Assessment of Jalan Sri Pulai/Lebuhraya Skudai-Pontian Signalized Intersection Performance

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Abstract—Traffic signal includes all mechanical or electrical controlled devices used to control, direct, or warn drivers or pedestrians.Main function of an installation of a traffic light at an intersection is to provide right–of–way to vehicles on each approach to increase traffic handling performance. Traffic delays and queues are principal performance measures that enter into the determination of intersection level of service (LOS).Level of service for signalized intersections is defined in terms of control delay, which is a measure of driver discomfort, frustration, fuel consumption, and increased travel time. The purpose of the study was to evaluate signalized performance of Jalan Sri Pulai/Lebuhraya Skudai-Pontian intersection located in skudai town, Johor Bahr, Malaysia to determine whether the vehicles movement at the junction is still in the stable condition or not. Data of traffic volume, saturation flow and traffic movements were collected during a peak hour. Based on analysis and findings done both by manual and TRANSYT 13 software, level of service (LOS) for this signalised intersection is stated as B, implying with good progression of traffic movement, short cycle lengths, or both in which consequently will decrease environmental externalities.

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1. INTRODUCTION

1.1 Background of the Study

Traffic signal includes all mechanical– or electrical–controlled devices used to control, direct, or warn drivers or pedestrians. Main function of an installation of a traffic light at an intersection is to provide right–of–way to vehicles on each approach to increase traffic handling performance.

The theory of traffic signals focuses on the estimation of delays and queue lengths that result from the adoption of a signal control strategy at individual intersections, as well as on a sequence of intersections. Traffic delays and queues are principal performance measures that enter into the determination of intersection level of service (LOS), in the evaluation of the adequacy of lane lengths, and in the estimation steady of fuel consumption and emissions.

Traffic carrying capacity of signalized intersections is of fundamental importance in designing new intersections and modifying existing ones. The saturation flow is used as the basis for the determination of traffic signal timing and evaluation of intersection performance.

1.2 Statement of the Problem

Traffic congestion has a number of negative effects such as; wasting time of motorists and passengers, delays, wasted fuel increasing air pollution and carbon dioxide emissions which may contribute to global warming that all of these things could be occurred when systems are design inappropriate. Signalized intersections permit conflicting movements to proceed efficiently and safely through space that is common to those movements. Evaluation of signalized junction capacity is very important since it is directly related to delay, level of service, accident, operation cost, and environmental issues.

1.3 Purpose of the Study

The purpose of the study was to evaluate Jalan Sri Pulai/Lebuhraya Skudai-Pontian intersection signalized performance to determine whether the vehicles movement at the junction is still in the stable condition or not (the saturation flow rate for arms is below the ideal saturation flow or not).

1.4 Objectives of the study

Objectives of the study were:

- To determine the saturation headway, flow and lost time
- To estimate the delay and queue length at the specified signalized intersection;
- To determine the level of service(LOS); and
- To determine the settings of signalized intersection using TRANSYT software.

1.5 Significance of Study

The study was conducted to investigate the level of service at signalized intersection located at the T junction at Jalan Sri Pulai / Lebuhraya Skudai – Pontian.

The level of sevice (LOS) criteria is stated in terms of the average stopped delay experienced by those who are using or who will use the intersection. Delay is a measure of driver discomfort, frustration, fuel consumption and lost travel time. Simulation can be used to evaluate a proposed strategy before it is implemented determining whether field implementation will have beneficial results

On the other hand this information at hand can be used for other stage such as transport safety and modify routes and junctions because this information can show whether there is necessity for the authority to upgrade the intersection geometry or changing the signal cycle time along Jalan Sri Pulai / Lebuhraya Skudai – Pontian intersection according to current performance or not.

1.6 Study Area

The study was conducted at signalized T junction at Jalan Sri Pulai/Lebuhraya Skudai-Pontian as shown in Figure 1 Some features of the road in study area:

- The major road consisting of three lanes and the minor road consisting of one lane.
- Major road is dual carriageway and minor road is single carriage way.
- There is signalized crossroad about 800 m from study area at Jalan terati/Lebuhraya Skudai-Pontian

Figure 1. Elected junction

2. LITERATURE REVIEW

2.1 Traffic Signals

Traffic signals, also known as traffic lights, stop lights, traffic lamps, stop-and-go lights, robots or semaphore, are signaling devices positioned at road intersections, pedestrian crossing, or other location to control the flow of traffic. The most common traffic lights consist of a set of three lights: red, yellow (officially amber), and green. When illuminated, the red light indicates for vehicles facing the light to stop; the amber indicates caution, either because lights are about to turn green or are about to turn red; and the green light to proceed past the light (with care is always implied).

