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GAP-ACCEPTANCE BEHAVIOR AT UNCONTROLLED INTERSECTIONS IN DEVELOPING COUNTRIES

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Abstract: Left-turn gap acceptance at an uncontrolled intersection is dependent on many factors. Most existing studies evaluate gap acceptance in developed countries and less deal with developing countries. Morover, most existing studies also do not differentiate between gap and lag when evaluating gap acceptance. In this paper, a binary logit left-turn gap acceptance model is developed using 1496 field observations in Egypt as one of the developing countries. Gap acceptance behavior was found to be influenced by the type of gap presented to the driver (gap or lag). Size of time interval, driver's time-to-turn, and oncoming driver yielding behavior were found to be the potential influencing factors. Equations for estimating the critical gap and lag were developed and applied for different scenarios. Critical gap and lag were found to be varying over a wide range of. These values were less than those of developed countries which confirms the more risky behavior of drivers in developing countries. The findings from this study can improve operational analysis of left turns at unsignalized intersections by using different critical gaps for different traffic and geometric conditions.

Keywords: *Gap acceptance, critical gap, critical lag, traffic flow, logit model, uncontrolled intersection*

1.0 Introduction

The correct modeling of the gap-acceptance behavior at uncontrolled intersection has a strong impact on the accuracy of capacity estimates obtained by micro-simulation models or, more generally, in intersection operational analysis. The analyses performed throughout various countries are performed using various traffic simulation software, such as HCS, VISSIM, SIDRA, CORSIM. The software tends to have various parameters such as gap values integrated into its functionality. The programs are formulated using ideal values from developed countries (e.g., United States of America) which may not be suitable for the case of developing countries (e.g., Egypt) since traffic and drivers' behavior may be entirely different. Nevertheless, few researches have been conducted on gap-acceptance behavior at uncontrolled intersections in developing countries.

Examples of gap acceptance behavior at uncontrolled intersection occur when left-turning vehicles from a minor approach cross with opposing through movement (Figure 1-a); merge with major street through movement (Figure 1-b); or when vehicles on a minor approach cross a major street (Figure 1-c). This paper focuses on gap acceptance behavior for left-turning vehicles at uncontrolled intersections.

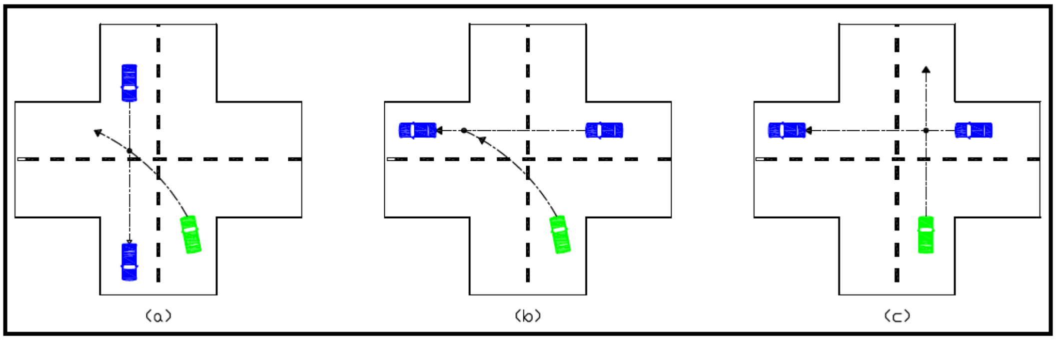


Figure 1: Gap acceptance behavior of left-turning vehicle

The term gap refers to the elapsed-time interval between arrivals of successive vehicles in the opposing flow at a specified reference point in the intersection area, while the term lag refers to the residual part of the first gap that faces the crossing driver. The minimum gap that a driver is willing to accept is generally called the critical gap which is used to estimate the opposed saturation flow rate.

