Evaluation of Start-Up Lost Time of Motorcycle at Signalized Intersection using Headway Distribution Analysis

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Abstract

Start-up lost time is one of the parameters of a signalized intersection that measures the efficiency of the road. It displays the difference between the drivers' traffic characteristics and behaviours. Perception and reaction time vary from driver to driver, and this heavily influences the value of start-up lost time. The introduction of signal countdown timers at signalized intersections intends to reduce this conflict and other traffic problems. Meanwhile, Manila, the capital of the Philippines, has felt a surge in the volume of road vehicles in the post-COVID period. The traffic congestion pushed people to look for alternative means of transportation, which is by riding a motorcycle. This led to the evaluation of the start-up lost time of motorcycles at signalized intersections with a signal countdown timer (SCT) and without an SCT using headway distribution analysis. The evaluation of the study was based on the field data collected at the two intersections in Manila. Different traffic parameters were collected, evaluated, and analyzed under the different countdown timer states. It has been found that the start-up lost time of a motorcycle at the intersection with SCT is 1.65 sec/cycle/lane, which is relatively lower than that at the intersection with non-SCT, with a start-up lost time value of 1.82 sec/cycle/lane. On top of that, the start-up lost time of motorcycles at both intersections has outperformed the 2.00 sec/cycle/lane fix value of start-up lost time proposed by the Highway Capacity Manual. Additionally, the saturation headway at SCT intersections was lower than that at non-SCT intersections; this means vehicles at SCT intersections cross the road faster than those at non-SCT intersections. A higher capacity of signalized intersections was also evaluated when SCT was present. The study found that the presence of a signal countdown timer increases the operational performance of signalized intersections.

Keywords: Start-up Lost Time; Signalized Intersection; Reaction Time; Signal Countdown Timer; Headway Distribution Analysis

1. Introduction

One of the parameters which set out the efficient road mobility of a signalized highway is the "Start-up lost time". Start-up lost time is established as the added time, usually in seconds, that is consumed by the first few vehicles lined-up in a queue at any signalized road, usually in an intersection, as a required allowance due to the reaction of the drivers upon the green-light phase (S. Caliskanelli, F. Coskun Atasever, S. Tanyel, 2017).

The Highway Capacity Manual (HCM, 2010) defined start-up lost time as the sum of the differences between the saturation headway and the headways of the first few vehicles. This leads HCM to recommend a standard of 2.0 seconds per phase as a standard value of start-up lost time. However, in the study of Li and Prevedouros (2002), it suggested that start-up lost time varies from 1.0 sec/phase to 2.0 sec/phase. Recent investigations have calculated a lost time value that is outside the given range mentioned above. These studies pronounced that start-up lost time varies depending on the disparate traffic conditions and has a high tendency to change.

One condition to be considered is the difference between the drivers' traffic characteristics and behavior. A driver at a stop line needs to decide when to start and accelerate in a red-to-green transition of a traffic signal. Perception/reaction time varies from driver to driver. This heavily influences the value of the start-up lost time phase (S. Caliskanelli, F. Coskun Atasever, S. Tanyel, 2017). To reduce this conflict, modern signalized intersections introduce a signal countdown timer to help drivers make such a decision. The installation of signal countdown timers reduces many traffic problems, such as fuel consumption, drivers' mental anxiety during queuing, accidents, collisions, and improves the level of service (Jatoth, Singh, & Mehar, 2020).

In the Philippines, specifically its capital city, Manila, a gradual rise in the volume of road vehicles is being observed due to the easing and removal of COVID protocols as the country enters its post-COVID period. This results in an increase in human mobility and, thus, contributes to traffic congestion. Due to this, people have resolved to a much more practical means of transportation, none other than transportation by motorcycle. It is well observed that the use of motorcycles is much less of a hassle to use as a means of transportation in a city that has a reputation for having very bad traffic situations (Cynthia, 2020).

A recent study by the Asian Development Bank (2020) finds that there was an approximately 26% increase in the total volume of registered motorcycles in the Philippines from 2016 alone. On top of that, by 2021, the Philippine motorcycle market had grown by 12.9% (Motorcycles Data, 2022). This statistical information clearly showed that motorcycles are changing the structure of the roads and highways in the Philippines, especially in urban areas.

