

## MIDBLOCK U-TURN FACILITIES ON MULTILANE DIVIDED HIGHWAYS: AN ASSESSMENT OF DRIVER'S MERGING GAP AND STOP DELAYS

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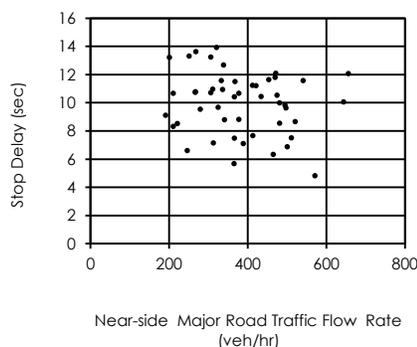
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### Graphical abstract



### Abstract

This paper discusses the results of a study which was carried out with a primary objective to evaluate the merging gaps and traffic delays at midblock U-turn facilities installed on multilane divided highways. A total of more than 2,000 U-turn drivers at a midblock U-turn facility on an urban multilane highway were observed using a camera-video recording technique. The data pertaining to the analysis of gap acceptance and rejection was abstracted from the video-playbacks using a computer event recording program. The analysis found that the critical gap of the drivers at a midblock U-turn facility is in the range of 4.0 – 4.5 seconds, which is different from the values reported for studies carried out in other countries. The effect of major road traffic volumes on the stop delays to the U-turn drivers could not be established because the data did not exhibit any specific trend. The drivers were observed to make forced merging maneuvers when traffic volumes in the main traffic stream are relatively heavy. Such maneuvers lead to flow breakdown in the major road to occur at a faster rate. The findings suggest that there is a need for a thorough study to be carried out to evaluate the current practice of U-turn facility design and assessment methods since traffic operations at such a facility is different from those at on-ramp facilities where their planning and design are generally based on the American Highway Capacity Manual.

**Keywords:** Midblock U-turn, critical gap, merging, delay, Greenshields, Raff, Probit

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## 1.0 INTRODUCTION

Heavy traffic volumes at signalized at-grade intersections on urban and suburban multilane divided highways may cause the traffic signal control system installed failed to function efficiently which in turn may lead to congestions and excessive traffic delays. A favorable approach is to close such intersections except for left-turning movements. This intersection closure is often coupled with a provision of midblock U-turn facility in the down-stream to accommodate

the right-turning traffic. The idea of a U-turn facility installation is to eliminate direct right turns. Drivers who wish to turn right need to make left turn followed by U-turn. Such an approach is usually adopted due to the major interest in 'access management' as a new response to the traffic congestion problem where it calls for improvements in access control, spacing, and design to preserve the functional integrity of the road system [1].

Traffic operation at a midblock U-turn facility is illustrated in Figure 1. Considering a U-turning vehicle,

A, arrived at the U-turn junction from major road of opposite direction, will enter the acceleration lane and reached merging arrival point. At this point, the vehicle will move slowly while searching for suitable gaps until it departs at the merging departure point. The departure point varies for each vehicle. During the merging activities, vehicle in acceleration lane will have conflict points with the vehicles from near-side and far-side lane of major road.

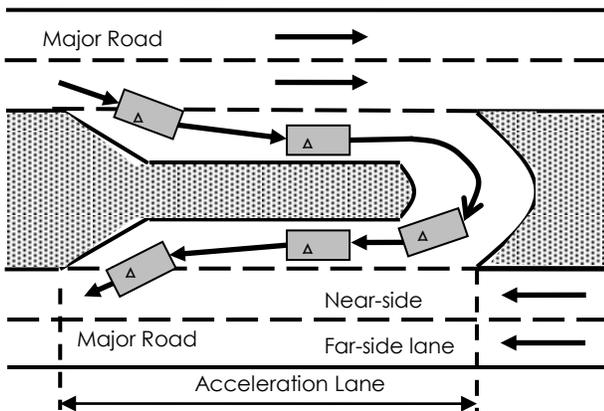


Figure 1 Merging activity at midblock U-turn junction

A particular concern about a midblock U-turn is that it may result in safety and operational problems. A precise analysis or design of U-turn is a very important task because undesirable incident at any U-turn junction can affect the operation of traffic on the entire highway. There is a need for traffic engineers to evaluate operational quality and design features of U-turn junctions from various perspectives. This paper discusses the result of a study carried out to evaluate stop delays and drivers' critical gap for merging maneuvers at midblock U-turn facilities. To date, limited reported studies that address such a facility were only focused on the merging gap acceptance behavior.

