Gap Acceptance Regression Model at Un-Signalized Intersections (Major-Minor Roads) in Amman-Jordan

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Abstract

The main purpose of this work is to identify the most influential factors on gap acceptance decisions and to determine the critical gap that will be accepted by local drivers, identify parameters that affect the driver’s gap acceptance decision under local conditions, observe the type of distribution of local gaps accepted in Amman, Jordan and to develop a gap acceptance microscopic model.

Provide an idea about the local gap acceptance decisions and critical values.

Key words: gap acceptance, model, intersection, capacity

1. Introduction:
The traffic flow process at unsignalized intersections is complicated since there are many distinct vehicular movements to be accounted for and most of which conflict with opposing vehicular volumes. The absence of adequate gap acceptance distribution results in decreasing capacity, increasing delays and increasing potential for traffic accidents. A driver waiting at a given way sign on a minor road and wishes to turn into the major road stream is faced with a series of gaps. Drivers must base their decision on the size of the gaps between the oncoming traffic. Gap acceptance and rejection are important parameters in determining the capacity of intersections.

Gaps are either accepted or rejected depending on a number of factors like driver age and gender, intersection geometric, acceleration capability of a vehicle and other factors[1].

Identification of the parameters that influence gap acceptance decision is very beneficial for traffic operation and traffic planning. The headway distribution on major roads along with the gap acceptance behavior enables the derivation of the potential capacity of the minor road. Thus, the results of this study analysis assist the
concerned authorities to develop their corporate plans for traffic operation's improvements. It is very important to determine the average minimum gap length (critical gap) that will be accepted by drivers to use in analyzing gap acceptance. Determining this gap will help in evaluating delays of vehicles on minor roads wishing to join a major road traffic stream at unsignalized intersections. Also shedding light on the delay of vehicles on a ramp wishing to join an expressway. So it therefore requires the acknowledgement of the frequency of arrivals of gaps that are at least equal to the critical gap. This in turn depends on the distribution of arrivals of main stream vehicles at the area of merge; it is assumed that for light to medium traffic the distribution of main stream arrival is Poisson. The application of the gap acceptance model can contribute greatly in many fields. For example, in the intelligent transport system (ITS), gap acceptance, merging and lane change are the main elements [2, 3].

Indicated that Drivers with low acceptance thresholds are more likely to accept the first gap offered to them, whereas drivers who want long gaps will often reject the lag and several gaps before obtaining an acceptable gap. The resulting effect of this bias is that the reported critical gap is somewhat larger than the actual critical gap[4].

Described estimation procedures for critical gaps at unsignalized intersections. stipulated that not all gaps presented to the driver should be considered in the process while waiting at an intersection. showed that nearly all gaps longer than 12 seconds are accepted and, therefore, should not be considered when determining the critical gap[5, 6].

Offered two approaches to driver’s critical gap values: the deterministic and the probabilistic approach. The deterministic critical values are treated as a single average value. The fundamental assumption is that drivers will accept all gaps that are larger than the critical gap and reject all smaller gaps. Highway Capacity Manual (HCM) has adopted the deterministic approach in the two way stop controlled roads (TWSC) capacity formula. As an alternative, probabilistic models solved some of the inconsistency elements in gap acceptance behavior by using a statistical treatment of minor street drivers’ gap acceptance behavior [7, 8, 9]. Explained how a long queue-waiting time may reduce the driver's critical gap. Drivers' frustration may increase as length of the queue and queue time increases. In addition, the pressure on the driver that is first in line from other vehicles queued behind will encourage the driver to accept a shorter gap. Finally, the longer the time a driver spends in queue, the better he or she will be able to estimate the size of upcoming gaps and the driver may come to accept a shorter gap [10, 11]. Also found evidence that drivers accept smaller lags and gaps during peak periods than during off-peak hours. Older drivers have problems to adequately detect, perceive and accurately judge the safety of a gap as indicated by [12, 13, 14]. Therefore, older drivers may experience greater difficulties at non-signalized intersections as the result of diminished visual capabilities, such as depth and motion perception. Prior results indicated that judgments about whether a potential collision would occur were less accurate for older drivers (40–64 years) compared with younger drivers (18–29 years) [15, 16, 17].

Collected gap acceptance data as a function of driver age for left turn, right turn, and through movements at stop-controlled intersections. The findings indicated that
younger drivers (20–40 years) accepted shorter gaps than older drivers (over 65 years) [18]. Through both simulator and field measures, indicated that older drivers show relative insensitivity to vehicle approach speed in left-turn maneuvers across the major road traffic when compared with younger drivers. This may increase the risk of accidents if there is a lone speeder in the traffic scheme [19, 20]. Concluded that older drivers generally over-estimate the speed of vehicles traveling at low speeds, while under-estimating the speed of those traveling much faster, which could explain the over-involvement of elderly drivers in accidents at junctions. Stochastic models of the gap-acceptance behavior of left-turn drivers on major roads at unsignalized intersections were programmed using (SLAM II), a simulation computer language [21].

