

Gap Acceptance Behavior at U-turn Median Openings – Case Study in Jordan

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ABSTRACT

U-turns have been considered among the most hazardous locations on highways. The maneuvering of the driver at these locations is quite complex and risky. The behavior of the driver when turning is governed by the gap acceptance concept. In this study, the driver's gap acceptance behavior at U-turn median openings was studied. 4 U-turn median openings in Irbid City were investigated. Data was collected by video recording. Two models were developed in this study. The first model estimated the time gap accepted by the driver. The second model calculated the turning function, which was used to estimate the probability of accepting gaps. Results showed that male drivers tended to accept shorter gaps than female drivers. Also, younger drivers were more likely to accept shorter gaps than older ones. The waiting time was also found to affect the gap acceptance behavior of the drivers. Drivers tended to accept shorter gaps after longer waiting times.

KEYWORDS: U-turns, Gap acceptance, Driver's behavior.

INTRODUCTION

A gap is defined as the time or space headway between two successive vehicles in a particular traffic stream. Gaps are expressed in terms of space when the distance between the fronts of the two vehicles is considered. They are expressed in terms of time when the time elapsed between the arrivals of the vehicles is considered.

Gap acceptance is the process through which a driver has to evaluate the gaps and judge whether they are enough or not for merging. The gap acceptance concept is widely used in the determination of the capacity, delay and level of service at various transportation facilities. It is also used for safety

evaluation at potentially dangerous locations such as unsignalized intersections, ramp merging points, U-turns and two-way two-lane sections where passing is permitted. Gap acceptance has been recently used to study simulation models and Intelligent Transport Systems (Hwang and Park, 2005).

U-turns at median openings are highly prevalent on highways of Jordan. U-turns are used as an alternative to direct left turns in order to reduce conflicts and improve traffic operations along arterial roads (FHWA, 2007). Compared with other turning movements, the U-turn movement at median openings is highly complex and risky.

Most of the road crashes occur due to mistakes or misjudgments made by drivers. Thus, understanding the driver behavior is essential for selecting the measures to be taken at prone locations and finding

solutions to minimize crash problems.

Only a few mathematical approaches for driver's gap acceptance are found due to vehicle interaction complexity. Most of the researchers, therefore, tend to use empirical methods leading to design and operational procedures. According to studies previously conducted, the gap acceptance behavior of the driver is strongly related to the attributes of the driver, vehicle and the road/intersection.

Over the past few decades, many studies on gap acceptance concept have been conducted to analyze gaps and develop models correlating the previously mentioned factors with gap acceptance. However, a very small portion of those studies addressed U-turns.

Tupper et al. (2011) studied the factors that influenced the driver's gap acceptance behavior and had clear impact on safety. Different driver's age and gender groups were found to have different gap acceptance behaviors. Factors that had the greatest effect on gap acceptance behavior were found to be the presence of a queue behind the driver, the driver's waiting time and the number of the rejected gaps.

Nabae et al. (2011) developed and validated a procedure for observing the driver's gap acceptance behavior accurately at two-way left turn lanes (TWLTL) on the major road. Characteristics such as driver's gender, driver's age, vehicle type, presence of a queue behind the leading vehicle and presence of passengers in the vehicle were collected as a function of the time of day (TOD). This work provided updated measures for the accepted gap with the variation of TOD and showed how accepted gaps were related to the waiting time of the vehicle.

Zhou and Ivan (2009) studied the gap acceptance behavior of left turning drivers at six unsignalized intersections. Logit models were used for estimating the probability of accepting a given gap. Results showed that the number of lanes on the major road, the presence of left turn lanes and the gender of the driver explained the variation in the gap acceptance probability. It was also found that older drivers generally tended to accept longer gaps.

Yan et al. (2007) studied the effect of major traffic speed and driver's age and gender on the gap acceptance behavior of the driver at stop controlled intersections. Results showed that older drivers, especially older female ones, exhibited the most conservative driving behavior.

Yang et al. (2001) studied the critical gap of the U-turn at median openings using Raff's method and Logit model. It was found that the critical gap of U-turning at median openings ranged from 5.8 seconds to 7.4 seconds with respect to varied geometric and traffic conditions at the studied ten locations. It was also found that the distance between the U-turn and the nearest signalized intersection significantly affected the behavior of the drivers maneuvering the U-turn.

