Effect of Waiting Time on the Gap Acceptance Behavior of U-turning Vehicles at Midblock Median Openings

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Abstract: The waiting time at the stop line, one of the factors affecting the gap acceptance behavior, was investigated in this study. The study focused on the u-turn movement of passenger cars at midblock median openings. The statistical analysis was conducted to judge the effect of the waiting time. The analysis results showed that the waiting time of more than 30 seconds would frustrate the drivers to accept the significant smaller gap than the drivers facing smaller waiting time at the 90% confidence interval. The critical gap parameters were also estimated by the classical regression method. The results showed the critical gap of 4.3 seconds and the follow-up time of 3.4 seconds. The capacity models showed the maximum u-turn capacity of 1,060 pcu/hr. The u-turn traffic control and management at median opening was recommended for safety purpose, especially when the u-turning vehicles might face the long waiting time.

Key Words: critical gap, gap acceptance, u-turn, waiting time

1. INTRODUCTION

U-turn facilities can be found in most urban arterials in the developing countries. One prominent cause is the improper city planning. In other words, the highway functional class is not well implemented. The proper street network can accommodate the u-turning vehicles by allowing the drivers to make one left turn plus three right turns (the left side driving rule) at the adjacent junctions to complete the u-turn movement. Alternatively, the drivers may change their route choices and use collector/local road instead. The u-turn maneuver on the urban arterials can be made at the following locations:

- signalized intersections,
- unsignalized intersections, and
- midblock median openings.

Since this research concentrated on the behavior of the u-turn vehicle, the study focused on the u-turn movement of passenger car at the midblock median opening in order to avoid the effects of other unrelated components. The objectives of this study were listed as below:

- to investigate the effect of waiting time on the accepted gap at a u-turn location,
- to determine the amount of waiting time that would lead to safety concern,
- to estimate the critical gap parameters for the u-turn movement, and
- to establish the capacity equations for the practical usage.
At a midblock median opening, each u-turning vehicle’s driver waits for the acceptable gap of the conflicting through traffic at the stop line. When the driver finds the sufficiently large gap, the driver makes a u-turn. This phenomenon is similar to the movement of the minor stream traffic at a two-way stop-controlled (TWSC) intersection. The u-turn movement at the midblock median opening is less complicate in term of traffic components comparing to the movement at the TWSC intersection. However, the u-turn movement is more complicate in term of the maneuver mechanism.

In this paper, the “waiting time” is the time period that a u-turning vehicle arrives at the stop line, waits for the acceptable gap, and starts to make a u-turn. The “rejected gap” is the time gap between two consecutive conflicting vehicles that the u-turning vehicle declines to make a u-turn. The “accepted gap” is the time gap between two consecutive conflicting vehicles that the u-turning vehicle makes a u-turn. During the waiting time, the u-turning vehicle may face one or more rejected gaps, but only one accepted gap. Some vehicles may accept the first gap; therefore, no rejected gap.

The control measures, which are currently used, at the midblock median openings include police control and traffic signal control. This is to accommodate the u-turning vehicles in the peak periods, when the conflicting traffic volume is high, in terms of capacity and safety. However, the effectiveness of these controls is still in doubt. There is lack of research work in this field. This study showed the necessity of the control measures for safer u-turn movement.

There are a number of researches, which are mentioned in terms of operation, safety, and capacity, on u-turn facilities. Most studies are on the replacement of direct left-turns (DLT) movement with right-turns followed by u-turns (RTUT) (Zhou et al., 2002; Liu et al., 2007a). The capacity of u-turn at median openings was first studied in Jordan by Al-Masaeid (1999). A correlated analysis was conducted to identify the factors affecting u-turn capacity. The results show the strong correlation with the conflicting traffic flow and the average total delay. The critical gap is strongly correlated with the average total delay and conflicting traffic speed. The move-up time relates to the average total delay. The empirical u-turn capacity model, developed by regression analysis, was compared with the gap acceptance model. The results show that the gap acceptance model provides reasonable results.

The recently effort to estimate the capacity of u-turn movement is undertaken by Liu et al., (2008; 2009). The critical gap was estimated from the study of gap acceptance characteristic of u-turning vehicle at unsignalized intersections by Liu et al. (2007b). The study reveals that the median width at the median openings greatly impacts the determination of critical gap, consequently the capacity of u-turn movement; the wider median, the higher capacity. The gap acceptance model, provided in the HCM 2000 for TWSC intersections, was used to estimate the potential capacity of u-turn movement. Liu et al. (2008) concluded that the gap acceptance model provides reasonable capacity estimation for u-turn movement at median openings comparing to the field data.

