implement the driver to accept a shorter gap size.

It is expected that when waiting time is extended for a long time, it 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, the 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, the capacity of turning movement (pcu/ hr), and q, the major approach opposing flow rate (pcu/ hr), as shown in Eqns. (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. This result is related to complying with Siegloch's formula for saturation flow rate and un-control traffic movements such as TWSC intersections and U-turn change direction opening.

4. DISCUSSIONS AND 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:

(1) Driver gap acceptance is strongly affected by waiting time;

(2) Negative Pearson correlation value certify inverse relationship between waiting time and gap size, peas Revers;

(3) Critical gap for the studied change direction U-turn equal to 3.75 sec, follow up time=1.1 sec;

(4) Siegloch's method and Harder's model depended on the development of the studied change direction U-turn capacity model;

(5) 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 good bases for more investigation.

The turning maneuver is difficult to follow a fixed and limited model that is related to moving dependency on the driver's own decision, regardless of vehicle characteristics.

Because of the complexity and risk 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.

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NOMENCLATURE

c	U-turn capacity (pcu/hr)
DLT	Direct Left-Turns
HCM	Highway capacity manual
pcu/hr	Passenger car per hour
q	opposing flow in major stream (pcu/hr)
RUT	Right-Turns- U-Turns
SD	Standard deviation
t_0	zero-gap factor
t_c	Critical gap
t_f	Follow-up time
TRB	Transportation Research Board
TWSC	Two-way stop control