SUBMISSION ID TP. 18: ANALYTICAL ANALYSES FOR SIGNALIZED INTERSECTION START-UP LOST TIME.

Lina B. Al-Helo¹, Ahmed Z. Al-Jabri², and Enan S. Omar³

¹Affiliation Middle East University/Jordan
Email address Linaalhello@hotmail.com

²Affiliation Middle East University/Jordan
Email address Jabiriahmad@hotmail.com

³Affiliation Middle East University/Jordan
Email address anansudqi94@gmail.com

ABSTRACT

This research aimed to observe factors contribute to the value of intersection start up lost time and saturation headway. Comparatively analyze on vehicles start-up lost time at different 16 signalized intersections in the capital of Jordan (Amman) was observed. The analyze included observation driver behavior, cycle length, driver age and gender, vehicle production year, vehicle type and signal installing position from stop line. It is found that driver age and gender, their attention, signal position from stop line has a direct effect on the start-up lost time. Start up time observed being ranging from 0.75s to 6.5 sec with an average value of 2.1 sec, while total lost time of 4 sec per phase was found. Al-Ersal intersection was considered a case study to observe how change in intersection lost time and saturation headway could change intersection capacity. A part of solution suggested is to change stop line position 200m backward by installing signal coordinated with main intersection signal. This suggestion reduces saturation flow rate headway from 2sec in average to less than 1sec, that increases intersection capacity approximately to double.

Keywords: Saturation flow rate, Start-up lost time, Signalized intersection.
Introduction

Capacity of signalized intersection is the maximum number of vehicles can cross intersection within an hour. This number depends basically on the average departure time headway between vehicles in queue, that illustrated by saturation flow rate and available green time compared to cycle length. Lost time is a measure of this no-use time, and it takes into account lost time at the beginning and ends of a phase. Start-up lost time is defined as the excess time that is needed for a number of vehicles to pass through the signalized intersection compared with that would be needed if the intersection did not exist. This time equals the difference between the time used by the first four vehicles in the queue to clear the stop line when the light turns green versus the time they would have taken at the average saturation headway for that lane group of the intersection, HCM 2000.

![Figure. 1 Time Headway for Vehicles in Queue Dissipation.](image)

Start-up lost time reduces effective green value that used by vehicles to pass an approach, as well as the capacity. Matsoukis et al. (2010), found dissipation of a queue of vehicles after the signal changes to green depends on the reaction time and acceleration characteristics of each individual driver and vehicle. In other hand driver behavior also found to be most important factor effecting lost time at signalized intersection. (Soegondo et al. 1990).

Mohammad et al. 2016, observed how using Red Signal Countdown Timers (RSCT) could effect on reaction time and the headway of the first vehicle waiting at queue. The developed model predicted 0.72 s reduction in the headway of the first queued vehicle resulting from the presence of RSCT, while the observed difference in mean headway was 0.82 s. The study concluded that Red Signal Countdown Timers could reduce start-lost time at signalized intersection as is assist motorists in decision-making.

Different studies observed factors effect on reaction time of driver, found that distracted driving increases driver response times. The total lost time for an intersection vary depending on the attentiveness and aggressiveness of the individual drivers and their familiarity with the intersection, (Matsoukis et al.2010). Type of vehicle has also contribution factor on startup lost time at signalized intersection. In observation effect of trucks on start-up lost time and saturation flow rate, results shows average start-up lost time was higher when trucks were in the queue and highest when trucks were among both vehicles 1-4 and 5-n of the queue. (Bruce et al. 2003). Startup Lost time observed to be different from area to other as Hurwitz et al (2013), found that startup headways ranged from 3.36 to 4.06 s in Kansas, 2.97 to 4.41 s in Oregon, and 2.25 to 5.14 s in Utah.
Methodology:

A total of 16 urban signalized intersections with different number of legs and operation characteristics were selected from Amman city. To avoid any bias in the collected data, the intersections was free from on street parking, pedestrian crossing or any activity may disturb driver, having almost same capacity per lane, with good pavement conditions and almost level and straight road alignments.

Work is divided for three parts. First part included data for observing start lost time, second part was on observing saturation headway on selected intersection while third part was on observing suggestion for improving effective green time and saturation flow rate for selected intersection.

For observing start up lost time at intersections, observation being undertaken during approximate peak hour. The observation being conducted for one approach only at each intersection along 16 intersections. Observation made for two groups, first group was for the first vehicle in stopped queue , and other group were the next 5 vehicles in queue. For the first group, number of data were collected for 160 vehicle including:

a) Startup time : that is the time lags between start of green interval till first vehicle leave stop line.

b) Vehicles model( production year) : this includes the production year. For this category the period are divided into 4 group as follow :
   1. From 2011 to 2016.
   2. From 2006 to 2010.