Assuming that drivers who approach an uncontrolled intersection face a choice of accepting a given gap/lag or rejecting it, this paper utilizes a binary disaggregate choice model to study drivers' behavior in accepting gaps in Egypt and other developing countries. Once modeled, the critical gap/lag will be estimated for different scenarios. The paper differentiates between gap and lag when evaluating gap acceptance.

2.0 Background

A number of articles and reports have made an effort to examine various aspects of gap acceptance behavior at intersections, using either deterministic or probabilistic methods. The deterministic critical values are treated as a single threshold for accepting or rejecting gaps. Examples of deterministic methods include the Raff's method (Fitpatrick, 1991; Gattis and Low, 1999; Raff and Hart, 1950) and Greenshields' method (Greenshields et. al., 1947; Mason, 1990). The probabilistic method involves constructing discrete choice models that predict the likelihood of accepting different gaps. Examples of probabilistic method include Logit model (Pollatschek et. al., 2002; Rossi et. al., 2013; Teply et. al., part 1, 1997; Teply et. al., part 2, 1997; Cassidy *et al*., 1995; Gattis and Low, 1998; Yan and Radwan, 2008; Maze, 1981; Harwood *et al*., 2000; Zohdy *et al*., 2010), Probit model (Hamed and Easa, 1997; Lassarre *et al*., 1991; Daganzo, 1981), and neural networks (Pant and Balakrishnan, 1994).

In another way, Fuzzy Logic can properly treat the uncertainty, which affects gap-acceptance decision process (Rossi et. Al., 2012; Rossi et. Al., 2010; Meneguzzer et. al., 2010; Rossi et. al., 2011). A set of (if-then) rules is built from the fuzzy knowledge base, properly describing the cause-effect mechanism of the decision process. The rules are generally easy to interpret, given the fact they are expressed in verbal terms. Moreover, the use of Fuzzy Logic is attractive since other additional variables, that can not easily be described in the utility function of the Logit model, can be included in a fuzzy logic model (e.g. drivers' characteristics vague by nature such as driving style or state of anxiety).

For this study, the definition used for the critical gap, is the gap size that is equally likely to be accepted or rejected by the driver, in other words, the gap size corresponding to 50th percentile of the accepting gap probability distribution (Hamed and Easa, 1997; Yan and Radwan, 2008).

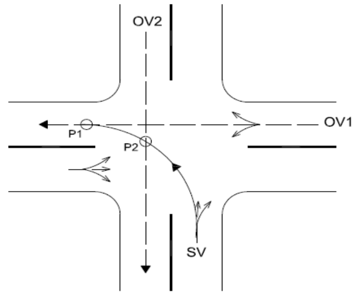
The HCM (2000) recommended that the critical gap accepted by left-turn drivers at signalized intersections with a permitted left-turn phase is 4.5 s. AASHTO (2001) recommended that critical gap for left-turning passenger cars be set equal to 5.5 s and for left-turning vehicles that cross more than one opposing lane to add an additional 0.5 s for each additional lane of travel. Harwood *et al*. (2000) recommended a critical gap of 7.1 and 4.1 s for left-turn maneuvers from minor and major roads, respectively.

Most of the studies investigated the gap acceptance behavior in developed countries. They found an influence of some variables such as gap duaration, driver's age and gender, presence of a passenger in the turning vehicle, class of the turning vehicle, type and speed of the opposing vehicle, opposing traffic volume, delay or number of rejected gaps, conflict type, type of maneuver, intersection control type, level of pedestrian activity at an intersection, rain intensity, and time of day. However, very rare effort has been carried out for developing countries.

3.0 Data Collection

3.1 Methodology

A field survey was carried out in two four legs-uncontrolled intersections in Ismailia, Egypt in busy urban areas. In this survey, vehicle crossing decisions were videotaped in real traffic conditions. The survey was conducted in January 2014 during working days in normal weather conditions. The data collection was performed by videotaping the intersection using a camera mounted on a side building at 27 meters height. At one intersection, the camera recorded left-turning vehicles from an approach and cross with opposing through movement, while at the other intersection, the camera recorded left-turning vehicles from an approach and merge with crossing street through movement. The survey period was about two hours for each location. Then, the required data was extracted using a QuickTime video application under the MS-Windows. With this tool, the user is able to modify the playback speed of the video and mark the times when specific events of interest occur. A schematic diagram of the studied intersection and conflict points is shown in Figure 2.