Critical gap is the threshold by which drivers in the minor stream judge whether to accept a gap. If the gap is larger than critical gap, drivers accept it and enter the intersection; otherwise, drivers reject the gap and wait for the next gap. At “a priority-controlled intersection” concluded that, critical gap is usually considered as a fixed value or to follow a certain distribution[22, 23].

2. Data Collection:
Six unsignalized intersections in Amman city were investigated in typical days. The intersections were chosen to be on major roads, and of high importance to all road users; as nearby areas contain many places of interest that attract many people. These intersections are shown in Figures (1 through 6).

![Figure (1): Loop Intersection for Queen Rania Road and Al-Madina.](image1.jpg)

![Figure (2): Loop Intersection for Istiqlal Road and Jordan Road. Al-Monawra Road](image2.jpg)
The selected unsignalized intersections were divided into two groups: loop geometry including three intersections, and three (90°) intersections geometry. Those are mentioned in Table (1).
Table (1): Roads Surveyed in the Study

<table>
<thead>
<tr>
<th>Intersection Name</th>
<th>Type of intersection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queen Rania</td>
<td>Loop</td>
</tr>
<tr>
<td>Istiqlal</td>
<td>Loop</td>
</tr>
<tr>
<td>Airport</td>
<td>Loop</td>
</tr>
<tr>
<td>Zahran (90°)</td>
<td>Intersection</td>
</tr>
<tr>
<td>Mecca (90°)</td>
<td>Intersection</td>
</tr>
<tr>
<td>Yarmouk (90°)</td>
<td>Intersection</td>
</tr>
</tbody>
</table>

3. Calculations and Results:
To obtain the critical gap in accordance with Raffs definition, the cumulative number of accepted gaps and rejected gaps were calculated for each gap size. Graphical representations of the previous data were made, and then the critical gap was obtained from the intersection of the two curves (Cumulative accepted and cumulative rejected gaps).

Figure (7): Critical Gap Determination for Queen Rania Road in Peak Period.
Figure (8): Critical Gap Determination for Queen Rania Road off Peak Period.
Figure (9): Critical Gap Determination for Istiqlal Road in Peak Period.
Figure (10): Critical Gap Determination for Istiqlal Road off Peak Period.
Figure (11): Critical Gap Determination for Airport Road in Peak Period.

Figure (12): Critical Gap Determination for Airport Road off Peak Period.

Figure (13): Critical Gap Determination for Zahran Road in Peak Period.

Figure (14): Critical Gap Determination for Zahran Road off Peak Period.

Figure (15): Critical Gap Determination for Mecca Road in Peak Period.

Figure (16): Critical Gap Determination for Mecca Road off Peak Period.
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The results of previous figures are illustrated in Table (2):

Table 2: Critical gap values for each intersection

<table>
<thead>
<tr>
<th>Road Name</th>
<th>Critical Gap Value (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>On-Peak</td>
</tr>
<tr>
<td>Queen Rania</td>
<td>3.3</td>
</tr>
<tr>
<td>Istiqlal</td>
<td>3.3</td>
</tr>
<tr>
<td>Airport</td>
<td>3.3</td>
</tr>
<tr>
<td>Zhran</td>
<td>3.1</td>
</tr>
<tr>
<td>Mecca</td>
<td>3.5</td>
</tr>
<tr>
<td>Yarmouk</td>
<td>3.3</td>
</tr>
<tr>
<td>Avg. (sec)</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Results showed that the mean critical gap values were equal to 3.3 seconds in peak periods and 5.02 seconds for off peak periods. The results of this study agrees with several previous studies.

4.1 Analysis of Parameters Affecting Gap Acceptance:
Data were inspected by logistic analysis in accordance with previous studies to determine the variables that affect gap acceptance. The results of this analysis are shown in Table (3). Input parameters that were considered; driver age and gender, the flow on major and minor road, the geometric of the roads, and speed of vehicles on major road.

Table (3) shows the results through the logistic analysis. The dependent variable was the driver decision on acceptance or rejection of a gap; the independent variables were driver age, driver gender, traffic flow on major road, traffic flow on minor road, speed
of vehicles on major road on the lane in which vehicles are merging, type of vehicles on minor road wishing to merge, and intersection geometry type.