Also string value being given for each group according to

c) Driver age : dividing the drivers age to groups (20s,30s,40s,50s,60s) year.

d) Driver gender : dividing the drivers gender to female and male. For statistical analysis purpose this variable entered as string , that 1 indicate male while 2 for female (1=M), (2=F)

e) Vehicles type : mention the cars type as in site.

f) Driver behavior and concentration: mention the attraction reason as seen on site or is the driver was distracted with something or not. For statistical analysis, 1 indicates that driver not distracted while 2 indicates that driver was distracted.

Table 1 summarize characteristics of selected sample for observing startup time.

<table>
<thead>
<tr>
<th>Model</th>
<th>Age</th>
<th>Gender</th>
<th>Distracted</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016-2011</td>
<td>2010-2006</td>
<td>&lt;2000</td>
<td>20s</td>
</tr>
<tr>
<td></td>
<td>2005-2000</td>
<td>2000</td>
<td>30s</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>40s</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&gt;50s</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Male</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Female</td>
</tr>
</tbody>
</table>

Percent under each group | 21 | 50 | 44 | 21 | 15 | 38 | 25 | 22 | 91 | 9 | 16 | 84 |

For second group the only data collected were time headway between vehicles reaches sixth vehicle in queue. These data used to observe the average saturation headway between vehicles. Also cycle intervals being measured as well as traffic volume per cycle being measured for 160 cycle.

For third part of data, Al-Ersal intersection being selected to observe how lost time and saturation headway could be reduced. Existing traffic peak hour volume, saturation time headway and cycle interval were being measured.
Data Collected Analysis

From data collected, startup time being ranging from 0.75s to 6.5 sec with an average value of 2.1 sec and 85% percentile of 3.1 sec. In observing relations between startup time and vehicle model, figure 2, illustrate the outcome. It can be observed that the relationship between the vehicle production and the start up headway is inverse. As the vehicle become older, start up time become less. This is not being expected, as in normal the older vehicle acceleration rate is lower compared to the newer.

Figure 2 Observed Relation Between 1st Veh. Start up time with Vehcile Production Period.

Figure (3 ) shows result obtained for the effect of driver age on startup time. The data shows that the older people has better response for the beginning of moving compared to young driver. This trend may due to carelessness of younger driver to the roles or due to attraction by other facilities as observed in site. The best result was founded in age of 50 , it was between 1 to 2 second ,this will be almost the ideal condition and when we compare it with the other results, it raised to 5 seconds at younger ages.

Figure 3 Observed Relation Between 1st Veh. Start up time with Drivers Age Group.

Regarding attraction or distracting, 20% of the driver were distracted by something while waiting for signal to turn to green. At this group the startup time was ranging from 3.1 sec to 6.6 sec with average of 4.2sec, while for other group it was ranging from 0.75sec to 4 sec with an average of 1.8 sec. In comparing gender effect, percent of females within sample is too small to be compared to males, to observe is gender has an effect on startup time. In general even with sample observed , females start up time found to be lower than males.
Other observed reason for increasing startup time is the vehicle stopping position. Most of the drivers were stopping under the signal, causing a limited vision for the signal when turns to green, and they move after hearing warning horn from back.

**Effect of departure average headway on traffic volume**

4 intersection performing over capacity being selected to observe how average departure headway could affect maximum traffic volume could departure intersection per cycle. Average headway measured here is for 10 vehicle were at stop condition before the start of green time. The departure vehicle was recorded for 10 cycles. For unbiased data, if any disturb occur while vehicles moving the data not recorded. It well observed that for the same green time, traffic volume effected by departure headway inversely.

Regression analysis performed (Using the IBM SPSS Statistics 19 computer package) to observe the relation between traffic volume, green time and average headway produced the following model.

**Max volume per cycle** = 22.335 + 0.344 Green time - 7.538 Average headway.----------------------Model 1

With $R^2 = 0.81$, $R^2_{adj} = 0.79$, and standard error of the estimate (SSE) = 3.0

**Where**

1. Green time = Actual green time in sec
2. Average headway= average headway departure for 10 vehicle (sec)
Table 4. 1 Analysis of Variance (ANOVA)

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Regression</td>
<td>1236.942</td>
<td>2</td>
<td>618.471</td>
<td>68.329</td>
<td>.000&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Residual</td>
<td>298.697</td>
<td>33</td>
<td>9.051</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1535.639</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. 8 Analysis of Variance (Coefficients)

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
</tr>
<tr>
<td>1 (Constant)</td>
<td>22.335</td>
<td>5.886</td>
</tr>
<tr>
<td>Green</td>
<td>344</td>
<td>.055</td>
</tr>
<tr>
<td>Avg_headway</td>
<td>-7.538</td>
<td>1.718</td>
</tr>
</tbody>
</table>

**Improving Intersection Capacity**

Al-Ersal intersection located at crowded area in Amman capital, being selected to observe how its capacity could be improved without changing its geometric characteristics. It is a four leg intersection have a cycle length of 145 sec with volume to capacity ratio of 1.7. Saturation flow rate headway for through and left movement being observed to be 1.7 for through and 2.25s for left movement. Figure 6 illustrates departure headway for through movement.