P1: conflict point of subject vehicle (SV) merging with through oncoming vehicle (OV1)
P2: conflict point of subject vehicle (SV) crossing with opposing through oncoming vehicle (OV2)

Figure 2: Schematic diagram of intersection and conflict points

3.2 Data Extraction and Analysis

The video data was analyzed to estimate the number and length of time of accepted and rejected gaps/lags presented to SV drivers.The video data were reduced manually by recording the time instant at which a subject vehicle (SV) initiated its search to make a left turn maneuver, then, actions of interest for this SV and oncoming vehicles (OV) were recorded. The rejected gap/lag sizes were first measured and followed by the other actions of interest.

Left turns initiated under conditions where there was no approaching OV vehicle were not included in the analysis. Left turn gaps in which the OV vehicle was distant more than 12 seconds from the intersection were universally accepted by SV drivers and were classified as "accepted" but not analyzed for length. Gaps/lags of 12 seconds or less were included in the analysis (Ragland *et al*., 2006). These gaps were categorized as "accepted" if the SV completed the turn before the OV entered the intersection and "rejected" if the SV did not complete the turn.

Table 1 lists and describes the variables extracted from the video records. Table 2 summarizes the gap/lag-acceptance data recorded during the survey and used for the analysis.

Table 1: List of Variables Extracted from Videotape

Variable	**Code**	**Description**
Gap/lag size (s)	G	Number of seconds for the lag or gap
Wait time (s)	W	Sum of wait time in queue and wait time at the head of the queue
Time to turn (s)	TT	Time taken by the vehicle to clear approach and opposing lanes
Gap or lag	GL	Type of presented interval, represented by a dummy = 1 for gap and 0 for lag
Number of vehicles in queue	N	Number of vehicles in queue when subject vehicle arrived
Yield	Y	Oncoming driver yielding behavior, represented by a dummy = 1 if yield (stoped or reduced his speed) and 0 if not
Vehicle size	VS	Size of the subject vehicle, represented by a dummy = 1, 2, and 3 for small, medium, and big respectively
Vehicle type	VT	Type of the subject vehicle, represented by a dummy = 1 for private and 0 for taxi (car, microbus, or minibus)
Accept or reject	AR	Driver accepted or rejected the gap/lag, represented by a dummy = 1 in the case of acceptance and 0 in the case of rejection

Table 2: Observations breakdown

Decision	Type of interval		
	Gap	Lag	Gaps and lags combined
Acceptance	61 (12%)	579 (59%)	640 (43%)
Rejection	448 (88%)	408 (41%)	856 (57%)
Total	509 (34%)	987 (66%)	1496 (100%)
Number of yielding OV's = 389 (26%) Number of non-yielding OV's = 1107 (74%)			

The data collection resulted in a total of 1496 observations. Of those, 509 observations were those for which the left turning vehicle was presented with a gap and the remaining 987 were those for which the left turning vehicle was presented with a lag. Nearly 59% of all lags were accepted by the drivers, whereas only 12% of all the gaps were accepted by the drivers. This indicates that drivers tend to pass through lag intervals more than gap intervals, which means more inclination towards risk in crossing and lack of patience.

It is clear also that 43% of presented intervals (lags and gaps combined) are accepted by the drivers, which is considered high acceptance percentage compared to drivers' behavior in developed countries (Devarasetty *et al*., 2012; Ragland *et al*., 2006; Hamed and Easa, 1997).

Concerning the driver yielding behavior, 389 OV drivers yielded which represents 26% of total observations. This indicates that this variable may affect crossing decision.