OBJECTIVES

The objectives of this study can be summarized in the following points:

- 1- To investigate the U-turning behavior of the drivers at median openings.
- 2- To study the relationship between the accepted gap length and the driver's age, driver's gender and waiting time.

METHODOLOGY

Location Selection

4 U-turn median openings in Irbid City were selected for the study. The locations had similar characteristics which included the following:

- 1) Four-lane divided highway.
- 2) Queue storage exists.
- 3) Highway speed limit = 80 km/h.
- 4) Opening not in the vicinity of a signalized intersection.
- 5) No traffic congestions are present.

Data Collection and Extraction

Data was collected in the study by video recording. Recording points were carefully selected such that the

variables of interest can be clearly observed. The video files were viewed on a computer device. The drivers' characteristics were recorded. Rejected and accepted gaps were measured by a stopwatch. The waiting time, which was the elapsed time between the arrival and the departure of each vehicle, was also recorded.

DATA ANALYSIS AND MODELING

Accepted Time Gap

Data of accepted gaps were transferred to the Statistical Package for Social Sciences (SPSS) software for analysis and modeling. The accepted time gap was used as the dependent variable, while the waiting time before turning (continuous variable), driver's gender and age group (dummy variables) were assigned as the independent variables. The model developed estimated the length of the gap accepted by the driver.

Turning Choice Model

Data of both rejected and accepted gaps were used in the model. A binary logistic model was used to determine the turning function which was used to estimate the probability of accepting gaps (Nikov, 2010). Variables used included: time gap, waiting time, gender and age group.

ANALYSIS AND DISCUSSION OF RESULTS

Accepted Gap

Data of the accepted gaps, waiting time, gender and vehicle size were used to develop a model that estimated the length of gap accepted by a particular driver. Observations of accepted gaps with gap lengths exceeding 10 seconds were disregarded, since such gaps were noticed to be always accepted regardless of all other factors. A logarithmic transformation of the time gap (dependent variable) was found to achieve best fitting. A description of the data used in this model is shown in Table 1.

Based on the data selected, the following model was developed:

$$\log_{10}(t_g) = 0.857 + 0.060 A - 0.055 G - 0.001 t_w \quad (1)$$

$$R^2 = 0.563$$

$$SEE = 0.0454$$

where:

t_g : The length of gap, seconds;

A : The age group of the driver, 0 for young (18 – 30 years), 1 for middle-aged (31 – 50 years) and 2 for elderly (above 50 years);

G : The gender of the driver (0 for female and 1 for male); and

t_w : The waiting time to the moment of turning.

The observations included 67 male drivers and 24 female drivers. The number of observations for each age group was 37 for young drivers, 41 for middle-aged drivers and 13 for elderly drivers.

From equation (1):

$$t_g = 10^{(0.857 + 0.060 A - 0.055 G - 0.001 t_w)} \quad (2)$$

The statistical details of this regression model are shown in Table 2. Table 3 presents the Analysis of Variance (ANOVA) for the model. All the variables were found to be significant at a level of $\alpha = 0.05$.

Assuming male drivers all the time, the difference in the accepted gap length was found as represented in Figure 1. From this figure, older drivers tend to accept larger gaps than younger drivers. Older drivers have lower perception and reaction abilities and usually practice more conservative driving. Hence, they tend to accept larger gaps.

Assuming middle-aged drivers all the time, the effect of the driver's gender on the accepted gap value was as shown in Figure 2. From this figure, male drivers tend to accept shorter gaps than female drivers. Female drivers, in general, are more cautious and careful, and, hence, they are less likely to accept shorter gaps.