1) History of Traffic Signals

In 1868 illuminated traffic signal was installed in London near the Houses of Parliament. It was designed to aid the traffic policeman there, particularly during hours of darkness when visibility was poor. The device had semaphore arms to signal drivers and pedestrians during the day and it had red and green lenses illuminated by gas for viewing at night. This was the first recorded use of illuminated red and green colors to control traffic. Unfortunately the device exploded in January of 1869, injuring the policeman that was operating it. This particular idea was not tried again.

2) Application of Traffic Signal

Traffic signals are used to assign vehicular and pedestrian right-of-way. They are used to promote the orderly movement of vehicular and pedestrian traffic and to prevent excessive delay to traffic. Traffic signals should not be installed unless one of the warrants specified by the Manual on Uniform Traffic Control Devices (MUTCD) has been satisfied. The satisfaction of a warrant is not in itself justification for a signal. A traffic engineering study must be conducted to determine whether the traffic signal should be installed. The installation of a traffic signal requires sound engineering judgment, and must balance the following, sometimes conflicting, goals:

- Moving traffic in an orderly fashion;
- Minimizing delay to vehicles and pedestrians;
- Reducing crash-producing conflicts; and
- Maximizing capacity for each intersection approach.

Advantages of traffic signal could be mentioned such as; provide for the orderly movement of traffic, reduce the frequency of certain types of accidents; right-angle collisions, pedestrians, etc .Provide a means of interrupting heavy traffic to allow other traffic, both vehicular and pedestrian, to enter or cross, promote driver confidence by assuming right-of-way. The following results from improper design or unwarranted signal intallations may occur;Excessive delay for motorists and pedestrians, particularly during off–peak periods,Increased accident frequency (i.e., rear–end–collisions) and disregard of signal indications.

2.2 Traffic Signal Control

Traffic signals are one of the most familiar types of intersection control; traffic signals allow certain parts of the intersection to move while forcing other parts to wait by using either a fixed or adaptive schedule. Traffic signals are delivering instructions to drivers through standard red-yellow-green light format. Traffic signal control at a junction reduces the conflict between traffic streams. In general, a traffic signal is installed at an intersection:

- To improve overall safety.
- To decrease average travel time through an intersection and consequently increases capacity.

- To equalize the quality of service for all or most traffic streams.

3) Types of Traffic signal control

Nowadays, there are primarily two types of signal controller units are use which is pre-timed controller and the traffic actuated controller. The actuated controllers can be divide to two types such as semi actuated (coordinated or non coordinated) and fully actuated.

a) Pre-timed Signals (fixed)

At pre-timed traffic signals each signal phase or traffic movement is serviced in a programmed sequence that is repeated throughout the day. Main street traffic receives a fixed amount of green time followed by the amber and red clearance intervals. The same interval timing is then repeated for the minor or side street. The amount of time it takes to service all conflicting traffic movements is referred to as the cycle length. The signal timings and cycle lengths may vary by time of day to reflect changes in traffic volumes and patterns. During peak traffic periods for example, higher cycle lengths may be needed to accommodate heavier volume and during off-peak traffic, lower cycle length may be needed to accommodate lighter volumes of traffic.

b) Actuated Signals

Actuated signal control differs from pre-timed in that it requires "actuation" by a vehicle or pedestrian in order for certain phases or traffic movements to be serviced. Actuation is achieved by vehicle detection devices and pedestrian push buttons. The most common method of detecting vehicles is to install inductive loop wires in the pavement at or near the painted stop bar. Video detection is also used at select locations.

4) Coordinated control

Attempts are often made to place traffic signals on a coordinated system so that drivers encounter long strings of green lights. The distinction between coordinated signals and synchronized signals is very important. Synchronized signals all change at the same time and are only used in special instances or in older systems. Coordinated systems are controlled from a master controller and are set up so lights "cascade" in sequence so platoons of vehicles can proceed through a continuous series of green lights. A graphical representation of phase state on a two-axis plane of distance versus time clearly shows a "green band" that has been established based on signalized intersection spacing and expected vehicle speeds.

In modern coordinated signal systems, it is possible for drivers to travel long distances without encountering a red light. This coordination is done easily only on one-way streets with fairly constant levels of traffic. Two-way streets are often arranged to correspond with rush hours to speed the heavier volume direction.