## 2.0 BACKGROUND

Merging is one type of vehicles' interaction in a traffic stream. It is defined as the movement of a vehicle from a ramp entering into a main lane traffic stream. In other words, it is a process where vehicles in two streams of traffic moving in the same direction combine to form a single stream of traffic [2]. The vehicle may remain in the new flow and merge with another stream once it diverges from a stream. Merging behavior can be observed at ramps. Therefore, the operation of a ramp is taken as the base knowledge in this study since a U-turn junction shares the same merging principle as a ramp.

Garber and Hoel [3] suggested that the most important factors to be considered during merging activity is the safe gap between two successive

vehicles where the driver could make a decision whether it is safe or not for them to enter the main stream. Whenever a driver wishes to merge into a traffic stream, he will have to decide the suitable gap so that there will be enough time for him to join the main traffic stream safely. During this merging activity, there will be few numbers of gap rejected; which not allowing the drivers to merge, and one accepted gap; which at this time the driver can merge into the main traffic stream. The numbers of the rejected and accepted gap varies depending on the driver's behavior, types of vehicles, and road geometry.

### 2.1 Gap Assessment

At a merging or crossing point a driver must evaluate the gap between himself or herself and the conflicting vehicle in order to decide whether it is safe for him or her to merge into or to cross the conflicting traffic stream. He or she has to find a suitable gap to perform this action considering the available gap and lag. In a gap acceptance study Ashworth and Green [4] measured gap from the rear bumper of the leading vehicle to the front bumper of the following vehicle. In other words, 'gap' is referred to the time and space that exist in between two successive vehicles. However, most researchers defined gap as the time interval between two successive vehicles measured at a specific reference point [5] and usually it is measured from front bumper of the leading vehicle to the front bumper of the following vehicle. Lag, on the other hand, is defined as the time interval between the arrival of the minor road vehicle at the merging point or at the stop line and the arrival of the potential conflicting vehicle in the main traffic stream at the conflict point. The illustration of definition of gap and lag adopted in this study is shown in Figure 2.

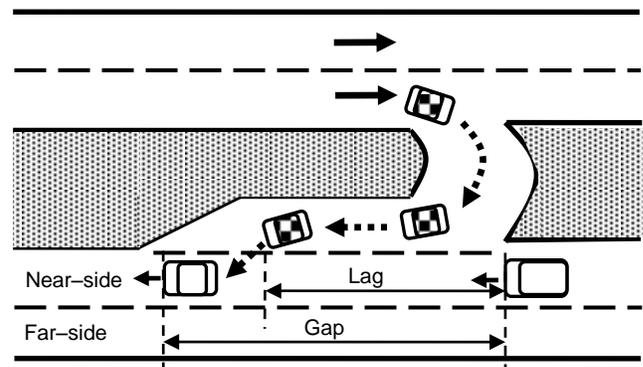


Figure 2 Illustration of gap and lag as defined for this study

One of the important parameters considered in a gap acceptance analysis is critical gap. In general, critical gap is defined as the minimum time headway that must be available in the conflicting traffic stream for the subject vehicle to merge with or cross. The value of a critical gap for a particular driver lies between the largest rejected gap and the one he or she finally accepted.

Most researchers in gap acceptance studies, for instance Ashalatha and Chandra [5], agreed that it is difficult to measure critical gap directly in the field. Its value also varies from driver to driver and is influenced by various factors such as time of day, type of intersection, type of movement and traffic situations. Because of these reasons many researchers have proposed various gap acceptance models to estimate the critical gap. Each of the models was based on various different assumptions and has its own advantages and disadvantages.

Pan Liu *et al.* [6] reported that critical gap for U-turns with wide median openings (i.e. a median nose width  $\geq 6.4$  m) is 6.4 seconds while for narrow median openings (i.e. a median nose width  $< 6.4$  m) the critical gap is 6.90 seconds. Research by Al-Taie [7] on U-turn with median openings obtained critical gap of 3.5 seconds. Drew [2] reported that the critical gap on ramp-freeway varied based on the merging strategies adopted by the merging vehicles, i.e. 3.1 seconds under stopped situation and 2.5 seconds under moving situation.