From Figures 1 and 2, it is clear that the value of the accepted gap decreased as the waiting time increased. That is explained by that drivers usually start

to lose patience after long waiting times. Therefore, gaps. they tend to take more risk and, hence, accept shorter

Table 1. Description of the variables used in the accepted gap model

Variable	Type	Description	Mean Value	Standard Deviation
Log(Gap) *	Dependent Continuous	The base 10 logarithm of the length of the accepted gap by the observed driver in seconds	0.85	0.07
Waiting Time	Independent Continuous	The total waiting time of the observed driver before turning in seconds	8.80	7.44
Gender	Independent Dummy	The gender of the observed driver, a value of 0 was used for female and 1 for male	0.74	0.44
Age	Independent Dummy	The age group of the observed driver, a value of 0 was used for young drivers, 1 for middle-aged drivers and 2 for elderly drivers	0.74	0.70

* Total number of observations used in the regression = 91.

Table 2. Statistical details of the regression model

Variable	Unstandardized Coefficients		t	Sig.	95% Confidence Interval for B	
	B	Std. Error			Lower Bound	Upper Bound
(Constant)	0.857	0.014	62.828	0.000	0.830	0.884
A	0.060	0.007	8.628	0.000	0.047	0.074
G	-0.055	0.011	-4.949	0.000	-0.077	-0.033
t_w	-0.001	0.001	-2.162	0.033	-0.003	0.000

Table 3. ANOVA table for model 1

Source of Variation	SS	d _f	MS
Regression	0.231	3	0.077
Residual (Error)	0.179	87	0.002
Total	0.410	90	-

Turning Choice Model

Both accepted and rejected gaps were used in this model. Variables included turning choice (Accept/Reject), gap length, waiting time, gender and age. The variables are described in Table 4.

Table 4. Description of the variables used in model 2

Variable	Type	Description	Mean Value	Standard Deviation
Turning	Dependent	The decision of the driver, a value of 0 was used for accepting gap and 1 for rejecting gap	0.22	0.42
Gap *	Independent Continuous	The length of the accepted or rejected gap by the observed driver in seconds	3.76	2.51
Waiting Time	Independent Continuous	The total waiting time of the observed driver before experiencing the gap in seconds	8.12	8.73
Gender	Independent Discrete	The gender of the observed driver, a value of 0 was used for females and 1 for males	0.66	0.47
Age	Independent Discrete	The age group of the observed driver, a value of was used for young drivers, 1 for middle-aged drivers and 2 for elderly drivers	0.69	0.68
* Both accepted and rejected gaps entered				

