ASSESSMENT OF DELAYS AT ROUNDABOUT

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Graphical abstract
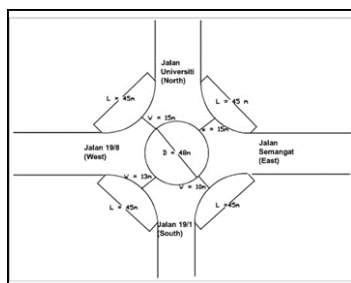
Abstract

Traffic delay is the additional travel time that experienced by a road user beyond what would reasonably be desired for a given trip. It is also a standard parameter that used to measure the performance of an intersection. This study concerns with the delay experienced by the drivers at a roundabout. The main objective is to evaluate the applicability of the existing theoretical delay models to estimate delays. Data pertaining to the analysis of delay was collected at a conventional roundabout in a sub-urban area. The t-test were conducted. The result shows that the observed delay at a conventional roundabout can be estimated using Akcelik & Troutbecks theory as there is no significant different between both observed and theoretical delay at 95% confident level. Whereas the observed delay has significant different if compared with theoretical delay estimated using Kimber & Hollis theory and CETUR formula. On the other hand, all of the theoretical and observed delay at the roundabout falls in the LOS A. However, more data are required in order to validate the result of this study.

Keywords: Traffic delay, roundabout, capacity

1.0 INTRODUCTION

Roundabout is a circular intersection with yield control of all entering traffic, clockwise or counter clockwise circulation, and appropriate geometric curvature. The appropriate geometric elements of the roundabout guide the drivers in approaching, entering, and travelling through a roundabout. Sometimes, these junctions are called as modern roundabout in order to differentiate from the older circular junction types which had different design characteristic and rules of operation.

Roundabout is classified into several types such as mini roundabout, small roundabout and conventional roundabout. Each types of roundabout have different capacity and criteria. The capacity of roundabout may varies based on the number of entry and circulating lanes, geometry design which includes the entry angle and lane width, and also from the volumes flow from various approaches.

There are three measures that used to estimate the performance of roundabout which are degree of saturation, delay and queue length. Each measure provides a unique perspective on the quality of service of a roundabout under a given set of traffic and geometric conditions. Delay is a standard parameter used to measure the performance of an intersection or approach. The Transportation Research Board, identifies that delay as the primary measure of effectiveness for both signalised and unsignalised intersections with level of service determined form the delay estimate [1].

Roundabout can operate much more efficiently than a signalised junction because the drivers are able to proceed without any delay such as waiting for the traffic signal to change. It does not require a complete stop by all entering vehicles which can reduces individual delays and also vehicle queues delay. However, the delays still occur in roundabouts during the peak hours due to excessive volumes flow at the

junction which affect the performance of roundabouts. In Malaysia, there are some cities that had change the traffic light system to roundabout system to prevent from traffic congestion but the result is delays still occur at that intersection. This shows that the delay occur in that junction has reduce the performance of roundabout. Currently, the delay estimate in Highway Capacity Manual, only includes control delay which the delay is attributable to the control device [2].

Therefore, this study focuses on the delay assessment at roundabout using several established theory. Besides to analyse the applicability of the Highway Capacity Manual in estimating the delays and the levels of service in Malaysian roundabout, the actual delays and theoretical delays will also be evaluated to identify the best theory suit Malaysian.

2.0 LITERATURE REVIEW

2.1 Roundabout Characteristics

In Malaysia, the numbers of vehicle are increasing tremendously especially at the major city such as Kuala Lumpur, Pulau Pinang, and Johor Bahru. In the big city, most of the family at least owned a vehicle and this has resulted to traffic congestion in the city which contributed in delay. Delay usually happened at intersection more compared with highway.

In general, delay is the additional travel time that experienced by a driver, passenger, or pedestrian beyond what would reasonably be desired for a given trip [3]. It is also a standard parameter that used to measure the performance of an intersection.