**Table 3:** The SPSS Output for the Logistic Model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Significance Level</th>
<th>-value^R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>-</td>
<td>0.000</td>
<td>0.376</td>
</tr>
<tr>
<td>Driver age</td>
<td>-0.078</td>
<td>0.000</td>
<td>-</td>
</tr>
<tr>
<td>Driver gender (male=1, Female=0)</td>
<td>3.029</td>
<td>0.000</td>
<td>-</td>
</tr>
<tr>
<td>Traffic flow on major road (on-peak=1, off-peak=0)</td>
<td>0.435</td>
<td>0.027</td>
<td>-</td>
</tr>
<tr>
<td>Traffic flow on minor road (on-peak=1, off-peak=0)</td>
<td>1.642</td>
<td>0.000</td>
<td>-</td>
</tr>
<tr>
<td>Vehicle speed on major road</td>
<td>-0.110</td>
<td>0.000</td>
<td>-</td>
</tr>
<tr>
<td>Vehicle type on minor road (pc=1, others =0)</td>
<td>0.412</td>
<td>0.021</td>
<td>-</td>
</tr>
<tr>
<td>Intersection geometry type (Loop=1; T@ 90º=0)</td>
<td>3.815</td>
<td>0.039</td>
<td>-</td>
</tr>
</tbody>
</table>

Therefore, the obtained logistic model is:

\[
D = -0.078*DA + 3.029*DG + 0.435 * F\text{ major} + 1.642*F\text{ minor} - 0.110 * M + 0.412* VT + 3.815* IG + E
\]

Where
- \(D\): decision to accept or reject.
- \(DA\): driver age.
- \(DG\): driver gender.
- \(F\text{ major}\): traffic flow on major road.
- \(F\text{ minor}\): traffic flow on minor road.
- \(M\): vehicle speed on major road.
- \(VT\): vehicle type on minor road.
- \(IG\): intersection geometry type.
- \(E\): error.

**4.2 Analysis of Gap Acceptance Model:**

Previous model was established to determine decision on gap acceptance. In order to establish a model to estimate the size of the gap, multiple regression model was used on the surveyed intersections.

Table (4) shows the results of the multiple regression analysis. The dependent variable was to accepted gap size; the independent variables were driver age, driver gender, traffic flow on major road, traffic flow on minor road, speed of vehicles on major road on the lane in which vehicles are merging, type of vehicles on minor road wishing to merge, and intersection geometry type according to [24, 25].
Table 4: The SPSS Output for the Multiple Regression Model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Significance Level</th>
<th>(R^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>-</td>
<td>0.000</td>
<td>0.633</td>
</tr>
<tr>
<td>Driver age</td>
<td>0.090</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Driver gender (male=1, Female=0)</td>
<td>-0.601</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Log(traffic flow on major road)</td>
<td>-0.024</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>Log(traffic flow on minor road)</td>
<td>-0.071</td>
<td>0.039</td>
<td></td>
</tr>
<tr>
<td>Vehicle speed on major road</td>
<td>0.040</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Vehicle type on minor road (pc=1, others =0)</td>
<td>-0.101</td>
<td>0.042</td>
<td></td>
</tr>
<tr>
<td>Intersection geometry type (Loop=1; T@90º=0)</td>
<td>-0.008</td>
<td>0.047</td>
<td></td>
</tr>
</tbody>
</table>

Therefore, the obtained multiple regression model is:
\[ AGS = 0.009 \times DA - 0.601 \times DG - 0.024 \times F \text{ major} - 0.071 \times F \text{ minor} + 0.004 \times M - 0.101 \times VT - 0.008 \times IG + E \]

Where
- AGS: the accepted gap size.
- DA: driver age.
- DG: driver gender.
- F major: the traffic flow on major road.
- F minor: the traffic flow on minor road.
- M: vehicle speed on major road.
- VT: vehicle type on minor road.
- IG: intersection geometry type.
- E: error.

Applying the obtained multiple regression model on surveyed data in different locations, for example, if:
- Driver age: 60 years old.
- Driver gender: male.
- Vehicle speed = 60 km/hr.
- Vehicle type: passenger car.
- Intersection type: loop.
- Gap = 6 seconds.
- Traffic flow on major road = 2073 veh/hr.
- Traffic flow on minor road = 858 veh/hr.
- Peak period.