Most studies on the gap acceptance relate to the TWSC intersections. The length of delayed time, the conflicting traffic flow rate, and the directional movement of the subject vehicle affect the size of the accepted gap (Kyte et al., 1991). The mean accepted gap decreases as the queue time or service time increases; the longer waiting time, the greater driver’s frustration and the better driver capability in estimation the size of an accepted gap. Pollatschek et al. (2002) also assumed, when developed the decision model for gap acceptance behavior, that
the longer a driver waits, the more the driver is willing to accept risk.

Dissanayake et al. (2002) studied on the gap acceptance capabilities of different driver age groups under different light conditions, daytime and nighttime, at TWSC intersections. Three driver age groups (old, middle, and young) were considered in accordance with two maneuvers (left-turn and through) for each light condition. The analysis results show the significantly differences (95% confidence interval) in the gap acceptance capabilities among three driver age groups under both day and night light conditions. The study by Yan et al. (2007) compliments the same conclusion. The older drivers tend to select the larger gaps than the gap selected by the younger and middle-age drivers. The male drivers accept smaller gaps than female drivers. In addition, the drivers are more likely to accept smaller gap when the speed of major-road vehicles are higher. This implies that the drivers judge the gap based on the distance or position of vehicles on the major road rather than speed (Yan et al., 2007).

Yan and Radwan (2007) studied on the effects of restricted sight distances on driver behaviors during unprotected left-turn phase at signalized intersections. The u-turn gap acceptance behavior at signalized intersections was also included. The logistic regression model was used to determine the critical gap of u-turn movement due to limited observation with no-queued condition. The results show that the sight distance problem affects the gap size.

The gap acceptance model is based on the two main parameters, critical gap and follow-up time (TRB, 2000). Brilon et al. (1999) summarized different methods to estimate the critical gap. The estimation technique for saturated condition is the Siegloch’s method, which is based on a regression analysis. The method yields both the critical gap and the follow-up time. For unsaturated condition, there are many methods to estimate the critical gap. The most popular method, which is used for the u-turn capacity calculation, is the maximum likelihood method. Based on the Liu et al. (2009), the Siegloch’s method and the maximum likelihood method yield the close results of the critical gaps of u-turn.

This paper presented the effect of the waiting time to the accepted gap of the individual u-turn driver at the midblock median opening. A video camera was set to record the traffic movement at a u-turn location. The required data, which included waiting time, gap size and relevant number of vehicles, was extracted in the laboratory. The data analysis process employed the statistical analysis methods. In addition, the critical gap and follow-up time were determined by Siegloch’s method, due to its simplicity. The estimated critical gap was compared with the mean accepted gap to ensure the traffic safety. The capacity models were also developed based on the available gap acceptance models. The u-turn vehicles are classified, based on vehicle characteristics and performance, into 3 main types including passenger car, motorcycle, and truck. It is worth to note that the u-turn vehicles in this study focused on only passenger car, which includes all kinds of car with passenger car equivalent (PCE) of 1.

The result showed the trend that the higher waiting time, the shorter accepted gap. The accepted gap for the drivers facing waiting time of more than 30 seconds was significant lower than the accepted gap for the drivers with waiting time up to 20 seconds. The critical gap and follow-up time were 4.3 seconds and 3.4 seconds, respectively. The capacity models showed the maximum u-turn capacity of 1,060 passenger car unit (pcu)/hour, when there is no conflicting traffic. Eventually, it can be concluded that the control measures was needed for the u-turning vehicles at midblock median openings.
2. METHODOLOGY

2.1 Data Collection
The traffic data was collected at a midblock median opening u-turn facility on Phetkasem Road, western Bangkok area, Thailand. The site location and its traffic condition were shown in Figure 1 and Figure 2, respectively. The selected site was located on a six-lane divided street with three lanes in each direction. There was an exclusive u-turn bay at the selected median opening. Most u-turning passenger cars encroached to the middle lane in order to complete the u-turn maneuver. This u-turn location was quite busy with the u-turn vehicles. The data were collected during the rush hours in the morning (AM Peak) and afternoon (PM Peak), which the off-peak period was also included. A digital video camera was set up to record traffic movement. The recorded data were reviewed in the laboratory to extract the necessary data and information.