Roundabout is used to reduce the conflicting movements with the application of 'give way to traffic coming from the left' concept. Figure 1 shows the conflicting point between intersection and roundabout. The roundabouts have less conflict points compared to the four way intersection. This shows that roundabout should be more effective than signalised and unsignalised junction.
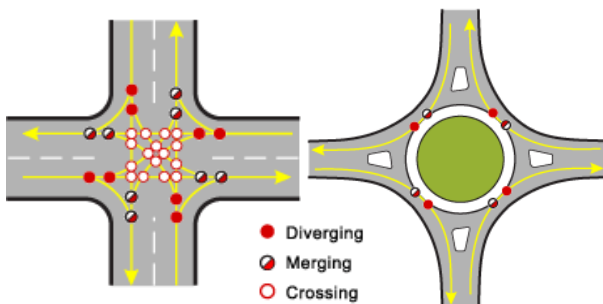

Figure 1 Comparison of conflict points between 4-way intersections and roundabout [3]

According to Wells, a roundabout is effectively elaborate channelizing island. Wells also stated that in

America, roundabout is designed for high speed operation and it is large, while in Britain, roundabout are expressly designed to slower down the traffic to less than 50km/hr [4].

According to Miller et al., there are wide range of intersection advantage that a roundabout can be used which are intersections on local and collector roads in urban areas, intersections on arterial roads in urban areas, freeway terminals, and intersections on high speed rural roads [5]. However, roundabouts can be considered to construct based on certain situation such as intersections where the traffic volumes on the intersecting roads cause greater delays than roundabout, intersection where it has high proportions of right turning traffic, at multi-leg intersections, at cross intersection that accident always happened during crossing, and so on. Besides, roundabouts cannot be constructed when the space is insufficient to provide a satisfactory geometric design, unbalanced traffic flows, a very major road intersects a very minor road which will cause delay and deflection to all traffic, and so forth.

Before designing the roundabout, the estimated capacity must be obtained for an entry to compute the measure of performances. This is because the capacity will influence the changes in the characteristics of the traffic. Capacity of roundabout can be computed according to the types of roundabout such as single lane roundabout and multilane roundabout.

Capacity for roundabout can be computed by applying Equations (1) – (7) [6].

$$Q_E = K(F - f_C Q_C), \qquad f_C Q_C \leq F \qquad (1)$$
$$\quad\; = 0, \qquad\qquad\qquad f_C Q_C > F$$
$$K = 1-0.00347(\varphi-30)-0.978((1/r)-0.05) \qquad (2)$$
$$F = 303x_2 \qquad (3)$$
$$f_C = 0.210\, t_D\, (1+0.2x_2) \qquad (4)$$
$$t_D = 1+\frac{(0.5)}{1+\exp(\frac{(D-60)}{10})} \qquad (5)$$
$$x_2 = v+\frac{(e-v)}{(1+2S)} \qquad (6)$$
$$S = \frac{1.6(e-v)}{l\grave{}} \qquad (7)$$

where,

Q_E = Entry flow, pcu/hr
$l\grave{}$ = Effective flare length, m
Q_c = Circulating flow across the entry, pcu/hr
S   = Sharpness of flare, m/m
e = Entry width, m
D   = Inscribed circle diameter, m
v = Approach half width, m
φ = Entry angle, °
r   = Entry radius, m

2.2 Level of Service

According to U.S. Department of Transportation, level of service (LOS) is a qualitative measure which describing operational conditions within a traffic stream, generally described in terms of service measures such as speed and travel time, freedom to maneuver, traffic interruptions, comfort, and convenience [3]. The

Transportation Research Board stated six levels of service and defines six corresponding volumes for a number of highways [2]. These volumes are referred to as service volumes or the maximum number of vehicles that pass over a lane during a specified period while operating conditions are maintained to the selected or specified level of service. The level of service (LOS) for roundabout is determined by the computed or measured average control delay and is defined for each lane and not as a whole for the intersection [7]. The LOS criteria are as in Table 1.