Figure 3 shows the graph of cumulative percentage of accepted gaps and lags versus the gap/lag time presented to the left-turning vehicle. Using Raff's method (Raff and Hart, 1950), the critical gap is 4.8 s while the critical lag is 3.9 s, as shown in Figure 3.

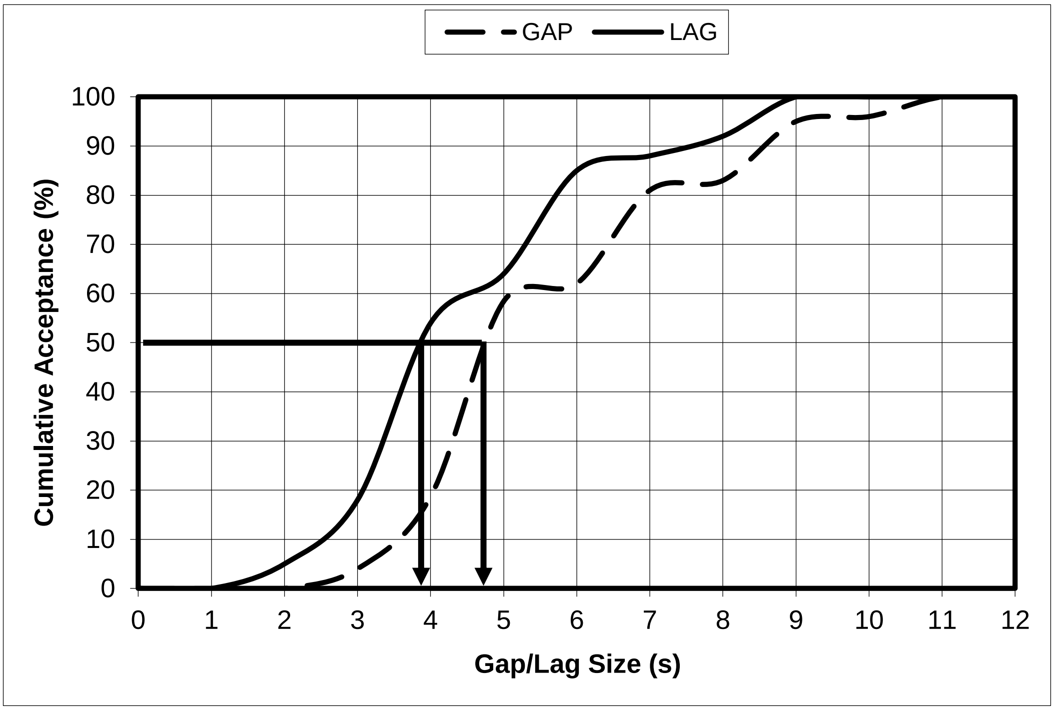


Figure 3: Cumulative percentage of accepted gaps and lags versus gap/lag time

4.0 Gap/Lag Acceptance Model

Given a gap, a driver can either accept or reject the gap. This is known as a binary choice. Gap acceptance research has shown that accepting and rejecting a gap on a roadway is a choice made by each driver based on the utility of this choice. In this research, the utility maximization concept of making a choice is used to analyze the choice of accepting and rejecting a gap.

The probabilistic Binary Logit (BL) model is adopted in this research, where the probability of accepting a gap/lag is predicted using the utility of that exact gap/lag. This utility may depend on, for example, the size of the gap/lag provided, the time to turn, and the wait time at the intersection. A simple utility function is given by:

$$U_i = V_i + e_i \quad \text{...} (1)$$

Where U_i = total utility, V_i = observed utility, and e_i = unobserved utility (error).
V_i, the observed utility, is a function of different variables that affect gap/lag acceptance. It may be of the following form:

$$V_i = a_0 + a_1.x_1 + a_2.x_2 + \text{.........} + a_n.x_n \quad \text{.................................} (2)$$