2.3 Intersection Design and Analysis

In transportation, intersection is also known as road junction where two or more roads are meeting or crossing at grade. The intersection can be classified into many ways such as 3, 4, 5 and 6 way intersections depending on the number of road segments or arms that come together at the intersection. Figure 2 below shows types of intersection applied on the road. T and Y junctions categorize as 3 ways intersection due to three road segments (arms) is connecting each other while for scissor and crossroads is under 4 way intersections.

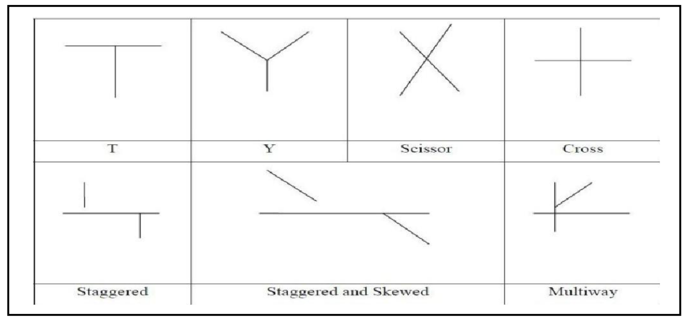

Figure 2. Basic Intersection Forms

Besides, intersections also can be classifying due to traffic control such as uncontrolled, priority controlled, space sharing, time sharing or grade separated. Table I illustrates the types of intersection due to traffic control.

TABLE I. TYPES OF INTERSECTION DUE TO TRAFFIC CONTROL

Types Intersection	Example
Uncontrolled	- without signs or signals
Priority controlled	- with signs such as Stop, Give Way
Space sharing	- roundabout
Time sharing	- traffic signal controlled
Grade separated	- interchange

5) Traffic Volume

Traffic volume defined as the number of vehicles that pass a specified point on a highway in a specified period of time. Such information is extremely crucial in attempting any highway planning as it furnishes a basic scale of comparison and show relative importance of roads and justifies the highway improvement programs. Information on traffic flow useful not only in traffic operations such as in traffic signals, traffic signs and markings but also in traffic design such as in intersection design, clearances and grades. Besides, it is useful in traffic planning for example, planning road developments in terms of expected traffic growth (Gordon Well;1979).

2.4 Saturation Flow Rate

Saturation flow rate is a basic parameter used to derive capacity. It is essentially determined on the basis of the minimum headway that the lane group can sustain across the stop line as the vehicles depart the intersection. Saturation flow rate is computed for each of the lane groups established for the analysis. A saturation flow rate is determined from field measurement by the headway. Headway (H) is defined as the time between two successive vehicles in a traffic lane as they pass a point (stop bar) on the roadway measured from front bumper to front bumper, in seconds to calculate the headway as following: (H). (figure 3)

$$H= T13 – T3 / 13\text{-}3 \quad (1)$$

Where: T13: the time for first 13 cars to clear Stop Bar.
T3: time for first 3 cars to clear Stop Bar

After that, Saturation flow rate(S) is calculated as following:

$$S = 3600/H \quad (2)$$

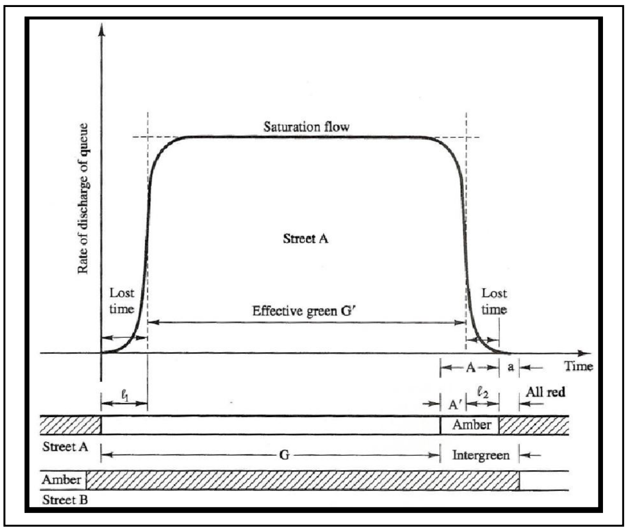

Figure 3. Saturation Flow

6) Lost Time

Due to the traffic signal's function of continuously alternating the right-of-way between conflicting movements, traffic streams are continuously started and stopped. Every time this happens, a portion of the cycle length is not being completely utilized, which translates to lost time (time that is not effectively serving any movement of traffic).Total lost time is a combination of start-up and clearance lost times. Start-up lost time occur because when a signal indication turns from red to green, drivers in the queue do not instantly start moving at the saturation flow rate. Lost time due to starting delays is the term used to describe the time lost due to acceleration and deceleration at the beginning and the end of the green period .It is given by:

