A Study on U-turning Vehicle Types and Their Accepted Headway

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Abstract

U-turn movement at midblock median opening is treated as the minor traffic stream. It has to judge the headway of the major traffic, whether it can make a u-turn. This headway acceptance behavior relies on various factors such as headway size, speed of major traffic, waiting time, and etc. The type of u-turning vehicle is of interest in this research. The vehicle type can represent vehicle-specific driver behavior and vehicle characteristics. This study compares the size of accepted headway of four different vehicle types, i.e. pick-up truck, taxi, sedan, and van, at a u-turn location in Bangkok. Data collection was conducted during morning peak, off-peak period, and evening peak in order to evaluate the effect of time of the day. The statistical analysis shows that each data group does not follow normal distribution. The Kruskal-Wallis one-way analysis of variance test is employed to check the difference in median. The result shows that the average accepted headway sizes of some vehicle types are significantly different. Pick-up truck requires larger accepted headway than taxi and sedan. However, there is no difference in accepted headway of all vehicle types during off-peak and evening peak periods.

Keywords: U-turn, Vehicle Type, Accepted Headway, Time of the Day

1. Introduction

There are a lot of midblock u-turn facilities on urban arterials in some cities such as Bangkok. The u-turn movement is quite risky because it conflicts with the through traffic stream on the lane with high speed driving. When a u-turn vehicle comes to the median opening, the driver has to judge the conflicting traffic stream. When the gap between two consecutive conflicting vehicles is large enough, the driver decides to make a u-turn. In addition to those minor traffic characteristics, the u-turn movement also needs large space to turn back the vehicle.

There are various factors affecting the u-turn decision, whether to make u-turn or not, including headway size, speed of major vehicles, u-turn waiting time and etc. Among those factors, the most influent factor is the headway size. When the headway size is small, the vehicle absolutely cannot make u-turn. The drivers will make a u-turn when they feel safe to move their vehicle between the gap of major vehicles. The u-turn vehicle type may affect the accepted headway selection because the vehicle type can reflect the vehicle characteristics (performance, space, turning radius) and driver behavior. Many Thai people think that the driver behavior depends on the vehicle type. The objective of this study is to investigate the effect of u-turn vehicle type on the accepted headway size. Four vehicle types were considered, including pick-up truck, taxi, passenger sedan, and van.

The data of u-turn vehicles was collected at a midblock median opening, including their vehicle types and accepted headway size. The data was collected during morning (AM) peak, off-peak, and evening (PM) peak, in order to evaluate the effect of time of the day as well. The nonparametric statistical analysis shows that there are significant differences in the average accepted headway sizes of some vehicle types,

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considering all time periods and AM peak. The multiple comparisons show that pick-up truck requires larger accepted headway than taxi and sedan. Considering the data collected in off-peak and PM peak, the analysis concludes no significant difference in average accepted headway, implying that all u-turn vehicle types behave the same in those time periods.

2. Literature Review

The u-turn movement at median opening is similar to the movement of minor traffic at two-way stop-controlled (TWSC) intersection. Nevertheless, the u-turn movement may have a better sight distance, need more space, and move slower. The latest highway capacity manual (HCM2010) includes the major traffic's u-turn movement in the capacity analysis [1]. The movement capacity is based on conflicting traffic volume, critical headway, and follow-up headway.

The different conditions (combination of driver, vehicle, traffic, and environment conditions) result in the different gap acceptance behavior at TWSC intersections. Most past studies concentrated on the driver characteristics, such as age and gender. Dissanayake et al. (2002) studies on the gap acceptance capabilities of different driver age groups under different light conditions, daytime and nighttime, at TWSC intersections [2]. 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 significant 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 [3]. The older drivers tend to select the larger gaps than the gaps selected by the younger and middle-age drivers. The male drivers tend to accept smaller gaps than female drivers.

In addition to the static driver characteristics, the gap acceptance also depends on waiting time or delay that the driver faces. 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 [4]. The longer a driver waits, the more the driver is willing to accept risk; the entry onto the main road occurs when the benefit from entry is greater than the associated risk [5]. A study at u-turn junction also shows that the longer time the driver waits at the stop line, the smaller gap the driver accepts [6]. When the driver accepts the significantly small gap, this situation may lead to traffic accident. So, there might be some aggressive drivers who force their vehicles into the major stream, making the conflicting vehicles to slow down or stop. Three major factors, affecting the probability of such a forcing maneuver, include driver age, car performance, and average speed on the major road [7]. The driver's total waiting time, while waiting for an acceptable gap, is of little significance in incurring the forcing behavior.

The previous study investigates the factors affecting the u-turn decision, whether to make a u-turn or not under various conditions. The significant factors include gap size, conflicting speed, and waiting time. The driver age group, gender, queuing time, and vehicle type are among the insignificant factors [8]. As the most influent factor is the gap size, this paper investigates the effect of vehicle type on the accepted gap selection. The vehicle type could be a representative of vehicle and driver characteristics.