![Figure 1 Site location of the u-turn facility](image)

The data extraction was based on the manual technique. A spreadsheet program, Microsoft Excel, was utilized to facilitate the data extracting process. When each vehicle passed the designate lines, the program recorded the time of such incidents by clicking the relevant buttons. The rejected gap time, waiting time, accepted gap time with the number of vehicles accepting that gap, and other useful information were obtained by the calculation from the recorded time.

The data that can be used for the waiting time analysis should be collected under the normal traffic condition; with no accident, no special event, and normal weather. In addition, the conflicting traffic should be under-saturated, which could reflect the pure gap acceptance behavior of u-turning vehicles. The traffic conditions in the PM Peak period could not be used for the gap acceptance analysis because the traffic condition in the major stream was in the
saturated condition. Moreover, the u-turn movement was controlled by traffic police. The traffic police acted as a traffic signal to prohibit the movement of the main traffic vehicles and allowed the u-turn vehicle to enter the main traffic stream.

Figure 2  Site condition of the u-turn facility

2.2 Data Analysis
After obtaining the traffic data, the data was screening for the waiting time analysis. The analysis was based on the statistical analysis methods. The data were analyzed on both individual data point basis and interval data basis. The descriptive statistic was calculated to explain the characteristics of data. The statistical methods for the comparison of means and variances were used. These comparisons were conducted to validate the significance of the differences. The confidence interval of the hypothesis testing for this study was 95%; in other words, level of significance was 5%.

2.3 Critical Gap Parameters Estimation
The u-turning vehicles act in the same manner as the vehicles in the minor approaches in the TWSC intersection. The vehicles have to wait for the gap of the conflicting traffic, which is large enough, to encroach into the road space. Therefore, the methodology of gap acceptance process was applied for the capacity analysis of u-turn movement in this paper. Based on the literature, Al-Masaeid (1999) and Liu et al. (2008) found that the gap acceptance model provides reasonable results for capacity estimation of u-turn movement.

From the data collection process that described earlier, all gaps were recorded with the number of u-turn vehicles utilizing with that gaps. This data could be used to estimate the critical gap parameters, which included critical gap and follow-up time. The method of estimating the critical gap parameters was based on the regression analysis, which was proposed by Siegloch. The method required the continuous queue condition on the minor street. Only the traffic data during the saturated u-turn traffic condition was used.

Akcelik (2007) provided a good summary of the Siegloch’s method. The observation would be made during the time when there is at least one vehicle queuing in the minor street. The number of vehicles, $n$, entering each main stream gap of duration $t$ were recorded, including
the zero acceptance \((n = 0)\). For each of the gaps accepted by \(n\) vehicles, the average of the accepted gaps \(t\) was computed. Finally, the linear regression of the average gap values as a function of the number of vehicles was fitted. Typically, the gap size \(t\), in seconds, was plotted on the X-axis while the number of vehicles \(n\) was plotted on the Y-axis. The zero-gap parameter, \(t_0\), was the X-axis intercept of the regression line. The slope of the regression line was the reciprocal of the follow-up time, \(t_f\). The critical gap, \(t_c\), can be calculated as below:

\[
t_c = t_0 + 0.5 t_f
\]  

(1)

2.4 Capacity Models Establishment

This study employed two classical gap acceptance models to establish the u-turn capacity models. The first model was based on the Siegloch’s formula, which was contained in the HCM 1994 (Al-Masaeid, 1999). The second model was based on the Harder’s model, which was used in the HCM 2000 (Liu et al., 2008). The Equations (2) and (3) showed the Siegloch’s and Harder’s models, respectively.

\[
c = (3600 / t_f) e^{-q/3600(t_c - 0.5 t_f)}
\]  

(2)

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

(3)

where

- \(c\) = capacity of u-turn movement (pcu/hr)
- \(q\) = major stream conflicting flow rate (pcu/hr)
- \(t_c\) = critical gap (seconds)
- \(t_f\) = follow-up time (seconds)

3. RESULTS

3.1 Waiting Time and Accepted Gap

According to the recorded video reviews and field observations, some major traffic stream gaps were distorted, especially, when more than one u-turn vehicles entered the main stream at the same gap. The gaps were not the real gaps because the main traffic vehicles stopped at the median opening and allowed the continuous u-turn vehicles to complete their maneuvers. Therefore, the waiting time study included only the traffic data of the gap, which the only one vehicle could make u-turn at that gap.