In practice, critical gap may be taken from one of the following parameters describing the distributions of gap acceptance and rejection data:

- a minimum gap accepted, or
- a mean or median gap accepted, or
- a gap at which the numbers of acceptance and rejection are equal (this gap is also often referred to as a critical gap)

The derivations of the above values depend on the method used in the analysis of the gap acceptance and rejection data. For example, the minimum gap accepted is often derived using a method called Greenshields and the mean or median gap accepted is often computed using a method called Probit. A method called Raff is often used to obtain the gap at which the numbers of acceptance and rejection are equal. The following sections described briefly each of these methods.

### 2.1.1 Greenshields Method

The Greenshields method, which was proposed by Greenshields and co-workers in 1947 may be regarded as one of the simplest technique for analyzing the gap acceptance data [8]. The method defines critical gap as the gap that has equal number of acceptances and rejections [5]. This method involves the plotting of histograms to represent the gaps accepted and rejected by the subject drivers. The vertical axis represents the number of gaps rejected or accepted for each gap interval. The average minimum acceptable gap is defined as the minimum gap that is accepted by at least 50 per cent of the drivers [8].

To date, a statistical approach for validating the value of the minimum accepted gap obtained from Greenshields method is not available. Therefore, the suitability of the method may be questioned if the gap acceptance and rejection data is limited and too

scattered. This is because the method involves inspecting the gap accepted at isolated times and does not consider the number of gaps accepted or rejected at other time gaps. Blunden *et al.* [9] improved the method by reducing each rejected gap size in proportion so that the total number of rejections is equal to the total number of acceptance to eliminate bias in the data.

### 2.1.2 Raff Method

The Raff method presents curves of cumulative numbers of accepted and cumulative numbers of rejected gaps as rectilinear plots. The point of intersection of the acceptance and rejection curves is termed the critical gap. According to Ashalatha and Chandra [5], this is the gap for which the number of accepted gaps shorter than it equals the number of rejected gaps longer than it.

The value of critical gap obtained from Raff method is influenced by the number of drivers accepting larger gaps. This is because the Raff method considers cumulative distributions. Like the Greenshields method, the critical gap value obtained from the Raff method cannot be statistically justified. A reasonably accurate value may be obtained if both cumulative data of gap acceptance and rejection form smooth plots of distribution curves.

### 2.1.3 Probit Method

Finney [10] described the theoretical aspects of the probit analysis. In summary, the method is based on the assumption that an explanatory (or independent) variable is represented by the log normal distribution. When the percentages of response (or dependent) variable are converted to probits, a linear relationship exists between the probit of the percentage response and the logarithm of explanatory variable. In applying the method to the gap acceptance data, the explanatory variable is the time gap and the response is the percentage of drivers accepting or rejecting a particular time gap. The probit of the proportion ( $P$ ) is defined as the abscissa corresponding to a probability of the proportion  $P$  in a normal distribution having a mean of 5.0 and a variance of 1.0. Thus, the probit of the expected proportion accepting a time gap is related to the time gap by the following linear Equation (1) [10].

$$P = 5.0 + (X - \mu) / \sigma \quad (1)$$

where:

- $P$  = probit of the proportion accepting time gap,
- $X$  = logarithm of time gap,
- $\mu$  = mean logarithm of tolerance distribution, and
- $\sigma$  = standard deviation of tolerance distribution.

The median gap obtained from the probit method is affected by the number of drivers accepting larger gaps because it considers the probability of accepting gaps of different sizes. However, the advantage of this

method is that the goodness of fit and precision of the estimation can be quantified statistically using the coefficient determination (i.e.  $R^2$ ) and the  $\chi^2$  test.

## 2.2 Delay Assessment

Delay is a critical performance measure in interrupted-flow facilities. There are several types of delay namely total delay, queue delay, control delay, and stop delay. Total delay is defined as the total queue delay, control delay and stop delay. Queue delay involves the time a vehicle spent on a queue in a platoon before they reach stop line of an intersection while stop delay involves the time a vehicle arrive at the stop line of minor road until it merges into the major road. Control delay includes initial deceleration delay, queue move-up time, stopped delay, and final acceleration delay [11, 12].