$$t_L = t_{sl} + t_{cl} \quad (3)$$

Where: t_L = Total lost time for a movement during a cycle in seconds

t_{sl} = Start-up lost time in seconds

t_{cl} = Clearance lost time in seconds

To calculate the loss time at the field, the time of first three cars (T3) will be recorded, next equation shows it:

$$\text{Loss Time} = T3\text{-}(3*H) \quad (4)$$

7) Effective Green Time

For analysis purposes, the time during a cycle that is effectively (or not effectively) utilized by traffic must be used rather than the time for which green, yellow, and red signal indications are actually displayed, because they are most likely different. The effective green time is the time during which a traffic movement is effectively utilizing the intersection. The effective green time for a given movement or phase is calculated as:

$$g = G+Y+AR- t_L \quad (5)$$

Where:

g = Effective green time for a traffic movement in seconds

G = Displayed green time for a traffic movement in seconds

Y = Displayed yellow time for a traffic movement in seconds

AR = Displayed all-red time in seconds

tL = total lost time for a movement during cycle in seconds

8) Cycle Time

A period for a complete sequence of signal indications (aspects) i e green followed with amber, and followed with red period. The British Transport and Road Research Laboratory (TRRL) have determined that the optimum cycle time Co is given by the Equation below.

$$C_o = (1.5L + 5) / 1 - \Sigma(V/s) \quad (6)$$

Where:

L= Sum of the lost time for all phases, usually taken as the sum of the intergreen periods (sec)

V/s= Ratio of the design flow rate to the saturation flow rate for the critical approach.

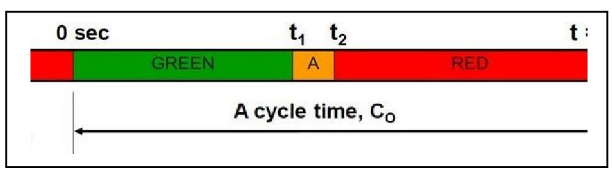

Figure 4. Cycle Time Diagram

The optimum cycle time should accommodate the arrival flows at a better quality of service than the available capacity and minimize the overall intersection delay.

9) Capacity of Signalized Intersections

Capacity of signalized intersections is based on the concept of saturation flow and saturation flow rates. Saturation flow rate is defined as the maximum rate of flow that can pass through a given lane group under prevailing traffic and roadway conditions, assuming that the lane group had 100% of real time available as effective green time and is expressed in units of vehicles per hour of effective green time (vphg). The flow ratio is defined as the ratio of actual or projected flow rate for the lane group, V, to the saturation flow rate, s. The flow ratio is (V/s)i for lane group i. The capacity of the lane group is:

$$c = s \times g/C \qquad (7)$$

Where:

c = Capacity of lane group (veh/h),
s = Saturation flow rate in veh/h,
g/C = Ratio of effective green time to cycle length

10) Delay and Level of Service (LOS)

One way to check an existing or planned signal timing scheme is to calculate the delay experienced by those who are using, or who will use, the intersection. The delay means average stopped delay per vehicle for the lane or lane group of interest. It will be measured in seconds. The delay experienced by the average vehicle can be directly related to a level of service (LOS). The LOS contains the information about the progression of traffic under the delay conditions that they represent. The first step in the LOS analysis is to calculate the delay per vehicle for various portions of the intersection. So, the equation to calculate the average delay is given below.

$$d = \frac{0.38C\left(1-\frac{g}{C}\right)^2}{1-\left(\frac{g}{C}\right)(X)} + 173X^2\left[(X-1)+\sqrt{(x-1)^2 + 16\left(\frac{X}{c}\right)}\right]$$

LOS	Control Delay per Vehicle (s/veh)
A	≤ 10
B	> 10–20
C	> 20–35
D	> 35–55
E	> 55–80
F	> 80

11) Computer Program: TRANSYT 13

TRANSYT13 Software is an acronym for Traffic Network Study Tool, version 13 for determining and studying optimum fixed-time coordinated traffic signal timings in any network of roads for which the average traffic flows are known. TRANSYT 13 also models time-varying traffic conditions, producing signal timings which are optimized for the complete time period and capacity, queue and delay results for each condition and for the overall situation. Transyt makes the following assumptions about the traffic situation:

- Junctions within the network are predominantly signalized.
- All the signals in the network have a common cycle time of half the value; details of all signal stages and their minimum periods are known.
- For each distinct traffic stream flowing betweens junctions, or turning at junctions, the flow rate, averaged over a specified period, is known and assumed to be constant.