The waiting time and the accepted gap for each u-turn vehicle according to the above conditions were acquired for further analysis. The traffic data were collected from the recorded video in the AM Peak and off-peak periods. After ruled out all outliers, the total of 169 observations remained for the analysis. Figure 3 showed the scatter plots of all data points. It can be noticed that the range of accepted gap was wide in the small waiting time. On the contrary, the range was narrow in the large waiting time, especially when the waiting time was more than 30 seconds. The wide variety of the small waiting time gap might be caused by the large amount of data points. However, the trend could be obviously seen that the higher waiting time, the smaller accepted gap.
3.2 Waiting Time Analysis
The correlation test between waiting time and accepted gap have been conducted. The resulting Pearson correlation was -0.0661, which indicated a low correlation between waiting time and accepted gap. The negative value of Pearson correlation indicated that the higher waiting time, the lower accepted gap. For the one-tailed statistical significance, the negative correlation was significant at the 80% confidence interval (p-value = 0.1966 < 0.20 level of significance).

To practically investigate the relationships between waiting time and accepted gap, the data was rearranged in the interval of waiting time. The parametric statistical tests were applied, given that the data in each interval was normally distributed. The determination of grouping time interval considered the shortest period, which the number of data in each interval was not too few for further analysis. The number of intervals should be reasonable for real practice. According to the data characteristic of this study, the grouping time of 10 seconds was selected.

Four intervals of waiting time were defined as follows; (1) waiting time up to 10 seconds, (2) waiting time between 11-20 seconds, (3) waiting time between 21-30 seconds, and (4) waiting time more than 30 seconds. After grouping the raw data into the above four intervals, however, the distribution of data in each group failed to follow the normal distribution at the 95% confidence interval. The normality test was based on the Shapiro-Wilk test (W test), which was the principle analysis of the data arrangement in the statistical consideration. The normal distribution of the data was needed. The data could not be statistically analyzed unless the data distribution followed the normal distribution.

In order to reduce the data scattering, the average accepted gap for the same waiting time was calculated and used as the new raw data (red points in Figure 3). Therefore, the number of data points was declined. There was only one value of accepted gap for each waiting time value. The average accepted gap data was rearranged again into the previously described four intervals. The data in each group passed the normality test at the 95% confidence interval (p-value > 0.05). Table 1 showed the statistic numerical summaries of the accepted gap. The range and mean values were also illustrated as in Figure 4.
The results showed that the mean accepted time was slightly decreased with the waiting time increased, especially when the waiting time is more than 30 seconds. Some drivers accepted the gap as short as four seconds for their u-turn maneuvers. This might lead to the unnecessary traffic accidents. When facing the longer waiting time, some drivers accepted the gaps just equal or shorter than the previously rejected gaps. This situation could be found according to the raw data from data collection processes.

Table 1  Statistic summaries of the accepted gap data

<table>
<thead>
<tr>
<th>Group</th>
<th>Waiting Time (sec.)</th>
<th>Mean (sec.)</th>
<th>SD (sec.)</th>
<th>Min (sec.)</th>
<th>Q1 (sec.)</th>
<th>Q2 (sec.)</th>
<th>Q3 (sec.)</th>
<th>Max (sec.)</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-10</td>
<td>6.25</td>
<td>0.88</td>
<td>5.00</td>
<td>5.54</td>
<td>6.19</td>
<td>6.96</td>
<td>7.50</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>11-20</td>
<td>6.17</td>
<td>0.85</td>
<td>4.50</td>
<td>5.88</td>
<td>6.07</td>
<td>6.73</td>
<td>7.50</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>21-30</td>
<td>5.75</td>
<td>0.82</td>
<td>4.67</td>
<td>5.00</td>
<td>6.00</td>
<td>6.33</td>
<td>7.00</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>more than 30</td>
<td>5.21</td>
<td>0.82</td>
<td>4.00</td>
<td>5.00</td>
<td>5.00</td>
<td>6.00</td>
<td>7.00</td>
<td>18</td>
</tr>
</tbody>
</table>

Note: SD = Standard Deviation, Min/Max = Minimum/Maximum, Q1/Q2/Q3 = 1\textsuperscript{st}/2\textsuperscript{nd}/3\textsuperscript{rd} Quartile, n = No. of Data