It is evident that the composition of the vehicles crossing the roads of Metro Manila is not the way it used to be, with motorcycles being the major trend due to their conformity with the traffic conditions of the city. Taking that into account, the performance of signalized intersections is put into question as many changes happen overtime. Lost time is a crucial factor to take into account when evaluating the effectiveness of a signalized intersection. The goal is to evaluate the start-up lost time of motorcycle in a signalized intersection within Metro Manila. This helps in the investigation concerning queue length, cycle length, traffic congestion, and most importantly, drivers' characteristics and behavior.

The intersections that will be used in the study are among the busiest intersections within the city so that the data that will be gathered is reliable and acceptable to other neighboring cities. The two intersections that will serve as study areas have one specific different characteristic; one is a signalized intersection with SCT, and the other one is a signalized intersection without the presence of SCT.

2. Objectives of the Study:

To evaluate the start-up lost time at signalized intersection with signal countdown timer (SCT) and non-SCT. Specifically, this study tried to determine the following:

1. To differentiate the start-up lost time of an SCT intersection and a non-SCT intersection.
2. To identify the effect of motorcycle volume to the start-up lost time.
3. To assess the lost time due to the driver attributes which occur at signalized intersection.
4. To determine the effectiveness of signal countdown timer at signalized intersections in terms of their respective start-up lost time.

3. Methodology:

The procedural approach to the study was presented below in Figure 1.1. It provided a conceptual framework developed specifically for the start-up lost time evaluation at a signalized intersection. A series of collections of data necessary for the determination of start-up lost time have been obtained. Data collection was done to measure different traffic parameters, such as time headway and saturation flow rate. These parameters are measured and analyzed using a videographic method. The data collected using the mentioned method have undergone headway distribution analysis. The start-up lost time of motorcycles in each lane per cycle at a signalized intersection has been determined using headway distribution analysis. Since an adequate number of start-ups lost time per cycle has been obtained, statistical treatments such as regression analysis and Pearson correlation were used to provide an analysis and interpretation of the acquired data. Start-up lost time has been assessed by utilizing headway distribution and statistical treatment.

The start-up lost times of motorcycles within each flow have been assessed using the combined concepts of headway distribution (time headway method) and the theoretical formula for start-up lost time given by the Highway Capacity Manual. The obtained values of start-up lost time have been divided into two categories; start-up lost time values obtained in a signalized intersection with SCT and without SCT. It was then integrated into a series of statistical treatments such as regression analysis, Pearson correlation, and analysis of variance.

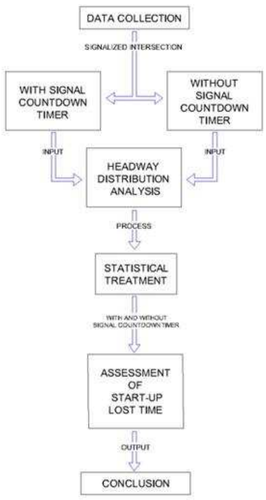

Figure 1.1 Conceptual Framework in Assessment of Start-up Lost Time

3.1 Headway Distribution – Time Headway Method:

Time Headway is the time gap between two successive vehicles that passes over a reference point in a road section. Headways can be determined by using the formula:

$$Time\ Headway, h = T_{n+1} - T_n \qquad \text{(eq'n .1)}$$

Where h = headway

T_n = First Vehicle

T_{n+1} = Succeeding Vehicle

3.2 Saturation Flow Rate:
Saturation Flow Rate is a parameter that estimates the particular movement of a vehicle. Saturation Flow Rate is expressed as the headway between vehicles in seconds (s) that moves in a queued condition, divided into 3600 seconds (s) per hour.

$$Saturation\ Flow\ Rate, S = 3600/H \qquad \text{(eq'n. 2)}$$

Wherein, H = average saturation headway

s = saturation flow rate

3600 = total number of seconds within an hour

3.3 Capacity:
Since continuous movement of one phase for an hour is generally not permitted for signals, capacity is the saturation flow rate adjustment that takes real signal time into account. It is the maximum hourly flow of vehicles allowed in an intersection under different traffic, signalization, or roadway conditions, and is calculated using the formula:

$$c = s * \frac{g}{c} \qquad \text{(eq'n. 3)}$$

Wherein, c is the capacity in vehicle/hour.

S is the saturation flow rate, taken usually in vehicle / h our

$\frac{g}{c}$ is the ratio of the effective green time in seconds to cycle length.