3. METHODOLOGY

3.1 Introduction

This section discusses the methodology of the research. The main purpose of the study described in this paper was to evaluate Jalan Sri Pulai / Lebuhraya Skudai – Portian intersection signalized performance to determine whether the vehicles movement at the junction is still in the stable condition or not. The data for the research were collected through observation count and measurement.

In this case whole of study roads are flexible pavement.

3.2 Data Collection

The data was collected on 1th March 2012 starting from 7.45 AM to 9.15 AM. It involved six observers where three of the observer records the timing for actual green for each phase and the other three records the timing taken for T3 and T13. The number of samples for each data is 25 samples. The numbers of stages for the signalized T junction are shown in Figure 5. The data have been collected then categorized into their classification based on type of car; passenger car, motorcycle, bus, lorry and van.

Problems at an intersection usually are related to a safety or operational deficiency. Defining a problem generally requires an assessment of performance from the perspective of all users of the intersection, regardless of mode of travel. At this stage in the project, a primary problem may have already been defined and be the cause for initiating the project. In these instances, the operations and safety conditions should be reviewed to confirm the problem exists and determine whether other problems exist or likely will exist in the future.

3.3 Site Layout Data

Figure 6 show the diagram for the signalized T junction. Lebuhraya Skudai is a major road and Jalan Sri Pulai is a minor road. Major road consists of three lane road and minor road consist of two lane road. Both roads are dual carriageway road.

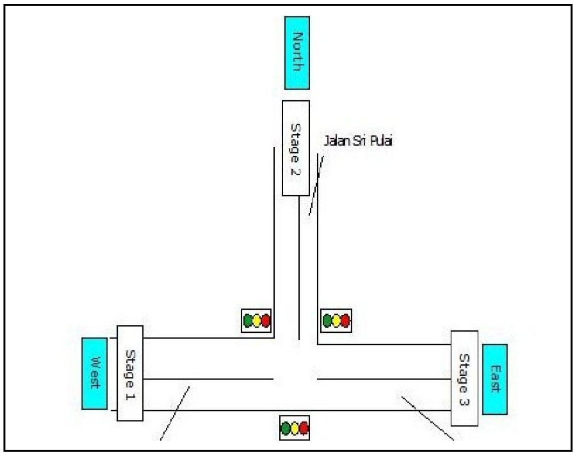

Figure 5. Signalized T-Junction

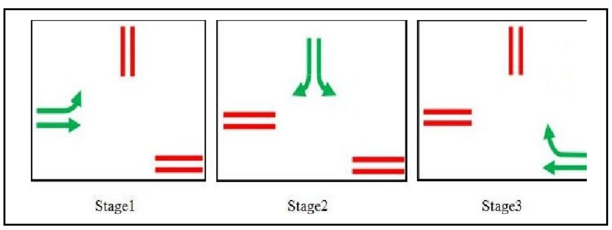

Figure 6. Stages for Signalized T Junction

TABLE III. PCE FACTOR FOR CROSSROAD AND ROUNDABOUT

Vehicles	Passenger Car (PC)	Motorcycle (MC)	Bus (B)	Lorry (L)	Van (V)
PCE for Traffic Signal	1.00	0.33	2.25	2.25	2.00
PCE for Roundabout	1.00	0.75	2.80	2.80	2.00
Urban	1.00	0.75	3	3	2.00
Rural	1.00	1	3	3	2.00

In this study, study area has traffic signal so those figures of PCE related to traffic signal have been chosen.

3.4 Turning Movement Data, Actual Green and Saturation Headway

Similar to vehicle volume data, turning movement data also collected using manual counting. The turning movement data at the junction was counting separately based on their direction.

TABLE IV. TURNING MOVEMENT AT T-JUNCTION

FROM	TO		
	Arm 1	Arm 2	Arm 3
Arm 1	x	√	√
Arm 2	√	x	√
Arm 3	√	√	x

Table V shows the vehicle volume data for every arm at the signalized T junction in pcu/hr.

TABLE V. TRAFFIC VOLUME DATA

Phase	Straight	Turn Right	Turn Left
1	2430	-	140
2	-	141	649
3	973	260	-

Table VI shows the results for actual green for each phase.