Figure 4  Ranges and means of the accepted gap for each waiting time interval

The statistical test was conducted to verify the differences of the mean accepted gaps in all waiting time intervals. The hypothesis testing, based on the mean accepted gap of the last group (waiting time more than 30 seconds), was conducted. The hypothesis of the statistical test was explained below;

Null Hypothesis  \( H_0: \mu_i = \mu_4 \)
Alternative Hypothesis  \( H_1: \mu_i > \mu_4 \)
where \( i = 1, 2, 3 \) represents the waiting time interval groups

The two-sample t-test was conducted for such comparison purpose. Beforehand, the Levene’s test was also necessary to check the differences in sample variances between the groups. Therefore, the corrected two-sample t-test was conducted properly. The results of the two-sample t-test, at the 95% confidence interval, were summarized as in Table 2.
Table 2  Comparisons of two means based on the means of Group 4 (more than 30 seconds)

<table>
<thead>
<tr>
<th>Waiting Time Group (Interval)</th>
<th>Group 1 (1-10 seconds)</th>
<th>Group 2 (11-20 seconds)</th>
<th>Group 3 (21-30 seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference in Variances (Levene’s Test)</td>
<td>Insignificant (Equal Variance)</td>
<td>Insignificant (Equal Variance)</td>
<td>Insignificant (Equal Variance)</td>
</tr>
<tr>
<td>Difference in Means (One-tailed t-Test)</td>
<td>Significant (p-value = 0.0021)</td>
<td>Significant (p-value = 0.0036)</td>
<td>Insignificant (p-value = 0.0597)</td>
</tr>
</tbody>
</table>

Note: The results were based on 5% level of significance.
* - The difference in means was significant at 10% level of significance.

The statistical test confirmed that the mean accepted gap for the drivers facing the waiting time more than 30 seconds was significantly less than the mean accepted gap for the waiting time up to 20 seconds at the 95% confidence interval. There was no remarkable difference in the mean accepted gaps, at the 95% confidence interval, between the waiting time more than 30 seconds and the waiting time in the range of 21-30 seconds. However, the difference could be statistically significant at the 90% confidence interval, according to the p-value.

3.3 Critical Gap Determination
The critical gap parameters were estimated by the Siegloch’s method. Since the collected data included both queued and non-queued conditions of the u-turn traffic, the data must be screened out to reflect only the continuous queued condition. Only the data from the AM Peak periods, which had continuous u-turn queue, were selected for the critical gap parameters determination. The total number of 1,236 gaps for continuous u-turn queue condition were acquired for the analysis, of which 1,096 gaps were rejected (no u-turn vehicle use such gaps). Figure 5 illustrated the scatter plots of gap sizes and number of vehicles making u-turn at the same gaps. Since the number of observations for the number of vehicles more than 5 vehicles making u-turn at the same gap is quite few (6, 8, and 9 vehicles – 1 observation for each; 7 vehicles – 3 observations), the analysis was established on the number of vehicles up to 5 vehicles only. The average gap size for each amount of vehicles was calculated and the linear regression line was also drawn as shown in Figure 6.

![Figure 5](image_url)  Scatter plots of all gap sizes and the number of u-turn vehicles
From the regression line, the zero-gap parameter, $t_0$, equaled to 2.6 seconds (the X-axis intercept). The follow-up time, $t_f$, was 3.4 seconds (the reciprocal of the slope). The critical gap, $t_c$, for the u-turning vehicle at midblock median openings was 4.3 seconds (based on Equation (1)). It should be noted that this regression line was created in order to determine critical gap parameters only. There was no logical meaning when either one of the two variables was less than zero. In addition, the number of vehicles would be a non-negative integer.

It was concerned whether the long waiting time would cause traffic accident at the u-turn facility. The mean accepted gap of the long waiting time group (more than 30 seconds) was statistically compared with the estimated critical gap. The results showed that the mean accepted gap of the long waiting time group was significantly more than the critical gap, at the 95% confidence interval. This could ensure the traffic safety of the u-turn movement at the median opening. However, a few drivers accepted the gap less than the critical gap, which might lead to the traffic accident.