3. Data Collection

3.1 *Site Characteristics*

The traffic data collection was conducted at a midblock median opening on Phetkasem Road, a six-lane urban arterial in western Bangkok, Thailand. Fig.1 illustrates the site location and road physical configuration. The site is located in front of the Future Park Bangkhae (currently Seacon Bangkhae), approximate a middle way between junctions of Ratchapruk Road and Kanchanaphisek Road. The road configuration, at the u-turn junction, has three through lanes in each direction with an exclusive u-turn lane on both directions. Most u-turn vehicles encroach to the middle lane in order to complete the u-turn maneuver. There was comparatively high u-turn traffic volume at the site, comparing to other u-turn locations on the same road.

Fig.1. Site location and physical configurations

3.2 *Field Data Collection*

The field data was collected during AM peak period (07:00-09:00), off-peak period (11:00-13:00), and PM peak period (16:00-18:00) on two days. A digital video camera was set up on the pedestrian bridge to record the traffic movements at the site. According to the video vision, the subjected movement was the u-turn from eastbound to westbound. The recorded video files were reviewed in the laboratory to extract the required data for further analysis. As observed from the site, there were many types of vehicle making u-turns. Only the vehicle types with the passenger car equivalent (PCE) equal one were considered in this study. Those included pick-up truck, taxi, passenger sedan, and van. The heavy vehicles, which require more space and larger gap, were excluded from this comparison.

3.3 *Laboratory Data Collection*

In the laboratory, the collected video files were run on a computer. For each u-turn vehicle, the vehicle type and its accepted headway size were recorded. The accepted headway is the time difference of the passing of two consecutive vehicles on all conflicting lanes; one passes before u-turn movement, the other passes after u-turn movement.

In the event that the conflicting vehicles sometimes stop for queued u-turn vehicles to move, this accepted headway is large and distorted. Therefore, the data was collected when only one vehicle can make u-turn. The movements with too large accepted headway, i.e. larger than 20 seconds, were also excluded from the dataset because all drivers were expected to accepted headway at this size. In addition, the study excluded some movements which did not follow the gap acceptance process, such as police control or forced u-turn.

Based on the above criteria, 637 u-turn vehicles were collected together with their accepted headway sizes, comprised of 274 pick-up trucks (43%), 105 taxis (16%), 239 sedans (38%), and 19 vans (3%). Most u-turn vehicles during data collection periods were pick-up truck and sedan. It should be noted that the size of van data was quite small.

Since there might be some effects of time of the day, the data attributes also included the data collection time, whether AM peak, off-peak, or PM peak.

4. Analysis Results

The statistical analysis in this study employed the freeware statistical package "R". The significance level of all analysis was set at 0.05. The hypothesis test was used to evaluate the difference in means of accepted headway among all vehicle types. Since the one-way analysis of variance (ANOVA) requires the normal distribution, the first step is to check whether all datasets follow the normal distribution. If the datasets do not follow the normal distribution, the nonparametric tests will be applied instead of the parametric one-way ANOVA.

4.1 *Normality Test*

For checking whether the datasets followed the normal distribution, the Shapiro-Wilk test of normality was employed. The null (H_0) and alternative (H_1) hypothesis are listed as below:

H_0: Data is normal distributed,

H_1: Data is not normal distributed.

The result of the Shapiro-Wilk normality test is summarized in Table 1.It could conclude that the data in each vehicle type group did not follow the normal distribution. The classical one-way ANOVA could not be applied to test the difference in means among all vehicle types. Therefore, the further analysis employed the distribution-free nonparametric tests, which focus on comparisons of the central location or median rather than the arithmetic average or mean.

Table 1 Shapiro-Wilk normality test results

Vehicle type	W	p-value	Conclusion
Pick-up truck	0.92336	1.15E-10	Reject H_0*
Taxi	0.82295	6.94E-10	Reject H_0*
Passenger sedan	0.91911	4.04E-10	Reject H_0*
Van	0.87101	0.01503	Reject H_0*

**Not follow normal distribution at 0.05 significance level*

4.2 *Analysis of Variance*

To analyze the differences in accepted headway sizes of all four vehicle types, the Kruskal-Wallis test was employed. This nonparametric test corresponds to the classical one-way ANOVA but does not require the assumption of normal distribution [9]. The result of the hypothesis test shows whether there is any difference in median of all groups. The null (H_0) and alternative (H_1) hypothesis are listed as below:

H_0: Median of all groups are equal; M_1=M_2=M_3=M_4,

H_1: At least one pair of unequal median exists.