Where the a_s are the parameters to be estimated by calibration and x_s are explanatory variables.
The probability of accepting a gap/lag (P) is given by the following BL model:

$$P(i) = \frac{1}{1 + \exp(-V_i)} \quad \text{..} (3)$$

For identifying the significant variables to be entered into the BL model, stepwise selection method is used by a statistical analysis software package (SYSTAT). The models estimate the probability that a gap/lag presented to the driver is accepted or rejected for different scenarios of the variable groups which are listed in Table 1. The statistical results of the most significant model are reported in Table 3. Hence, the final model with the best statistical results is the following:

$$P_{acceptance} = \frac{1}{1 + \exp\left[-(-4.111 + 1.299G - 0.342TT - 0.924GL + 0.637Y)\right]} \quad \text{.....} (4)$$

Table 3: Descriptive statistics results for the binary Logit crossing choice model

Variable	**βi (Coefficient)**	**Standard error**	**t-statistics**	**p-value**
Constant	- 4.111	0.275	-12.235	0.001
G	1.299	0.024	11.941	0.001
TT	- 0.342	0.038	- 8.320	0.004
GL	- 0.924	0.053	- 10.201	0.000
Y	0.637	0.044	5.347	0.001
R^2 = 0.75				

The significance of the independent variables is considered with the effect of t-statistics and p–values. The R-square value is 0.75 which indicates that the calibrated model provides acceptable prediction accuracy. Hence, the proposed model is strong enough to predict the gap/lag acceptance behavior at uncontrolled intersections.

5.0 Discussion

The gap/lag acceptance BL model includes, as utility explanatory variables, the size G of the time interval, the driver's time-to-turn across the intersecting road TT, the type of interval (represented by a dummy GL, which takes the value of one in the case of a gap and zero in the case of a lag), and the OV driver yielding behavior (represented by a dummy Y, which takes the value of one in the case of yielding and zero, otherwise).

As could be expected, the acceptance probability increases with the increase of the interval size G and the decrease of the time-to turn TT. The weight of time interval size is significantly larger than the weight of the time-to turn. Given values of G and TT, the negative sign of the coefficient of interval type GL results in a lag-acceptance probability larger than gap-acceptance probability. This result can be explained if a specific geometric layout of the intersection is considered, which allows vehicles making a turn from the minor road to enter the intersection without stopping, in case of lags of acceptable size. This is not possible if the interval was a gap, because in this case the vehicle has to stop before completing the maneuver. These results are coherent with the findings of previous studies about gap-acceptance Logit models.

The new variable, oncoming driver yielding behavior Y, which has not been introduced in previous studies conducted for developed countries, is significant in this model. This can be interpreted as the behavior of drivers in developing countries is more risky or they, to some extent, do not follow traffic rules, so the oncoming cars are forced usually to yield.

This also explains the insignificant effect of the wait time W on the choice probability. The observed data showed that nearly most of accepted intervals (640) were lags (579) and the majority of drivers who accepted lags (nearly 85%) had WT less than 2 s, i.e. did not completely stop.

The model also shows insignificant effects of vehicle type VT and vehicle size VS on interval acceptance.

The analyses were confirmed by applying the calibrated BL model to different scenarios of suggested combinations of interval type (gap and lag), yield behavior (yield and not yield), and SV turning time (3 s, 4 s, 5 s, and 6 s).

The results of gap/lag acceptance probability versus interval time were represented graphically as shown in Figures 4, 5, and 6.

Figure 7 shows a representation of all possible scenarios. It is clear that the introduction of the exponential of time interval size in the utility function of BL model gives an acceptance probability P that tends to zero for time interval size close to zero (less than 1.5 s) and tends to 100% for time interval close to 12 s (more than 9 s).