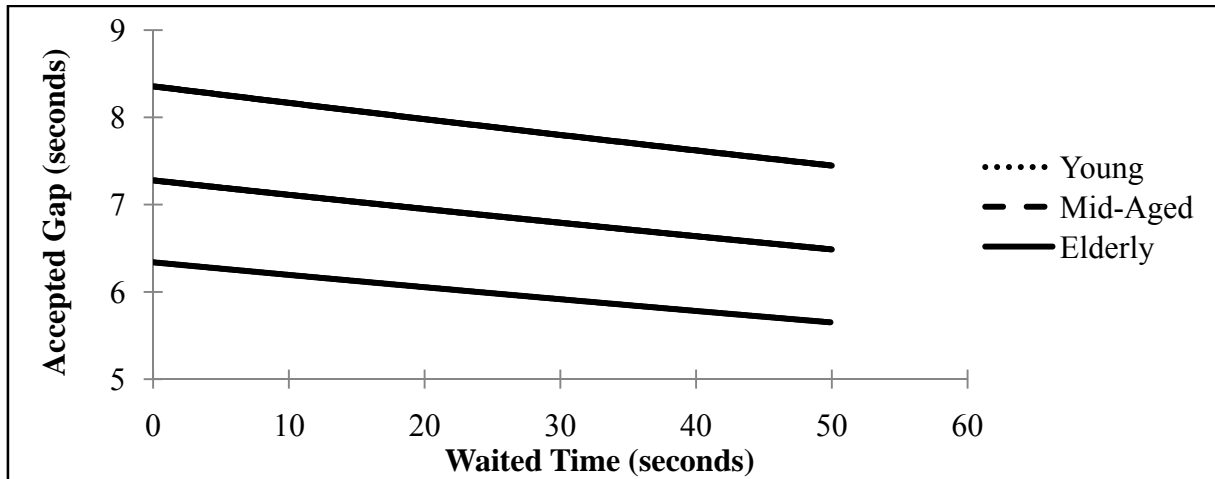


Figure 1: Accepted gap for different age groups

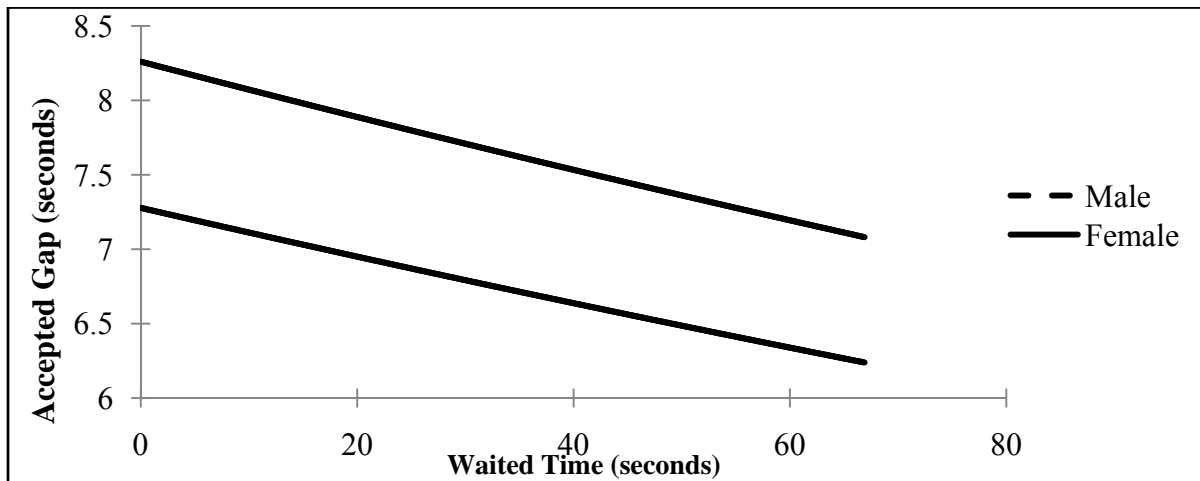


Figure 2: Accepted gap for male and female drivers

Based on the collected data, which comprised 441 observations (98 accepted gaps and 343 rejected gaps), a binary logistic model was developed to calculate the turning function. The turning function was used in estimating the probability of turning within a given gap with a given set of conditions. The developed turning choice model is shown below:

$$U = 5.141 t_g + 0.280 t_w + 5.285 G - 2.394 A - 34.447 \quad (3)$$

$$\text{Cox \& Snell } R^2 = 0.629$$

$$\text{Nagelkerke } R^2 = 0.962$$

where:

U : The turning function;

t_g : The length of gap, seconds;

t_w : The waiting time to the moment of experiencing the gap, seconds;

G : The gender of the driver, 0 for females and 1 for males; and

A : The age group of the driver, 0 for young (18 – 30

years), 1 for middle-aged (31 – 50 years) and 2 for elderly (above 50 years).

Cox & Snell R^2 and Nagelkerke R^2 are pseudo R-squared values that evaluate the goodness-of-fit of logistic models. They are calculated using the following equations:

$$R_{C\&S}^2 = 1 - \left(\frac{L_M}{L_0}\right)^{2/N} \quad (4)$$

$$R_N^2 = \frac{1 - \left(\frac{L_M}{L_0}\right)^{2/N}}{1 - (L_M)^{2/N}} \quad (5)$$

where:

L_0 : The value of the likelihood function for a model with no predictors; and

L_M : The likelihood for the model being estimated.

The statistical details of the coefficients of the model are shown in Table 5. All variables were found to be statistically significant at a level of $\alpha = 0.05$.

The turning probability (P) can be calculated from the turning function using the following equation:

$$P = \frac{e^U}{1 + e^U} \quad (6)$$

Table 5. Statistical details of the turning choice model

Variable	B	S.E.	df	Sig.	95% C.I. for Exp.(B)	
					Lower	Upper
t_g	5.141	1.129	1	0.000	18.699	1560.904
G	5.285	1.493	1	0.000	10.580	3677.846
A	-2.394	1.015	1	0.018	0.012	0.667
t_w	0.280	0.104	1	0.007	1.079	1.624
(Constant)	-34.447	7.700	1	0.000		

Assuming conditions of male driver and 10 seconds of waiting, the probability of crossing a given time gap varied among different age groups as shown in Figure 3. It can be noticed that the probability of turning for lower age groups is higher than that for higher age groups.