4.2.1 Aggregate data from all periods

All data points, collected from AM peak, off-peak, and PM peak periods, were combined and analyzed. This is to evaluate the overall result and maximize the sample size. The test result is summarized in Table 2.The result shows that at least one pair of vehicle types has significant difference in accepted headway. In other words, the u-turn vehicle types may affect the selection of accepted headway. However, the result could not identify which pairs of vehicle types that have different values of median accepted headway.

Table 2 Kruskal-Wallis test for data in all periods

Vehicle type	n	Mean	S.D.	Median	Kruskal-Wallis Test
Pick-up truck	274	6.95	2.73	6.39	Chi-Square =12.581
Taxi	105	6.28	2.82	5.46	df = 3
Passenger sedan	239	6.34	2.49	5.75	p-value =0.005636
Van	19	6.81	3.36	6.15	Reject H_0*

**Differences in median accepted headway among 4 vehicle types at 0.05 significance level*

4.2.2 Data from each time period

The Kruskal-Wallis test was also conducted for the data collected from each period in order to evaluate the effect of operation time of the day. The results are shown in Table 3, 4, 5 for AM peak, off-peak, and PM peak periods, respectively.

Table 3 Kruskal-Wallis test for data in AM peak period

Vehicle type	n	Mean	S.D.	Median	Kruskal-Wallis Test
Pick-up truck	118	7.22	2.50	6.89	Chi-Square =11.093
Taxi	28	5.93	2.09	5.33	df = 3
Passenger sedan	108	6.48	2.57	5.84	p-value =0.01123
Van	9	6.62	2.72	6.53	Reject H_0*

**Differences in median accepted headway among 4 vehicle types at 0.05 significance level*

Table 4 Kruskal-Wallis test for data in off-peak period

Vehicle type	n	Mean	S.D.	Median	Kruskal-Wallis Test
Pick-up truck	113	6.57	2.78	6.19	Chi-Square =1.41
Taxi	53	6.49	3.13	5.61	df = 3
Passenger sedan	91	6.29	2.59	5.70	p-value =0.7032
Van	8	7.63	4.20	6.72	Accept H_0**

*** No difference in median accepted headway among 4 vehicle types at 0.05 significance level*

Table 5 Kruskal-Wallis test for data in PM peak period

Vehicle type	n	Mean	S.D.	Median	Kruskal-Wallis Test
Pick-up truck	43	7.23	3.11	6.37	Chi-Square =4.9406
Taxi	24	6.19	2.90	5.47	df = 3
Passenger sedan	40	6.05	2.02	5.79	p-value =0.1762
Van	2	4.41	1.77	4.41	Accept H_0**

*** No difference in median accepted headway among 4 vehicle types at 0.05 significance level*

The test result of AM peak period is the same as the result from all periods; rejecting the null hypothesis. Unlike the AM peak period, the result shows that median accepted headway of all four vehicle types were the same in the off-peak and PM peak periods. In off-peak period, the median accepted headway of 6.19, 5.61, 5.70, and 6.72 seconds were not significantly different, at the 5% level of significance. Similarly, the median accepted headway of 6.37, 5.47, 5.79, and 4.41 seconds were considered no difference in the PM peak period.

4.3 *Comparison of two groups*

For identify the vehicle types that have different accepted headway with others, the median of each pair of vehicle types were compared. The location test for two independent samples utilizes the Mann-Whitney-Wilcoxon test. This rank sum test is the nonparametric alternative to the classical Student's t test for two mutually independent random samples [9].

The test can be either one-tailed or two-tailed, depending on the alternative hypothesis. The p-value of one-tailed test is a half of p-value of two tailed test; dividing two-tailed p-value by two results in one-tailed p-value. For facilitating the result summary and avoiding the direction confusion (whether greater or less), all the analysis in this section are two-tailed test. The null (H_0) and alternative (H_1) hypothesis are listed as below:

H_0: Median of two groups are equal; $M_1=M_2$,

H_1: Median of two groups are unequal; $M_1 \neq M_2$.

The results of all tests are summarized in Table 6 and 7 for data in all periods and data in AM peak period, respectively. The results from both tables show the similar directions of conclusion. There were significant differences when comparing the median accepted headway between (1) pick-up truck versus taxi and (2) pick-up versus passenger sedan. The other four pairs of comparisons did not yield significant differences.