### 3.4 U-turn Capacity Models

The Siegloch’s formula and the Harder’s model for the u-turn capacity as a function of conflicting traffic flow rate were shown in Equation (4) and (5), respectively. Figure 7 illustrated the both capacity models in graphical format.

$$c = 1060 \ e^{-0.000722q}$$  \hspace{1cm} (4)

$$c = q \frac{e^{-0.001195q}}{1 - e^{-0.000943q}}$$  \hspace{1cm} (5)

where

- $c =$ capacity of u-turn movement (pcu/hr)
- $q =$ major stream conflicting flow rate (pcu/hr)

Both models showed that the largest capacity of u-turn, when there was no conflicting traffic, was 1,060 pcu/hr. The Siegloch’s model predicted the slightly higher capacity than the
Harder’s model, when the conflicting traffic flow rate was higher. It should be noted that these capacity models were developed based on the six-lane divided street in urban area with narrow median.

![Figure 7 Capacity of the u-turn at midblock median opening](image)

4. DISCUSSIONS AND CONCLUSIONS

This research investigated the effect of waiting time, one of the main factors affecting the gap acceptance behavior, of u-turning vehicles at midblock median openings. The results showed that the waiting time affected the accepted gap. However, based on the collected data, the negative correlation was very low and insignificant. After grouping the collected data into intervals, the trend of the relationship was clearer. Nevertheless, comparing the cases of the waiting time more than 30 seconds and between 21-30 seconds, the difference in the accepted gap values was not significant at the 95% confidence interval.

The result of this study agrees with the previous research on the gap acceptance at the TWSC intersections. Kyte et al. (1991) studied the capacity and delay characteristics and found that the length of delayed time affects the size of accepted gap. Pollatschek et al. (2002) also mentioned that the duration of the wait affects the risk tolerance of the driver. They concluded that the longer waiting time, the smaller size of accepted gap. In addition to the previous research, this study focused on the u-turn facility, which is the different transport facility but has similar gap acceptance process. This study also yielded the threshold value of waiting time that might frustrate the driver to accept the very short gap.

The critical gap parameters would differ from place to place. In USA, the critical gap for u-turn movement on six-lane streets is 5.6 seconds while the follow-up time is 2.3 seconds (Liu et al., 2009). For a case study of Bangkok, Thailand, in this research, the critical gap was 4.3 seconds while the follow-up time was 3.4 seconds. The speed of the major stream traffic might be one of the primary causes of the difference. It seems that the speed of major stream traffic in USA is higher than the speed in Bangkok. The u-turning vehicle facing the higher speed traffic stream required the larger gap and shorter follow-up time. Comparing to the other movements at TWSC intersection, the relatively low critical gap of u-turn movement
might be caused by the better sight distance. On the other hand, the relatively high follow-up time of u-turn movement might be caused by the slower movement mechanism.

The capacity models were developed based on the classical gap acceptance models, Siegloch’s method and Harder’s model. Both models yielded similar result when the conflicting flow was low. When the conflicting flow was higher, the Harder’s model yielded the lower capacity. The largest capacity, when there was no conflicting traffic, could be used to determine the average free flow speed of u-turn movement at midblock median openings. The established models in this study were not validated due to the limited field data.

The limitation of this research was the data collection. The data was collected from only one u-turn location with the total of six hours video recording. The more data collection would yield the more reliable results. The waiting time in this research was the waiting time at the stop line only. The waiting time in queue was excluded from the study because the location of video recording could not capture the queue movement. The queue time also affects the size of the accepted gap (Kyte et al., 1991). Nevertheless, the waiting time at the stop line directly relates to the driver’s behavior of gap acceptance since the driver faces the gap there. The u-turn movement depends only on the driver’s own decision, not the leading vehicle.

The conclusions from this study could be listed as follows:

- the larger waiting time, the smaller accepted gap for the u-turning vehicles at median openings,
- the waiting time of more than 30 seconds would frustrate the drivers to accept the significant smaller gap,
- the smallest mean accepted gap from the analysis was larger than the estimated critical gap, and
- the maximum capacity of u-turn movement, at the midblock median opening on the six-lane divided street with narrow median, was 1,060 pcu/hr.

Since the u-turn movement was complex and risky, the appropriate control and management of the u-turn traffic was highly recommended for improving the operation and safety of the u-turn movement. The safety concerns would be arisen when the u-turning vehicles faced the long waiting time and behaved to accept extremely unsafe gap. The further study on the u-turn traffic control is needed to evaluate the various control measures.

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