Implementation of the previous data in the multiple regression model, the answer was 6.8 seconds. The significance levels show that the effects of the studied variables were significant, and were less than 0.05. This means that the selected variables have a significant effect on determining the accepted gap size.
Analyzed data show that each factor in this model has an effect on the accepted gap size. Multiple regression model shows positive sign for driver age, which means in case of increasing in driver age; the required gap size increased. For driver gender, model shows positive sign for female, this means that females use larger gap size more than males, because females more cautions for ending their waiting time. For intersection geometric factor, model shows positive sign for (90°) intersection and negative sign for loop geometry type. This is because merging vehicles in (90°) intersections need larger gap size than loop type. For traffic flow on major stream, model shows negative sign because drivers accept smaller gap size in peak period. Vehicle type factor have negative sign for passenger car because it needs smaller gap size compared with buses. Finally, Model shows negative sign for vehicle speed on major road, because it shortens the accepted gap size [26].

4.3 Applications of Models:
The phenomenon of gap acceptance can be used in many important aspects such as queue lengths, delays and road capacities. Results shown in Table (5) indicate the existence of short queues in some roads (3-4 vehicles) and long queues (9-16 vehicles) on other roads. Despite the length of the queue the delay seems to be significant (8-14 sec/veh). This can be explained by that roads dimensions are small in general, and therefore, are affected significantly even by small queue.

**Table 5:** Summary of Results

<table>
<thead>
<tr>
<th>Road Name</th>
<th>Peak Period</th>
<th>Off-Peak Period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Queue length Q(veh)</td>
<td>Delay D (sec/veh)</td>
</tr>
<tr>
<td>Queen Rania</td>
<td>9</td>
<td>8.96</td>
</tr>
<tr>
<td>Istiqlal</td>
<td>16</td>
<td>11.52</td>
</tr>
<tr>
<td>Airport</td>
<td>3</td>
<td>6.86</td>
</tr>
<tr>
<td>Zahran</td>
<td>4</td>
<td>14.17</td>
</tr>
<tr>
<td>Mecca</td>
<td>3</td>
<td>13.97</td>
</tr>
<tr>
<td>Yarmouk</td>
<td>4</td>
<td>11.89</td>
</tr>
</tbody>
</table>

It was noticed that the calculated capacity in peak and off-peak periods are less than the estimated capacity obtained from (GREATER AMMAN MUNICIPALITY), this result explains the high levels of congestion in the studied roads.

4.4 Comparing with HCM:
Capacity values obtained from GREATER AMMAN MUNICIPALITY and HCM were compared and examined using the T-test. The HCM formula is shown below.

\[ c = v^*\left(\frac{e^{-v*tc /3600}}{1 - e^{-v*tf /3600}}\right) \]  

(1)

where:
\[ c \] = capacity of minor road (veh/h).
\[ v \] = flow rate for major road (veh/h).
\[ tc \] = critical gap(s).
\[ tf \] = follow up time(s).

Table (6) shows the results for T-test. It was noticed that the actual capacity of minor road calculated using the HCM equation is less than the values that was obtained from GREATER AMMAN MUNICIPALITY by ratio equal to 0.93. Also the significance level shows that the studied variables were significant and were less than 0.05.

**Table 6:** The SPSS output for T-test

<table>
<thead>
<tr>
<th>Number of readings</th>
<th>Mean value</th>
<th>Standard deviation</th>
<th>Significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0.93</td>
<td>0.05</td>
<td>0.00</td>
</tr>
</tbody>
</table>

5. Conclusions
Based upon the analysis performed in this study, the following conclusions were made:

1. The critical gaps at the six locations in Amman (the capital city of Jordan) ranged between (3.1-3.5 seconds) for peak periods and between (4.5-5.5 seconds) for non-peak periods.
2. Gaps investigated in the study followed Poisson distribution.
3. For gap acceptance decision, a logistic model is developed. The obtained logistic model is:
\[ D = -0.078*DA + 3.029*DG + 0.435 * F_{major} + 1.642*F_{minor}-0.110 * M + 0.412* VT + 3.815* IG + E \]
4. For determination of accepted gap size, a multiple regression model is developed. The obtained multiple regression model is:
\[ AGS = 0.009*DA-0.601* DG-0.024* F_{major} – 0.071* F_{minor} + 0.004* M-0.101* VT – 0.008* IG + E \]
5. The analysis indicated that there is a decrease in the roads capacities, and increase in delays due to the absence of adequate gap acceptance. These results require more attention from traffic engineers in solving congestion, delays, capacities problems, and level of service. It can be concluded that operations on ramps studied in this research may be improved by using control system, for example, ramp metering. Ramp metering is defined as the process of facilitating traffic flow on freeways by regulating the amount of traffic entering the freeway through the use of control devices on entrance ramps to allow vehicles to enter the freeway at a predetermined rate. This will ease congestion by controlling the rate of flow of merging vehicles. This will also
assist in reducing pollution and energy waste. An alternative solution is to provide an additional lane; this will increase the capacity. Selection of most appropriate solution will require cost-benefit analysis.

References

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