Salter [13] reported that many early studies on capacity of priority intersections in the U.S.A have used the average delay to minor road vehicles as a measure of the practical capacity of such a type of intersection. He summarized that the average delay increases considerably with small increases in volume when traffic volumes have exceeded the practical capacity of the intersection. However, Raff and Hart [13] who have carried out one of the early studies on this aspect were unable to establish an empirical relationship between main road traffic volume and average delay to minor road vehicles because the data was considerably scattered

## 3.0 METHODOLOGY

### 3.1 Studied Parameters and Site

The basic data required for this study are the arrival and departure time of the u-turning vehicles, the arrival time of the conflicting vehicles in the main stream traffic at the conflict point, hourly flow rates of both u-turning traffic and main stream traffic, and average spot speed of vehicles on main traffic lane.

It is realized that a relatively accurate measurement of drivers' critical gap or lag may be obtained from an extensive field observations and large quantity of gap acceptance and rejection data. However, the quantity of data collected for this study was a compromise between a reasonable, realistic data collection effort and the need for adequate data for numerical analysis.

Ideally the selection of the site to be used for data collection purposes should be based on the following criteria:

- (a) good access and safety for the enumerators and equipment during the data collection process,
- (b) good overhead vantage points for video recording purposes,
- (c) reasonable traffic volumes on both major and U-turn lanes so that good quality of data is obtained, and

- (d) good sight distances (to ensure that the sight distances do not influence the interactions between drivers)

Unfortunately, midblock U-turn facilities that have all the criteria described above were difficult to find. Therefore, the site selected for this study was a compromise between the criteria given above. A midblock U-turn facility located on FT003 Pekan-Kuantan highway was selected for the study. Figure 3 shows the layout of the area. Although the choice for positioning the recording equipment is limited, this U-turn facility was selected because the preliminary short traffic counts showed reasonable amounts of turning movements which is appropriate for objectives of the field observations.



**Figure 3** Layout of the studied site (source: Google earth map)

### 3.2 Data Collection and Analysis

In this study, video cameras were used in the field data collection exercises. The application of a video recording method for traffic data collection has many advantages as described by Ashworth [14]. The method has also been used in many gap acceptance studies (for example, Ashalatha and Chandra [5]). The recording periods were between 7.00 am to 11.00 am which was carried out for three consecutive days. These recording periods were considered appropriate for evaluating the required traffic parameters under a range of traffic flows.

Each of the video recordings containing the recorded scenes was played back several times to retrieve the data as listed below.

- Vehicle arrival times for major road traffic.
- Vehicle arrival and departure times for vehicles on the U-turn lane.
- Arrival times of major road traffic at two points for spot speed study; and
- Traffic composition

A computer-based event recorder was used to extract the information defining the above data from the recordings.

For vehicle arrival and departure time data, the recordings were played back in real-time. A vehicle arrival time was recorded by pressing a pre-defined key each time the front of a vehicle reaches a specified reference line. All these arrival and departure time data were extracted using the same time reference for all directions of traffic. This was an important procedure because all events have to be arranged in a correct order based on the individual occurring times for gap acceptance analysis.

In the analysis, the accepted and rejected data were calculated based on its definition and expressed in unit seconds. The time difference between the arrival of a U-turning vehicle and the arrival of the

conflicting major road vehicle at the median opening was recorded as a reject gap. An accept gap was measured from the time the U-turning vehicle departs into major road until the time the first major road vehicle arrives at the median openings after its departure as illustrated in Figure 4.

For delay analysis, the stop delay considered in this study refers to the time a U-turning vehicle arrived at the merging point until it departed into the major road. The stop delay is expressed in unit seconds. The volumes of traffic in the near side lane of the major road were also enumerated to evaluate their effects on the average traffic delay to the U-turning vehicles.