TABLE VI. RESULTS FOR ACTUAL GREEN FOR EACH PHASE

Phase 1	Phase 2	Phase 3
50.09	3.15	18.65
49.51	6.17	19.26
50.22	11.51	14.87
50.18	10.46	9.23
50.07	1.90	16.84
50.19	20.08	12.19
50.41	6.92	25.05
50.19	20.11	19.16
49.99	12.31	12.01
50.66	5.76	23.27
49.94	12.85	20.73
50.29	9.15	10.12
49.93	2.33	11.80
50.34	19.34	14.22
49.97	17.38	14.97
50.41	17.59	11.76
50.32	15.05	17.33
50.19	10.25	15.49
50.22	19.94	24.56
49.94	18.84	14.06
50.00	10.32	7.71
49.92	17.38	18.96
49.98	10.47	24.88
50.09	11.23	17.76
49.93	11.51	7.34

For saturation data (T3, T13 vehicle demand flow) were recorded by other observer respectively

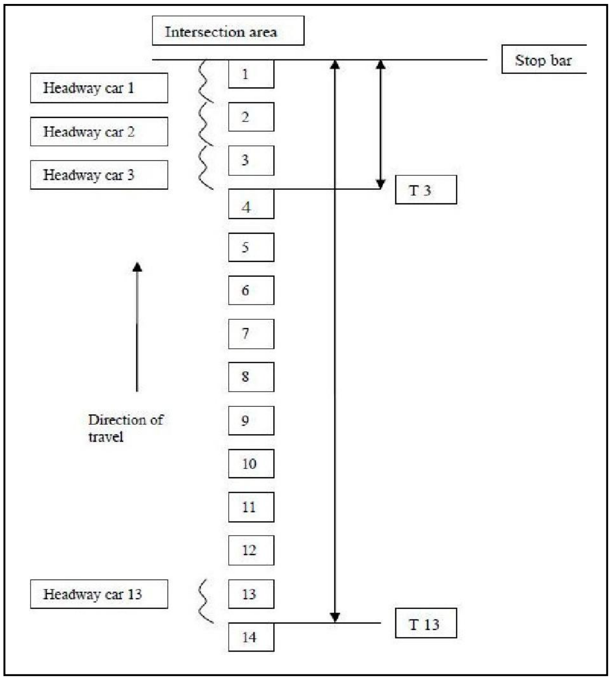

Figure 7. Measurement of Saturation Flow Rate

Table VII show the result for T3 and T13 time data.

TABLE VII. RESULTS FOR T3 AND T13

T3	T13
7.20	25.47
6.99	23.32
7.10	25.72
6.79	24.53
8.60	26.98
7.78	26.79
7.53	27.11
6.99	25.36
7.75	23.77
8.30	24.24
7.65	23.28
7.38	24.71
10.58	28.8
8.77	27.82
7.40	27.61
8.30	25.42
7.60	26.79
8.25	25.13
7.10	23.63
8.78	27.72
7.10	29.77
7.60	29.16
8.30	28.65
8.57	24.75
6.99	23.65

4. ANALYSIS AND FINDINGS

4.1 Data Analysis for Headway, Saturation and Loss Time

Saturation flow rate is the number of vehicles served by a lane for one hour of green time. In order to determine saturation flow rate, we must know the headway and saturation headway. Headway is the time interval between the passages of successive vehicles moving in the same lane measured from head to head as they pass a point on the road.

Saturation headway is the headway of the vehicles in a "stable moving platoon" passing through a green light. A stable moving platoon is a group of vehicles that are traveling, but not really moving in relation to each other (i.e. all going the same speed). The headway of the first four vehicles leaving an intersection after a red light will have a higher value so the saturation headway will not be realized until the 4th or 5th queued vehicle leaves the intersection.

If every vehicle requires a time equal to the saturation headway (h), in seconds, to be serviced at a signalized intersection, then the maximum number of vehicles that can be serviced in an hour of green is given by the equation s = 3600/h , where s is saturation flow rate, in veh/hr.

Table VIII illustrates saturation flow rates and lost time which have been calculated from 25 samples of T3 and T13 for that critical approach. For instance, saturation headway, saturation flow and lost time for first sample is 1.827 sec/veh and 1970.443 veh/hr and 1.719 sec respectively.

1. Sample calculation for saturation headway

H = T13 – T3 / 13 – 3

H = 1.827 sec/veh

2. Saturation flow results based on headway

S = 3600 / H

S = 1970.433 veh/hr

3. Loss time

I = T3 – (3 x H)

I = 1.719 sec

For obtaining the average saturation flow, headway class of 25 samples has been tabulated and based on it standard deviation (SD) and standard error (SE) has been calculated. After calculation, saturation flow rate has been equaled to 1978.022 veh/hr. Table IX illustrates an example of calculation process.