![Figure 6 Departure Time Headway for Through Movement](image)

Intersection capacity could be increased by reducing saturation headway of passing vehicles while departing a signal. This could be achieved by increasing vehicle speed while crossing the intersection after being stopping. At normal condition vehicle speed while crossing intersection ranging from 30–45 km/hr resulting higher time headway. To increase vehicle speed while crossing the intersection, suggestion of back warding stopping line being observed. This can be done by installing corridor signal (signal NO.1) before the intersection signal (signal No2), figure 7, at required approach as shown in figure below. Distance between 1 and 2 has to be short that required for increasing speed from 0k m/hr to required speed. By coordinating between signals, vehicles could reach intersection at speed >50km/hr.
Using Highway capacity manual method at arrival peak flow rate = 860 veh/hr / lane, timing at signal 1 and 2 being measured. Start up lost time value from figure 6 = 4 sec, while end lost time assumed to be = 1s

Implication for this suggestion is done at Al-Ersal intersection. The required crossing speed was 60km/hr. For this speed at measured acceleration rate of 1.6 m/s², distance traveled to reach 60 km/hr using below equation = 75m.

\[ D = V_0t + \frac{1}{2}at^2 \]  

(1)

Where:

- \( V_0 \) = Initial speed
- \( a \) = acceleration rate
- \( t \) = observation distance

Suggested distance was 200m between two signals. Travel time required from signal 1 to 2 measured to be 17 sec. This time will be offset timing between signal 1 and 2.

Table 2 below shows the traffic parameters at signal 1 and signal 2. It can be seen that approach capacity at signal 1 = 860 veh/hr/lane that is = traffic flow rate at the same approach. This will insure that volume / capacity ration = 1.

<table>
<thead>
<tr>
<th></th>
<th>( L_s )</th>
<th>( S_T )</th>
<th>( S_L )</th>
<th>( St )</th>
<th>( C )</th>
<th>( G_a )</th>
<th>( C_a )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal 1</td>
<td>4</td>
<td>1.9</td>
<td>-</td>
<td>1900</td>
<td>160</td>
<td>73</td>
<td>865</td>
</tr>
<tr>
<td>Signal 2</td>
<td>0</td>
<td>1.2</td>
<td>1.5</td>
<td>(3000+2400)/2</td>
<td>160</td>
<td>51</td>
<td>860</td>
</tr>
</tbody>
</table>

Where:

- \( L_s \) = Start up lost time as measure (sec)
- \( S_T \) = Through saturation headway (sec)
- \( S_L \) = Left saturation headway (sec)
St= Average saturation flow rate (veh/hr/lane)

C= Cycle length (sec)

Ge= Effective green time (sec)

Ca= Approach capacity( veh/hr/lane)

It can be seen that intersection approach capacity equals to the flow rate at the same and the capacity increased with minor increasing at cycle length from 140 to 160 sec. This suggestion increased approach capacity from 1990 vehicles/hr to 3440 vehicles/hr.

Summary and Conclusion

After performing site visits for 16 intersection to observe factors effecting on startup time, considering age , gender and attention of driver, vehicle type and production year as factors, it is being found that start up time value depends on drivers behavior : lack of attention at the intersection and not follow traffic laws, also driver age and gender and vehicles model has another contribution factor on the startup time. Another factor also position of signal to stop line. Most of driver tend to stop under the signal pole, this does not provide for driver a clear vision for the signal causing longer time to start. Start up time range from 0.75s to 6.5 sec with an average value of 2.1 sec .

Number of vehicles can pass intersection depends on green time allocated and saturation headway. This last depends on speed of vehicles crossing a section. To improve intersection capacity crossing speed has to be increased and lost time reduces. Installing a control point with signal before an intersection just to accommodate traffic and release them at certain time could modify the problem of high lost time and low saturation flow rate as well as capacity. The location of the point was about 200m downstream from each approach. The object from this that the vehicles can reach the suitable speed (60km / hr) to the main intersection. This arrangement increases intersection capacity approximately to double due to moving lost time problem to upstream signal and reduce saturation headway at downstream signal.

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References.