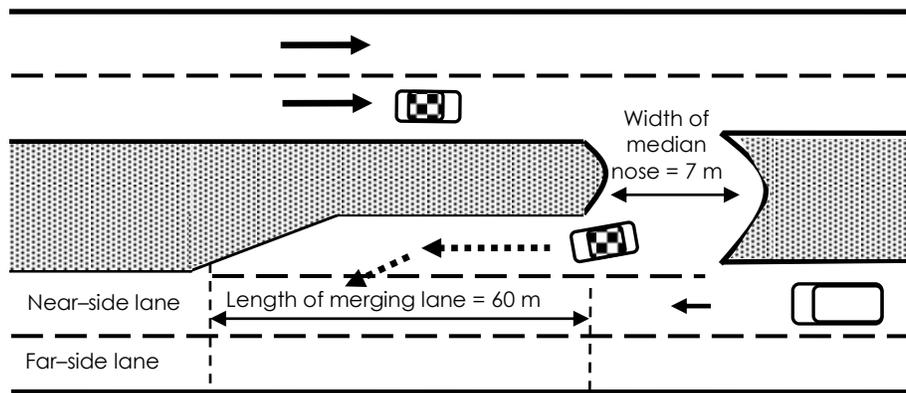


Figure 4 Configuration of the U-turn on FT003

## 4.0 RESULTS AND DISCUSSION

In general, a total of 7,300 major road vehicles and 2028 U-turning vehicles were observed. After the processing of acceptance and rejection data, only 5262 rejected gaps and 1680 accepted gaps were obtained and used in this analysis.

### 4.1 Characteristics of Main Traffic Stream

The average compositions of hourly traffic volumes on both the conflicting stream and the u-turn merging segment are summarized in Table 1. In general, traffic movements in terms of merging maneuvers within the u-turn influence area are governed by the behavior of the drivers of the light vehicles since the presence of vehicles categorized as light vehicles is significantly higher than the heavy goods vehicles.

Table 1 Percentage of traffic composition

Types of vehicles	U-turn, %	Nearside main stream, %
Car	65	58
Light goods vehicles	14	16
Heavy lorries	5	6
Buses	2	4
Motorcycles	14	16

In terms of average speed of major road vehicles, spot speed analysis showed that the average speed of vehicles within the area of influence was 82 km/h. Such a high speed of vehicles in the conflicting traffic stream makes the merging maneuvers difficult and thus demands the correct judgment of safety merging gap by the U-turning drivers.

### 4.2 Merging Gap

Merging gap was analyzed using three methods, i.e. Greenshields, Raff, and Probit as described in the previous sections. Figure 5 shows the histograms of accepted and rejected gaps based on the Greenshields method. The critical gap, as defined for the method, is the gap at which the numbers of accepted and rejected gaps are almost equal. Based on this definition, the critical gap is, therefore, can be taken at 4.5 seconds.

As explained earlier, critical gap based on Raff method is the gap for which the number of gaps accepted by the drivers are shorter than it equals the number of rejected gaps longer than it. This critical gap can be derived by plotting the cumulative number of gap acceptance and rejection data against gap size as shown in Figure 6. The critical gap can then be obtained by projecting a line at the point of intersection of the two curves, i.e. 4.0 seconds in this case.