Assuming a middle-aged driver and 10 seconds of waiting time, the probability of turning varied among male and female drivers as shown in Figure 4. It can be seen that for a given age and waiting time, the probability of accepting a particular gap is larger for male drivers.

Assuming a middle-aged male driver, the effect of waiting time on the probability of turning is shown in Figure 5. From this figure, it is clear that the probability of accepting a gap becomes larger as the driver waits for a longer time.

SUMMARY

This study addressed the driver's gap acceptance behavior at U-turn median openings. 4 U-turn median openings in Irbid City were investigated. Data was collected by video recording. Two models were

developed in this study. The first model estimated the length of the time gap needed by the driver based on the driver's gender, driver's age and the elapsed time between arriving and experiencing the gap. The second model was a turning choice model, which calculated

the utility function of crossing based on the length of the gap, the driver's gender, the driver's age and the waiting time. The utility function was used to estimate the probability of turning.

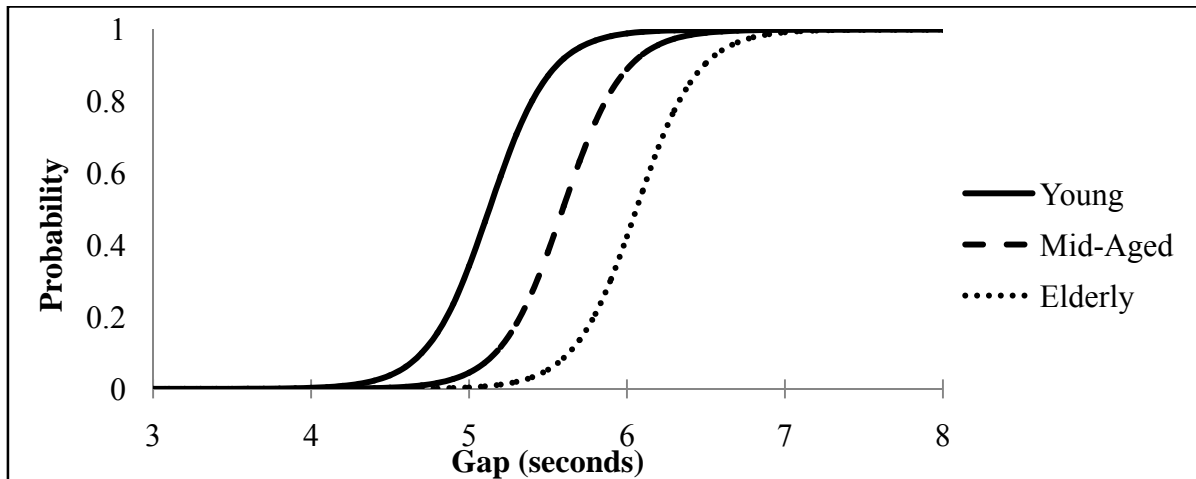


Figure 3: Probability of gap acceptance for different age groups

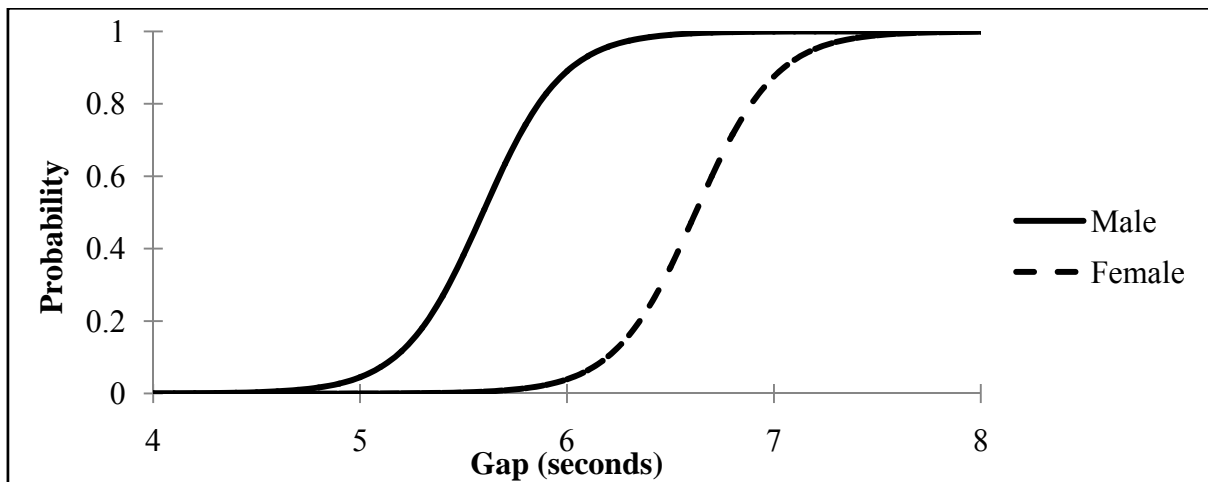


Figure 4: Probability of gap acceptance for male and female drivers