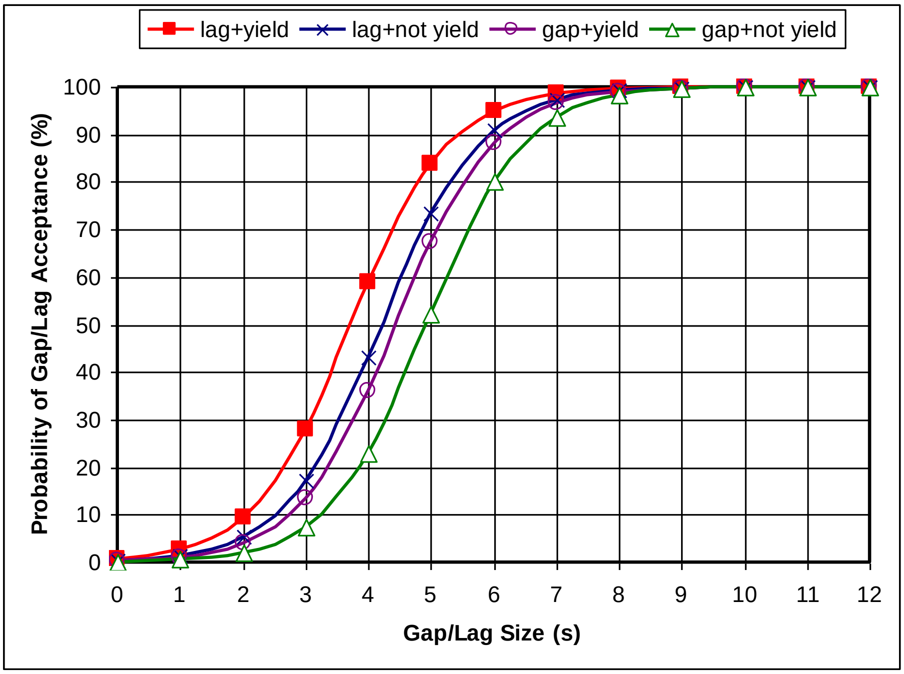


Figure 4: Estimated probability versus gap/lag size for interval type and yield behavior scenarios