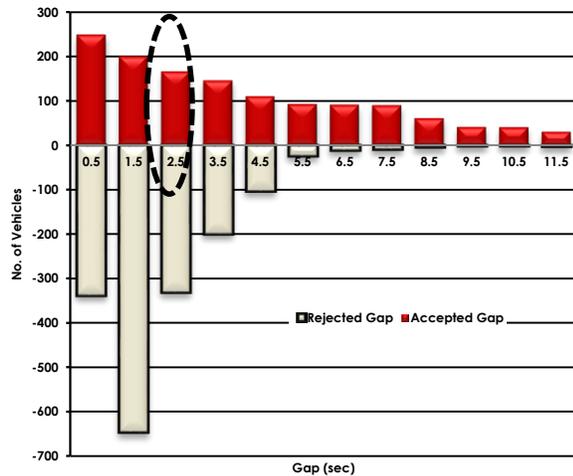


Figure 5 Greenshields plot for near side gap acceptance and rejection data

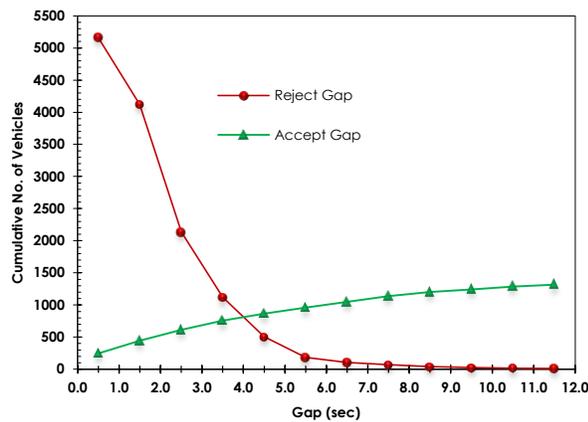


Figure 6 Raff plot for near side gap acceptance and rejection data

For the Probit method, the conversions of the percentages of gap acceptance data into probits were based on Finney [10]. Figure 7 shows the probit plot for the data considered. It shows that 50 percent of the drivers accepted a near side gap of 4.5 seconds (median). This value is obtained by taking the anti-logarithm of time gap ( $X_{50}$ ) at  $P = 5.0$ . This value can be found from the graph or by substituting  $P = 5.0$  into the regression equation.

The result of the analysis shows a reasonable agreement in the acceptable gaps between the methods of analysis, i.e. in the range of 4.0 to 4.5 sec. The high  $R^2$  value for the equation established for the Probit method indicates that the estimations were relatively accurate. The critical gaps obtained from this study and other researchers are tabulated in Table 2 for a comparison.

Based on the limited data available, the critical gaps derived by all researchers listed in Table 2 vary considerably with each other. The critical gap obtained from this study was 4.5 seconds which is

higher than the values reported by Drew [2] and Al-Taie [7] and much lower than the values reported by Pan Liu *et al.* [6].

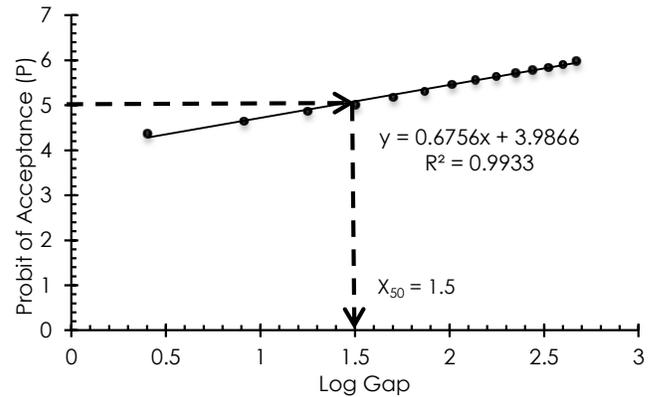


Figure 7 Probit plot for near side gap acceptance data

Table 2 Comparison of gaps

Source of Information	Type of facility	Reported Gaps (sec)
This study	U-turn	4.0 – 4.5
Pan Liu <i>et al.</i> [6]	U-turn	6.4 – 6.9
Al-Taie [7]	U-turn	3.5
Drew [2]	Ramp on freeway	3.1 (for stop situation), 2.5 (for moving situation), 2.8 (for all data set)

Limited information on the studies by Pan Liu *et al.* [6] and Al-Taie [7] make it difficult to establish the reasons why the gap values are different from each other. It is possible that the different behavior of the drivers and traffic characteristics from which the data was deduced has lead to a different value of critical gap obtained. Pan Liu *et al.* [6], for instance, studied gap acceptance and rejection data based on American traffic behavior and they have used the maximum likelihood method to deduce the critical gap value. The maximum likelihood method is based on the assumption that a driver's critical gap is always smaller than his or her accepted gap and greater than his or her largest rejected gap.

Al-Taie [7] derived critical gap based on the data collected for drivers in Iraq. He considered gap as the time interval between the rear bumper of the leading vehicle and front bumper of the following vehicle. He also used lag in his analysis. The critical gap reported by Drew [2], on the other hand, was actually for drivers merging from ramp into a freeway section. Less complexity in merging situation on ramp as compared with the U-turn manoeuvres may be one of many reasons for the drivers to consider a merging gap shorter than those who are on the midblock U-turn facility.