12) Example Calculation of Saturation Headway Distribution

1. Mean = fx / f =1.82 sec/veh

2. Standard deviation, SD

SD = √ [(∑Fixi2 / ∑Fi) - (∑Fixi / ∑Fi)2] = 0.19

3. Standard error of mean, SE

SE = SD / √n = 0.03

SD + SE = 021

4. Mean = 1.82 ± 0.21 sec/veh

Therefore, the saturation headway, H is 1.82 ± 0.21 sec/veh.

5. Saturation flow rate, S
S = 1978 veh/hr

Also for obtaining average lost time, same process has been done and 2.375 sec calculated for the average lost time.

TABLE VIII. ANALYSIS FOR HEADWAY, SATURATION AND LOSS TIME

T3	T13	H (sec)	S (veh/hr)	LOST TIME (sec)
7.20	25.47	1.827	1970.443	1.719
6.99	23.32	1.633	2204.532	2.091
7.10	25.72	1.862	1933.405	1.514
6.79	24.53	1.774	2029.312	1.468
8.60	26.98	1.838	1958.651	3.086
7.78	26.79	1.901	1893.740	2.077
7.53	27.11	1.958	1838.611	1.656
6.99	25.35	1.836	1960.784	1.482
7.75	23.77	1.602	2247.191	2.944
8.30	24.24	1.594	2258.469	3.518
7.65	23.28	1.563	2303.263	2.961
7.38	24.71	1.733	2077.323	2.181
10.58	28.8	1.822	1975.851	5.114
8.77	27.82	1.905	1889.764	3.055
7.40	27.61	2.021	1781.296	1.337
8.30	25.42	1.712	2102.804	3.164
7.60	26.79	1.919	1875.977	1.843
8.25	25.13	1.688	2132.701	3.186
7.10	23.63	1.653	2177.858	2.141
8.78	27.72	1.894	1900.739	3.098

TABLE IX. SATURATION HEADWAY DISTRIBUTION DATA ANALYSIS

Headway Class (sec/veh)	Average Headway Class (x)	Frequency (f)	fx	x²	fx²
1.550 - 1.650	1.600	6	9.600	2.560	15.360
1.660 - 1.750	1.705	4	6.820	2.907	11.628
1.760 - 1.850	1.805	5	9.025	3.258	16.290
1.860 - 1.950	1.905	5	9.525	3.629	18.145
1.960 - 2.050	2.005	3	6.015	4.020	12.060
2.060 - 2.150	2.105	0	0.000	4.431	0.000
2.160 - 2.250	2.205	1	2.205	4.862	4.862
2.260 - 2.350	2.305	1	2.305	5.313	5.313
Total		**25**	**45.495**	**30.980**	**83.658**

4.2 Actual Green for Timing Diagram

13) Actual Green (Phase 1)

a) Example Calculation for Actual Green phase 1

1. Mean = fx / f = 50.13 sec
2. Standard deviation, SD
SD = √ [(∑Fixi2 / ∑Fi) - (∑Fixi / ∑Fi)2] = 0.20
3. Standard error of mean, SE
SE = SD / √n =0.01
SD + SE= 0.20 + 0.01 = 0.21 **0.21**
4. Mean = 50.13 ± 0.21 sec/veh

Therefore, the actual green time for phase 1 is 50.13 ± (0.21) sec. Also, actual green time for phase 2 and phase 3 obtained 12.25 ± (5.98) sec and 16.15 ± (5.49) sec respectively.

4.3 Timing Diagram

The timing diagram using 4 second intergreen is shown in Figure 10.

Actual green, Phase 1 = 50 sec
Actual green, Phase 2 = 12 sec
Actual green, Phase 3 = 16 sec
Cycle time, C = 50 + 12 + 16 + 15
= 93 sec < 120 sec

TABLE X. ACTUAL GREEN TIME FOR PHASE 1

Headway Class (sec/veh)	Average Headway Class (x)	Frequency (f)	fx	x²	fx²
49.510 - 49.700	49.605	1	49.605	2460.656	2460.656
49.710- 49.900	49.805	0	0.000	2480.538	0.000
49.910 - 50.100	50.005	12	600.060	2500.500	30006.000
50.110 - 50.300	50.205	7	351.435	2520.542	17643.794
50.310 - 50.500	50.405	4	201.620	2540.664	10162.656
50.510 - 50.700	50.605	1	50.605	2560.866	2560.866
Total		**25**	**1253.325**	**15063.766**	**62833.973**