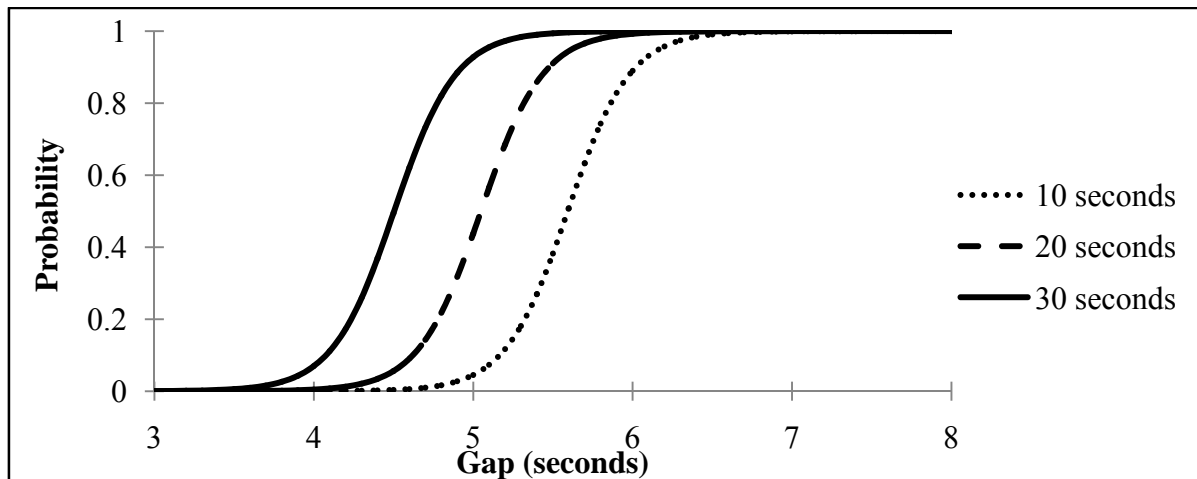


Figure 5. Probability of gap acceptance for different waiting time periods

CONCLUSIONS

The following conclusions were drawn from this study:

1. The value of the accepted gap varies among drivers of different age groups. Younger drivers tend to accept shorter gaps than older drivers.
2. Male drivers are more likely to accept shorter gaps than female drivers.
3. The longer the drivers wait at the median opening, the more likely to accept shorter gaps they become.
4. The probability of accepting a given gap is a function of driver's gender, driver's age and waiting time.

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RECOMMENDATIONS

The following points summarize the recommendations for further studies:

- 1- Covering the effect of the time of the day on the driver's behavior at U-turns in the study is recommended and is believed to produce better relationships.
- 2- This study addressed the effect of driver-related factors on the gap acceptance. It is recommended to study the effect of traffic conditions like traffic volume, speed limit, the existence of nearby traffic control devices and the presence of pedestrians in the area. Also, it is recommended to study the effect of the geometric conditions of the facility such as number of lanes, lane width, median width and the existence of a storage lane.

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