3.4 Cycle Length:
Cycle length is the full signal time allocated on all phases of the traffic light indicator, including any interval changes. Shorter cycle lengths account for a larger total of lost time compared to longer cycle lengths, while more phases occur on longer cycle lengths compared to shorter cycle lengths, and as a result, has lesser lost time. It tends to starve the flow of traffic.
The basic empirical formula for minimization of intersection delay of cycle lengths is:

$$c = \frac{(1.5 * L + 5)}{1.0 - \sum Yi} \qquad \text{(eq'n. 4)}$$

Wherein, C is optimum cycle length measured commonly in seconds.

L is the unutilized time per cycle measured in seconds typically taken as a total of the vehicle signal change intervals; and

SY_i is the critical lane volume for each phase / saturation flow.

3.5 Saturation Headway:
Saturation Headway is the absolute minimum time separation of vehicles in queue where they are improbable to follow each other. It is the average headway commonly measured in seconds per vehicle.

3.6 Data Collection:

The study was stationed on a footbridge above each of the two intersections for the data collection. The data were collected over a one-week course (Monday to Sunday) that took place during the morning (7:00 AM – 10:00 AM) and afternoon peak hours (4:00 PM – 7:00 PM). The data gathered during these timeframes was used for the calculation of the start-up lost time in the area of study.

Recording the traffic conditions using video recording devices has been used to capture events in real time. The researchers used manual processing of the recorded videos. The amount of time on the Signalized Countdown Timer (SCT) stoplight, non-SCT stoplight, the volume of motorcycles ahead of the queue, and the discharge headway of motorcycles on both SCT and non-SCT intersections are among the data that the researchers have recorded.

3.7 Data Analysis:

The start-up lost times of motorcycles within each flow have been assessed using the combined concepts of headway distribution (time headway method) and the theoretical formula for start-up lost time given by the Highway Capacity Manual. The obtained values of start-up lost time have been divided into two categories; start-up lost time values obtained in a signalized intersection with SCT and without SCT. It was then integrated into a series of statistical treatments such as regression analysis, Pearson correlation, and analysis of variance.

In a typical analysis of a signalized intersection, each vehicle in queue will submissively wait for their traffic signal to turn from redlight to greenlight, and when they do, each vehicle will leave its corresponding lane and cross the intersection beginning with the first vehicle and so on. The time separation between the vehicle departures which is the time it takes for the first vehicle to cross the stop lane and the next vehicle to do the same. This time difference is a quantifiable parameter known as time headways and they are commonly measured in seconds.

Figure1.2 illustrates the idea of time headway using an actual road scene.

Figure 1.2 Parameters for Time Headway Method (cross-sectional view)

4. Results and Discussion:

In theory, start-up lost time is determined by getting the sum of the time difference between the first five headways and the saturated headway given in equation 1. During the seven-day manual observation, a combined total of 627 start-up lost time values were gathered from the two intersections, 401 start-up lost times were extracted from Juan Luna-Tayuman SCT intersection, while 226 were from the Recto-Abad Santos non-SCT intersection. Presented below are the descriptive statistics of the start-up lost times of SCT and non-SCT intersections, respectively.

Table 1.1 Descriptive statistics of start-up lost time population of SCT intersection.

Mean	Std. Deviation	Median	Minimum	Maximum	Confidence Interval (95%)
1.65	0.81	1.6	0.02	5.99	0.08

Table 1.2 Descriptive statistics of start-up lost time population of non-SCT intersection.

Mean	Std. Deviation	Median	Minimum	Maximum	Confidence Interval (95%)
1.82	0.85	1.69	0.11	6.625	0.11

According to the 2010 highway capacity manual, the value of start-up lost time in general when no observations were made is 2.00 seconds per cycle. Conversely, the findings of the study showed in the tabulations above that the average start-up lost times for motorcycles from SCT and non-SCT intersections were 0.35 and 0.18 seconds less than the suggested value by HCM, respectively. That is equivalent to 17.5% and 9% percentage difference. Also, it can be deduced that the estimated values from both intersections were not spread widely, as reflected in the very low standard deviation value. Regarding the confidence interval values of 0.08 for SCT and 0.11 for non-SCT, it can be recalled that a confidence interval indicates where the population parameter is likely to reside or fall. This means that it helps the study estimate the value of a random start-up lost time sample. In this context, the study was 95% certain that when a queue of motorcycles crosses the intersection, the estimated value of their start-up lost time would be 1.65 ± 0.08 seconds for the SCT intersection and 1.82 ± 0.11 seconds for the non-SCT intersection.