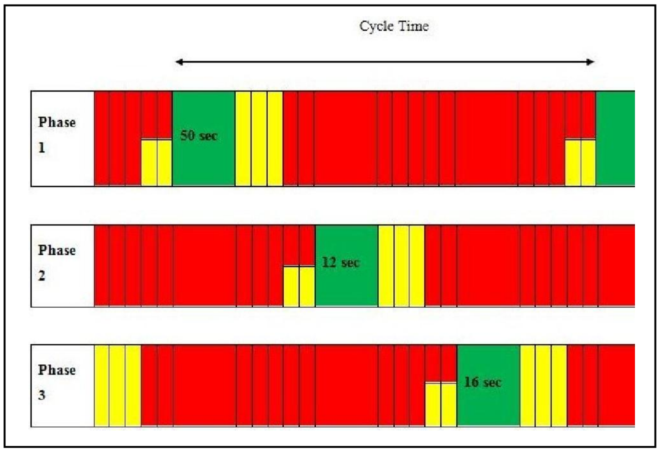

Figure 8. Timing Diagram

4.4 Delay Analysis

The first step in the LOS analysis is to calculate the average delay per vehicle for various portions of the intersection. Average stopped delay for critical approach (arm 1) has been calculated and equaled to 14 sec/vehicle. This is achieved using equation (7).

$$D = 13.89 \approx 14 \text{ seconds}$$

5. Discussion

Based on the analysis that has been done in this report, the saturation flow was calculated 1978 veh/hr. So the saturation flow rate is higher than ideal saturation flow rate (1900 veh/hr) which software assumes for calculation, and this is because of pattern of driving in Malaysia which drivers normally drive fast owning to lower standard headway and higher saturation flow rate. Also it has variable green time for different condition of demand, but in the arm one, we have a long queue of vehicle and this kind of signal could not response to the existent demand. It is better to put separated green time more than 50sec for arm one or design again this signalized junction based on new demand.

The signal timing analysis shows that stage 1=50sec, stage 2=12sec and stage 3=16sec. The cycle time for this signalized is C=93sec. The actual green for stage 1 and 3 are bigger comparing to the stage 2. This is due to stage 1 and stage 3 is major road. So more vehicles used this road for their activities such as go to working, going and shopping.

While the lost time at this signalized junction is 2.37sec. The lost time remains fixed, regardless of cycle length. For shorter cycle lengths, the lost time will comprise a larger percentage of cycle lengths, and will result in a larger total of lost time over the course of a day than for longer cycle lengths. Longer cycle lengths usually have more phases than shorter cycle lengths, which may result in similar proportions of lost time.

The delay at signalized intersection is around 14sec. From the delay, the levels of service (LOS) have been identified and for this signalized intersection is B based on: Level of Service B - Operations with delays between 5.1 and 15.0 seconds per vehicle. This LOS implies good progression, with some vehicles arriving the red phase. It means this LOS implies good progression, with some vehicles arriving the red phase. Some adjustment can be done to the signal timing so that it can solve the queue problem during the peak hour.

6. CONCLUSION

Based on the analysis and findings, it could be concluded that:

- The actual green for each phase and the cycle time are

    a. Actual green; Phase 1 = 50sec,
       Phase 2 = 12sec
       Phase 3 = 16sec
    b. Cycle time = 93 sec < 120 sec

From this studies have been done, all parameter below can be calculated:

- The estimated saturation headway, saturation flow rate, loss time and delay are 1.82 sec/veh, 1972 veh/hr, 2.37 sec and 14 sec respectively.
-
- From the delay, the level of service (LOS) has been identified and for this signalized intersection is B. It means this LOS implies good progression, with some vehicles arriving the red phase.
-

Results from TRANSYT show:

Max queue = 71 pcu

- Also the delay is:
- d = 8.21sec

In comparison with manual delay (14 sec), the difference is moderate and usual.Because in manual result for calculating delay; we average the actual green and also delay for 25 samples.

In this signalized junction, it is better that arm1 (going straight) has more than 50sec actual green. In software result, it can be seen 58 sec. In other hand, software chose the best and optimum actual green time for this intersection regarding the demands and other parameters which should be related. Also software chose best actual green for other links or arms which have difference from manual calculating. Actually in manual calculating, we did not design actual green for this intersection. We just average the actual green which got from 25 samples in study area. In practice this intersection has floating actual green time. It depends on the volume of demands in special time.

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