Table 1 Level of service criteria for roundabouts

Level of Service	Average Control Delay, d (s/veh)
A	$d \leq 10$
B	$10 < d \leq 20$
C	$20 < d \leq 35$
D	$35 < d \leq 50$
E	$50 < d \leq 70$
F	$70 < d$

2.3 Previous Studies on Delays at Roundabout

There are a lot of studies on delays at roundabout that has done around the world such as Kimber & Hollis theory in year 1979, Akcelik & Troutbeck theory in year 1991, while Centre d'Etudes des Transports Urbains (CETUR) formula in year 1988. According to Salter, in many traffic situations, the demand is close to capacity or even exceeds it for short periods of time [8]. A combination of both steady state and deterministic theory has been proposed by Kimber & Hollis [8]. The delay equation as Equations (8) – (10), is developed using coordinate transformation technique.

$$\text{Delay per unit time} = \frac{1}{2}\left[(F^2 + G)^{\frac{1}{2}} - F\right] \tag{8}$$

$$F = \frac{(1-\rho)(\mu t)^2 - 2(L_o-1)\mu t - 4(1-C)(L_o + \rho\mu t)}{2\,(\mu t + 2(1-C))} \tag{9}$$

$$G = \frac{2\,(2L_o + \rho\mu t)[\mu t - (1-C)(2L_o + \rho\mu t)]}{\mu t + 2(1-C)} \tag{10}$$

where,
ρ = q/μ
q = Demand
μ = Capacity
t = Analysis time period
L_o = Length of queue at start of time interval
C = 1 for random arrivals and service
= 0 for regular arrivals and service

Control delay is the time that a driver spends in queuing and waiting for an acceptable gap in the circulating flow while at the front of the queue [9]. Akcelik & Troutbeck has brought out a formula to compute this delay which is given as equations (11) – (12) [9]:

$$d = \frac{3600}{c_{m,x}} + 900T\left[\frac{v_x}{c_{m,x}} - 1 + \sqrt{\left(\frac{v_x}{c_{m,x}} - 1\right)^2 + \frac{\left(\frac{3600}{c_{m,x}}\right)\left(\frac{v_x}{c_{m,x}}\right)}{450T}}\right] \tag{11}$$

$$c_{m,x} = \frac{V_{cx}\left(e^{-\frac{V_{cx}t_c}{3600}}\right)}{1 - e^{-V_{cx}t_f(3600)}} \tag{12}$$

where,
d = average control delay, sec/veh
V_{cx} = conflicting flow rate for movement x, veh/h
t_c = critical gap
t_f = follow-up time
v_x = flow rate for movement x, veh/h
$c_{m,x}$ = capacity of movement x, veh/h
T = analysis time period, h, 0.25 for a 15min period

CETUR (Centre d'Etudes des Transports Urbains) formula is the original French formula for roundabout capacity. According to Transportation Research Board, the CETUR formula expresses the entry capacity as a function of the impeding flow [10]. The impeding flow is a summation of circulating flow plus a proportion of the existing flow at the same branch. The average delay, t in this model is as Equations (13) – (15):

$$t = (2000 + 2Q_g)/(C - Q_e) \text{ in second} \tag{13}$$
$$Q_g = (Q_c + \frac{2}{3}Q_{s'})\,(1 - 0.085(l_a - 8)) \tag{14}$$
$$Q_{s'} = Q_s\,(15 - l_i)/15 \tag{15}$$

where,
t = Average delay
l_a = Width of circulating flow, m
l_i = Width of splitter island
C = Entry capacity, C = 1500-(5/6 Q_g) for Q_g <1800 and 0 for Q_g >1800
Q_c = Circulating flow
Q_s = Exiting flow
Q_g = Impeding flow
Q_e = Entering flow

3.0 METHODOLOGY

3.1 Site Location

The site location is at Bulatan Rothmans, Petaling Jaya, Selangor at a conventional roundabout in a sub-urban area. Bulatan Rothmans is the meet point of four roads which are Jalan 19/8, Jalan Universiti, Jalan Semangat, and Jalan 19/1. Jalan 19/8, Jalan Universiti and Jalan Semangat are the major roads link to this roundabout where each junction has three lanes while Jalan 19/1 is the minor road with only two lanes. Figure 2 showed map for the observed roundabout.
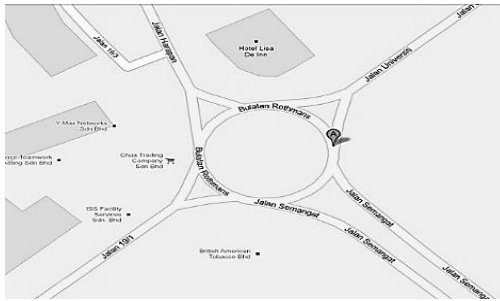
Figure 2 Bulatan Rothmans