Table 1.3 Comparison of obtained parameters from the two intersections with different traffic light conditions.

Parameters (on average)	Juan Luna-Tayuman Intersection With Signal Countdown Timer	Recto-Abad Santos Intersection Without Signal Countdown Timer
Start-up Lost Time, SLT (secs)	1.66	1.82
Saturation Headway, H(secs)	1.11	1.27
Queue Length, Q(veh in queue)	10	8
Saturation Flow, S (vphgpl)	3243	2835
cycle length,C (secs)	137	180
Actual Green Time, G (secs)	58	80
Effective Green Time, g(secs)	57.34	79.18
Capacity, c (veh/lane)	1357	1247

The comparison of the evaluated start-up lost time and other parameters for signal timing analysis for both intersections is shown in table 1.3. The analysis of the data confirms that the start-up lost times of both intersections outperformed and below the fix value of 2.00 seconds per cycle suggested by the HCM. On top of that, it is very clear that the difference in lost time values between the two intersections is significant, with the non-SCT intersection being slightly higher than the SCT intersection. This supports other observations and studies where intersections with a signal countdown timer have a lower start-up lost time value than intersections without a signal countdown timer. Based on the results, the presence of a countdown timer at a signalized intersection has a significant effect on the reaction time of motorcycle riders waiting to maneuver in front of the queue. Two important points to note are that: (1) there is a decrease in the start-up lost time of motorcycles when a signal countdown timer is present in the intersection, and (2) vehicles waiting to cross a non-SCT signalized intersection take more time to operate.

Table 1.4 Summary of Start-Up Lost times From Current Study, Highway Capacity Manual, and Foreign Studies.

SUMMARY		Start-up Lost time (sec)	
		SCT	Non-SCT
Highway Capacity Manual		2.00	
Current Study		1.65	1.82
Foreign Studies	India	2.9	4.8-5.8
	Sri Lanka	1.06-4.62	
	Turkey	2.32	

Based on Table 1.4, the average start-up lost time in seconds, for motorcycles, was 1.82 for a non-signalized countdown timer and an average time of 1.65 seconds for a signalized countdown timer. Comparing the value of other start-up lost time, the lowest start-up lost time for motor bicycles was 1.06 seconds. There is a difference of 0.76 seconds and 0.59 seconds for the local start-up lost time of motorcycles when compared to foreign studies.

Both local and foreign results implemented the first five vehicles of the same category (motorcycle only) in front of the traffic queue, and both intersections traffic conditions are heterogeneous in nature. Significant factors that affect start-up lost time were observed for both local and foreign firms. Factors such as traffic authorities controlling traffic flow, sudden lane changes, and motorists going first before the green light are common characteristics that influence and compromise the precision of data.

From Table 1.4, it can be observed that there is start-up lost time values that exceed the 2.00 secs given by HCM, these numbers correspond to non-motorcycle vehicles. With the land vehicle having the highest start-up lost time (4.62 seconds). The foreign study concluded that the higher the PCU value and the vehicle size, the higher the start-up lost time of the vehicle.

For the study in India, the start-up lost time value for an intersection without a timer range from 4.8 seconds to 5.8 seconds, while both junctions resulted in 2.9 seconds of lost time for an intersection with a timer. In comparing the values of the current study, there is a significant difference of 2.98 and 3.98 seconds in intersections without timers and a 1.25 second difference in intersections with timers for the start-up lost time.

The results in Table 1.4 showing a higher value for a non-signalized countdown timer in comparison to a signalized countdown timer are due to factors such as traffic enforcers controlling the traffic, discharging before the green phase of the traffic light, and the category of vehicle. On the other hand, the start-up lost time for both intersections without a timer in India also resulted in a higher value compared to with a timer; the results were due to the presence of a countdown timer decreasing the average control delay of vehicles, and countdown timers reduce the start-up lost time of discharging vehicles.

Both intersections, local and foreign, are heterogeneous in nature and achieved the same trend, with intersections without timers having a higher start-up loss time compared to those with timers. The trend of the results is attributed to factors such as vehicle category, queue length, and the presence of traffic authorities controlling the traffic flow.

For the study in Turkey, the average start-up lost time resulted in 2.32 seconds, which is above the standard 2 seconds per phase given by HCM. In comparison with the start-up lost time of the study, which has a start-up loss of 1.82 seconds and 1.65 seconds, the difference between the two intersections is 0.5 seconds and 0.67 seconds, a lower value difference compared to other foreign studies.