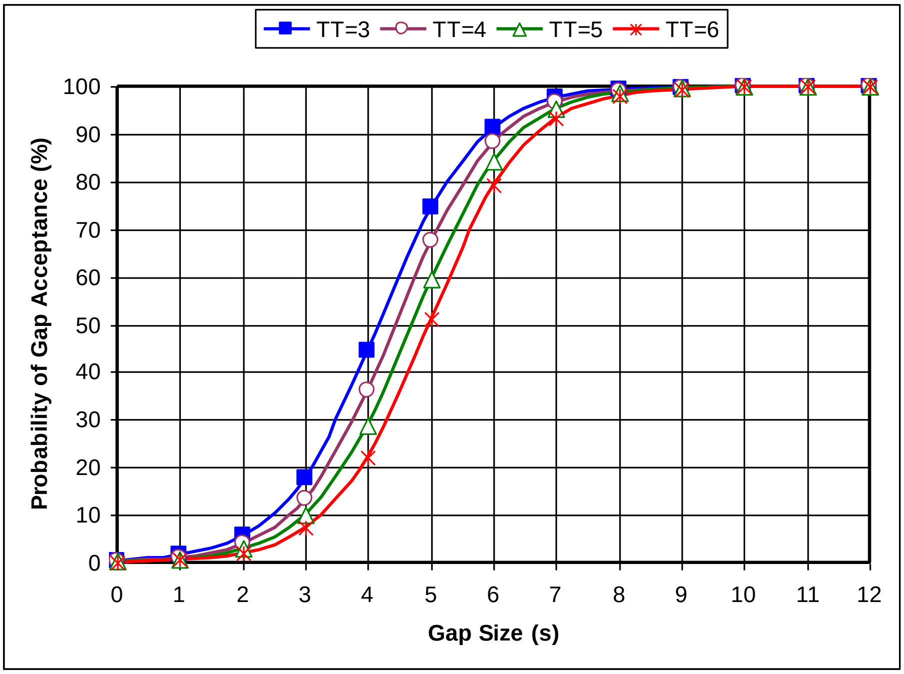


Figure 5: Estimated probability versus gap size for of time-to-turn scenarios

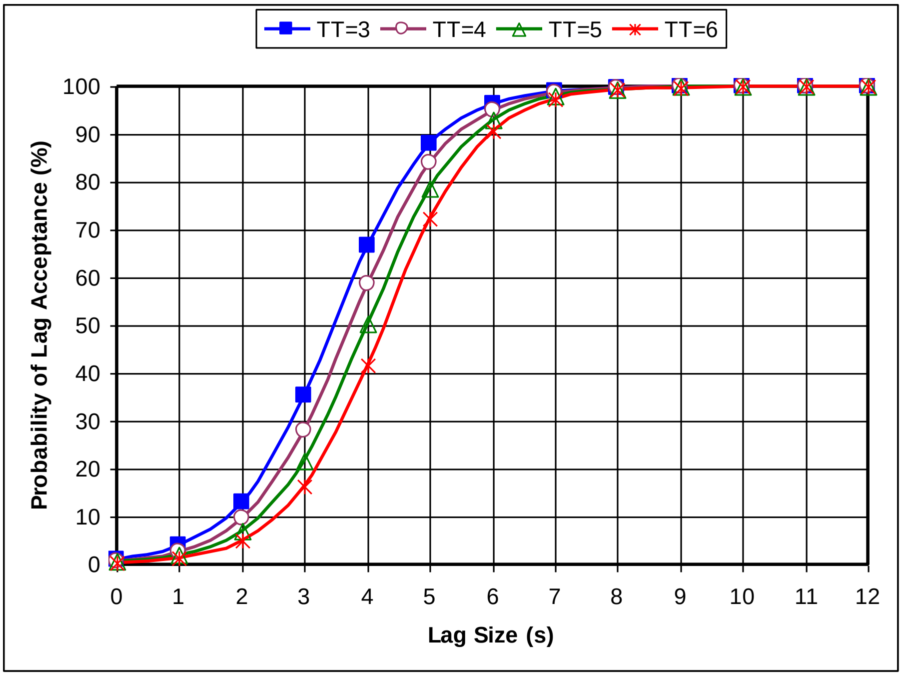


Figure 6: Estimated probability versus lag size for of time-to-turn scenarios

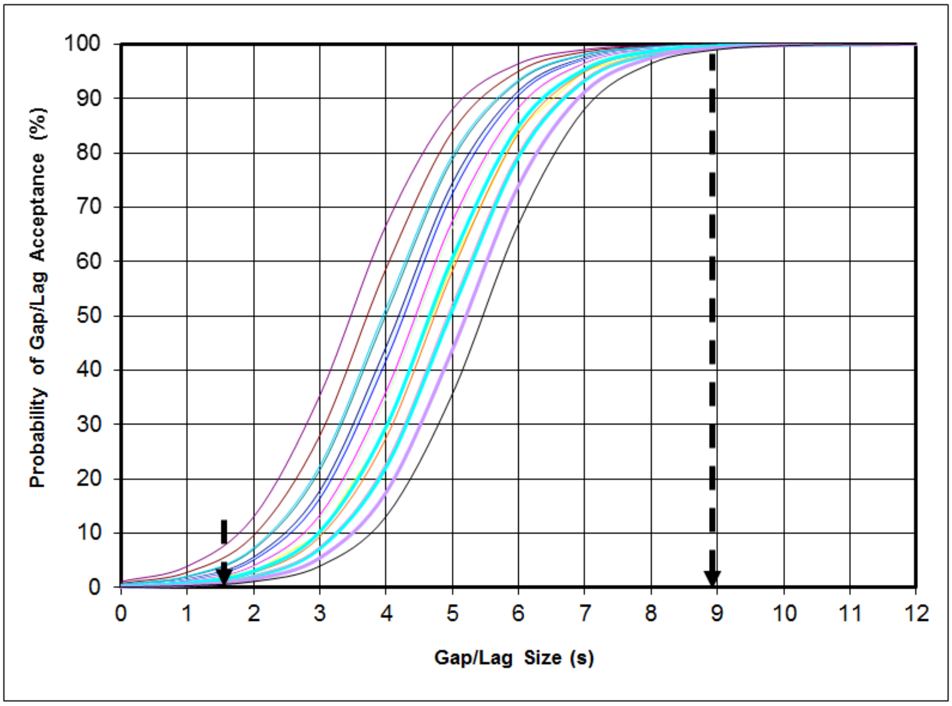


Figure 7: Estimated probability versus gap/lag size for all possible scenarios

Based on equation (4), the critical gap/lag can then be computed by setting the probability of accepting a time interval to 0.5. Consequently, the critical gap/lag can be computed as:

$$\text{Critical gap/lag} = 3.165 + 0.263\ TT + 0.711\ GL - 0.49\ Y \quad \text{............. (5)}$$

It is clear that the critical gap/lag decreases as the OV yields (i.e. drivers become more aggressive as they expect that the OV would stop or slow down). Moreover, it is clear that the critical gap is usually greater than the critical lag.

The critical gap and lag for the 16 suggested scenarios were estimated using equation (5). The results are listed in Table 4.

Table 4: Critical Gap and Lag for Different Scenarios

Scenario	Time to turn (s)	Gap or Lag	Yield or not	Critical gap (s)	Critical lag (s)
1	3	gap	yes	4.18	
2	3	gap	no	4.67	
3	3	lag	yes		3.46
4	3	lag	no		3.95
5	4	gap	yes	4.44	
6	4	gap	no	4.93	
7	4	lag	yes		3.73
8	4	lag	no		4.22
9	5	gap	yes	4.70	
10	5	gap	no	5.19	
11	5	lag	yes		3.99
12	5	lag	no		4.48
13	6	gap	yes	4.97	
14	6	gap	no	5.46	
15	6	lag	yes		4.25
16	6	lag	no		4.74
Weighted Average = 4.34 s					

Table 4 shows that the critical gap and lag are different for each scenario and critical lag is less than critical gap in all cases. The values also vary across different scenarios. The smallest critical gap was found to be 4.18 s and the largest was 5.46 s. Similarly, the smallest critical lag was found to be 3.46 s and the largest was 4.74 s.

To find a standard value of critical interval time, a weighted average of critical gaps and lags for the different scenarios was calculated based on the percentage of occurrence of each scenario which was extracted from the observed data. The resulted weighted average was 4.34 s.