To highlight the implication of the actual critical gap used by most drivers on the midblock installation, the critical gap obtained from this study is compared with the design standards as summarized in Table 3.

**Table 3** Merging gaps as suggested in the design standards

Highway Geometric Design Standards	Suggested values (sec)	This Study (sec)
Malaysian Public Works Department [15]	5.0 – 8.0	4.0 – 4.5
Transportation Research Board [16]	4.0 – 6.0	
California Department of Motor Vehicles [17]	≥ 4.0	

As summarized in Table 3, Transportation Research Board [16] suggested that a driver making a U–turn at a midblock median opening will require a minimum gap of 4.0 to 6.0 seconds to enter the opposing roadway. The Californian Department of Motor Vehicles [17] advises the drivers to use a minimum gap of 4.0sec to merge on a motorway. The Malaysian Public Works Department [15], on the other hand, suggested that those drivers who wish to enter main road should have clear sight distance on the approaching main road vehicles to get a safe gap between 5.0 – 8.0 seconds.

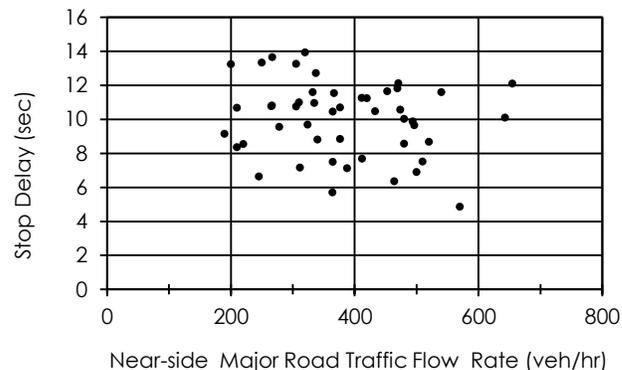
The critical gap obtained from this study, i.e. 4.0 – 4.5 seconds, implies that the range of values suggested by the Transportation Research Board [16] has to be used with cautious since the value observed from site is close to the lower bound of the suggested value. This means that there will be no safety margin exists if the lower bound value is used in the design of such a facility. On the other hand, there will be no safety implication if the range of values proposed by the Malaysian Public Works Department [15] is used in the design and performance evaluation of a midblock median opening U–turn facility.

### 4.3 Average Stop Delay

As explained earlier, stop delay measured in this study referred to the time a U–turning vehicle arrived at the merging point until it departed into the major road. Figure 8 shows the scatter plot of stop delays and conflicting traffic volumes on the near side lane of main stream traffic.

An empirical relationship between U–turning vehicles' stop delays and the conflicting traffic volumes could not be established because the data is considerably scattered. However, visual inspection of the pattern of the plot appears to indicate that the stop delay reduces as the volume of conflicting traffic flow increases. It was observed that under relatively high volumes of traffic in the conflicting stream where the availability of longer gap is limited, the U–turn drivers tend become more aggressive in finding the opportunities to merge. In such a situation, the U–

turning drivers merged by force by slowly moved into the major road which has lead to the main stream drivers to give way by slowing down their speeds. Such maneuvers lead to flow breakdown in the major road to occur at a faster rate. The forced merging maneuvers might be one of the possible factors that caused a considerable scatter of the data.



**Figure 8** Variation of stop delay to U–turn drivers and traffic flow rate in the near side major road traffic stream

## 5.0 CONCLUSION

This paper has presented information about gap acceptance behavior of U–turning drivers and the stop delays at a midblock U–turn facility on a multilane divided highway. The findings from this study can be summarized as follows:

- (i) The merging critical gap of U–turning drivers at a midblock U–turn facility on a multilane divided highway is in the range of 4.0 – 4.5 seconds;
- (ii) The critical gap obtained from this study is lower than the values suggested by the Malaysian Public Work Department [15] and lies in range of values suggested by TRB [16]. This implies that the application of values taken from the Malaysian Public Work Department [15] for design and assessment of a midblock U–turn facility would not lead to a negative safety implication.
- (iii) Empirical relationship between the main road traffic volumes and the stop delays to U–turn drivers could not be established because of the considerable scatter of the data. The drivers were observed to employ forced merging maneuvers when traffic volumes in conflicting stream were relatively high.

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