According to Minh and Sano (2003), vehicle acceleration is a part of start-up lost time alongside start reaction time. This indicates that vehicle acceleration can be attributed to the category of vehicle, vehicle size and Passenger Car Unit (PCU) value, and that it has a significant effect on whether the start-up lost time is higher or lower than the standard start-up lost time of 2 seconds/phase given by the Highway Capacity Manual (2010). Also, for all studies, the motorcycle has the lowest vehicle size and Passenger Car Unit value out of all vehicle categories, which resulted in the lowest start-up lost time value, a clear indication that motorcycles leading in front of the queue on the traffic lane leads to overall lower start-up lost time.

5. Conclusion:

The study aimed primarily to evaluate the value of start-up lost time of motorcycles using headway distribution analysis. In addition, the presence of a signal countdown timer was considered because it has been observed based on other studies that the reaction time of drivers leading the queue is compromised when the signalized intersection has or does not have a SCT. Based on the results of the data extracted from the seven-day observation, both intersections, SCT and non-SCT, have outperformed the fix-value of start-up lost time given by the Highway Capacity Manual. The SCT intersection yielded a 1.65 sec/cycle/lane start-up lost time for motorcycles, while the non-SCT intersection yielded a 1.82 sec/cycle/lane start-up lost time for motorcycles. It is clearly evident that SCT intersections have a lower start-up lost time value compared to non-SCT intersections. In theory, it is ideal for an intersection to have a lower start-up lost time because start-up lost time is one of the parameters that describe the performance of a signalized intersection. Specifically, start-up lost time measures how efficient the serviceability of the intersection is.

Based on the collected data, an analysis of linear regression was used to determine the effect of motorcycle volume on the start-up lost time. It shows that there is a significant relationship between the queue length and start-up lost time in intersections with and without a signal countdown timer (SCT). Both analyses of intersections with and without SCT resulted in a positive trend, which means that as the queue length increases, the start-up lost time also increases. It is statistically clear that the higher the number of motorcycles lined up at a stoplight, the higher the value of start-up lost time that can be computed because the reaction time of the drivers at a stoplight is also dependent on the motorcycle in front of them. It can also be concluded that as more motorcycles are stacked up in a queue, the average saturation headway decreases, contributing to the increase in start-up lost time.

The study compared the reaction times of local drivers to those of foreign drivers based on the start-up lost time computed at the intersections. For the local driver attributes, the signalized countdown timer intersection has a 1.66 second start-up lost time, while the non-signalized countdown timer intersection has a 1.82 second start-up lost time, both of which use motorcycles as the vehicle category, and the condition of traffic flow is heterogeneous. For the foreign driver attributes, the motorcycle in Sri Lanka has the lowest start-up lost time value of 1.06 seconds, while the individual vehicles in India have the highest start-up lost time value of 5.8 seconds. Considering the values and traffic conditions of both local and foreign studies, the vehicle category, vehicle size, and nature of the traffic flow are huge factors in the value of start-up lost time, whether it is higher or lower based on the 2.0 sec/phase given by the 2010 HCM Manual. The researchers also concluded that out of all the vehicles, motorcycles have the lowest value of start-up lost time in both the local and foreign studies, indicating that motorcycles are the most efficient vehicles to lead in front of the traffic queue to lessen the time delays for every traffic cycle.

The study calculated the start-up lost time for two intersections, where both results outperformed the suggested value of start-up lost time in the Highway Capacity Manual. Concurrently, the researchers evaluated the results from the intersection in order to identify the effects of signal countdown timers on Filipino motorists. For the intersection that operates with a signal countdown timer (SCT), the result was 1.65 seconds, which is approximately 20% faster than the fix value of start-up lost time. Meanwhile, for the intersection that utilizes a standard stoplight system (non-SCT), the lost time value was 1.82 seconds, which is still around 10% faster. With a 10% difference between the two evaluated values of start-up lost time, the researchers have concluded that having a signal countdown timer is more effective in reducing start-up lost time during a cycle change at an intersection. These results show that the motorist can perceive the sudden change of cycle using a countdown timer during the change from red to green. A much faster response time was more notable in the intersection employing a countdown timer, which resulted in a faster traffic flow after the first few vehicles. The effectiveness of these signal countdown timers may be efficient in creating a stable traffic flow with a minimum delay per cycle change.

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