Table 6 Mann-Whitney-Wilcoxon test for each pair of vehicle type for data in all periods

Comparison of Median	Taxi (5.46)	Passenger sedan (5.75)	Van (6.15)
Pick-up truck (6.39)	p-value = 0.003058*	p-value = 0.004149*	p-value = 0.5937**
Taxi (5.46)		p-value = 0.4079**	p-value = 0.4331**
Passenger sedan (5.75)			p-value = 0.6015**

**Differences in median accepted headway at 0.05 significance level*

***No difference in median accepted headway at 0.05 sig. level*

Table 7 Mann-Whitney-Wilcoxon test for each pair of vehicle type for data in AM peak period

Comparison of Median	Taxi (5.33)	Passenger sedan (5.84)	Van (6.53)
Pick-up truck (6.89)	p-value = 0.01157*	p-value = 0.005266*	p-value = 0.4438**
Taxi (5.33)		p-value = 0.4118**	p-value = 0.4465**
Passenger sedan (5.84)			p-value = 0.6055**

**Differences in median accepted headway at 0.05 significance level*
***No difference in median accepted headway at 0.05 sig. level*

Considering one-tailed test, all the p-values from the above tables are divided by two. The results could imply that the average accepted headway of pick-up truck (6.39 seconds for overall and 6.89 seconds for AM peak) was significantly larger than those of taxi (5.46 seconds for overall and 5.33 seconds for AM peak) and passenger sedan (5.75 seconds for overall and 5.84 seconds for AM peak).

5. Discussion and Conclusion

This study investigated the effect of u-turn vehicle types on their accepted headway. Four passenger-car sized vehicle type were considered, i.e. pick-up truck, taxi, passenger sedan, and van. For each u-turn vehicle, the data, including its vehicle type and its accepted headway size, were collected. The average accepted headway size of all vehicle types were compared by statistical procedures.

The classical statistical tests, e.g., Student's t test, ANOVA, etc., requires the valid assumption of normal distribution of data. This study concerns about the time headway between two consecutive vehicles. The headway distribution is usually not normal distributed, depending upon the vehicle arrival process. For example, if the vehicle arrives randomly or follows the Poisson distribution, the time headway data will follow the negative exponential distribution. Other distributions that have been applied for intermediate volume conditions include the Pearson Type III, Gamma, Erlang, and shifted negative exponential [10]. However, the accepted headway in this study are the only large headway that u-turn vehicles select for their movement, not all headway. The data were evaluated whether they followed the normal distribution. The results from Table 1 show that the accepted headway data were not normal distributed for all vehicle types. Therefore, the further statistical analysis utilized the nonparametric test procedures.

The distribution of the accepted headway may refer to the distribution of the critical headway, which is also the headway that a driver expects to accept. In measuring the driver's critical gap by maximum likelihood method, the critical gap is assumed to follow the log-normal distribution [11]. Recently, the log-normal distribution and Weibull distribution were compared to fit with the empirical distribution of critical gaps. The results show that the Weibull distribution is better to represent the distribution of critical gap [12].

When the data is not normal distributed, the arithmetic mean cannot properly represent the average of all data points. Instead, the nonparametric statistical methods consider the middle location of all data as the average. So, the distribution-free methods consider the median as the representative of the data rather than the mean. In this study, the values to compare are the median accepted headway of all vehicle types. The Kruskal-Wallis one-way analysis of variance test was employed to check the difference in median accepted headway among all groups. The results show that there were significant difference in accepted headway among vehicle types for the data in all periods and the data in AM peak period. The opposite results were shown in the off-peak and PM peak periods. This can imply that the u-turn vehicle types do not affect the accepted headway during the off-peak period. For PM peak period, the size of sample is quite small comparing to the other periods. Because the westbound traffic direction is the city outbound direction, the traffic volume is high in the PM peak period. Mostly, the police controlled the u-turn movements, by stopping the conflicting through traffic, making this situation not gap acceptance behavior. So, the data during the police control could not be used. In addition, the number of data points for van is also a few. The results about van may not be accurate.

For AM peak period and overall, the vehicle types may affect the accepted headway. To identify which pair of vehicle types that has difference, the Mann-Whitney-Wilcoxon test was employed to check difference of each pair. The results show that pick-up truck required larger accepted headway than taxi and passenger sedan. The pick-up truck length and its turning characteristics may be the cause of this conclusion. The pick-up truck requires more space and time to complete the u-turn maneuver. So, the driver need to select the larger accepted headway size so that he/she can make a safe u-turn. As expected, there was no difference between taxi and sedan because those vehicles' characteristics are quite the same. For van, there was no difference with other vehicle types.

It seems that the analysis results did not imply the effect of driver behavior. The vehicle characteristics can appropriately explain the results. People may think that driver of each vehicle performs differently on driving. Some pick-up truck drivers may be more aggressive than sedan drivers and would select the smaller accepted headway, but not shown in this study. The limitation of this study is the data collection, which relies on only one u-turn location. The results of the study cannot expand to other locations unless other sites are also studied and compared.

As stated in the literature review, the waiting time affects the accepted headway size. The u-turn driver may select the small accepted headway size after waiting for a long time. The future research should incorporate the u-turn waiting time into the analysis of accepted headway. The data collection should be conducted from many locations, with similar and different physical configurations and driver populations, in order to investigate the effect of local conditions and evaluate the similarity of characteristics.

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