6.0 Summary and Conclusions

A field survey was carried out at two uncontrolled intersections in Ismailia, Egypt. The purpose was to model gap acceptance behavior of drivers and to find the critical gap values which are widely used in intersection operational analysis and capacity estimates.

A binary Logit model was developed using 1496 observations (640 accepted and 856 rejected, 509 gaps and 987 lags) to predict the probability of accepting or rejecting a given gap or lag. The significant variables of the model are the size of the time interval, the driver's time-to-turn across the intersecting road, the type of interval (gap or lag), and the oncoming driver yielding behavior (wait/stop or not). A new variable, oncoming driver yielding behavior, which had not been introduced in previous studies conducted for developed countries, was significant in the developed model.

The model analyses showed that the behavior of drivers in developing countries is more risky or they, to some extent, do not follow traffic rules. Moreover, for different scenarios, the model resulted in gap/lag acceptance probability P that tends to zero for time interval size less than 1.5 s and tends to 100% for time interval more than 9 s.

The critical gap and lag for different scenarios were estimated using the developed model. They were found to exist over a wide range of values. However, the range of critical gaps was smaller than that of critical lags. The smallest critical gap was found to be 4.18 and the largest was 5.46 s. Similarly, the smallest critical lag was found to be 3.46 and the largest was 4.74 s. However, the weighted average of gap/lag interval was found to be 4.34 s. These values were less than those of developed countries which confirms the more risky behavior of drivers in developing countries.

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