3.2 Geometry of the Roundabout

Geometry is one of the factors that may influence the delay in traffic flow. In this study, the configurations of the roundabout were measured. The parameters measured include entry width at each junction, weaving width, and weaving length. The diameter of centre circle at Bulatan Rothmans is 48 m and the diameter of inscribed circle is 75m. Based on the diameter of centre circle and inscribed circle, the studied roundabout is categorised as conventional roundabout. Figure 3 shows the diagram of roundabout.
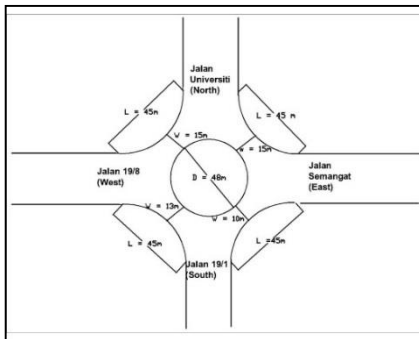

Figure 3 Roundabout diagram

Table 2 Geometry parameter for bulatan Rothmans

Parameter	West	North	East	South
Entry Width (m)	18 (3 lanes)	18 (3 lanes)	18 (3 lanes)	15 (2 lanes)
Weaving Width, W (m)	15	15	10	13
Weaving Length, L (m)	45	45	45	45
Entry Angle, φ °	35	22	20	24
Effective flare length, l'(m)	18	23	18	20
Entry radius, r (m)	34	36	40	34

3.3 Size of Samples

The data were collected for four days in a week. Two days in weekday and two days in weekend. The periods of time for data collection are as below:
i.   Morning peak between 7.30am till 9.00am (1 hour)
ii. Evening peak between 4.30pm till 7.00pm (1 hour)

3.4 Data Collection

This study focuses on the control delay at roundabout. The data were collected using video recording technique in order to make the procedures of data collection easier, efficient and accurate. The time for a vehicle to enter the roundabout was recorded. There are some criteria need to be consider during recording. The criteria are as below:
i.   Video recorder must be placed in a place that can record all the movement at the roundabout.
ii. Site data collection conducted when weather is good which is no raining.
iii. No unusual incidents i.e. accident during the collection of data.
iv. The video recorder must be placed in a stable condition to avoid any unwanted movement during collection of data. Tripod used to provide stability and clearance of the video recorder.

3.5 Data Analysis

The data were analysed for every 15 minutes according to the parameter that used in the theoretical equation and also in the level of service. The data or parameters that are required in analyses consist are listed as below:
i.   Traffic demand;
ii.   Circulating flow;
iii. Headway – the time interval which separates between the fronts two consecutive vehicles when entering the roundabout circle;
iv.   Vehicle that stopped before entering the roundabout;
v.   Vehicle type;
vi.   Geometry of the roundabout – single lane or double lane; and
vii. Actual delay at the survey location site – also known as observed delay where the time started to count when the vehicle start queuing waiting to enter the roundabout until the vehicle reach the entry line of travel arm of roundabout.

3.6 Comparison of Observed Delay and Theoretical Delay

The observed delay for each vehicle were extract from the video recording, while the theoretical delay were estimated based on the established delay models which are Kimber & Hollis theory (Equation (8) to (10)), Akcelik & Troutbeck theory (Equation (11) to (12)), and CETUR formula (Equation (13) to (15)). Then, both observed and theoretical delay were compared to evaluate the accuracy of the theoretical estimated delay.

In this study, t-test is used to evaluate the equality of the observed delay and theoretical delay value. The t-test were conducted at 95% confident level (α = 0.05) with number of sample n, 32. Two-tailed t-test were conducted with the null hypothesis; H_o: X = μ_o and were rejected if the value of t-test is less than t-critical in the negative region or more than t-critical in the positive region. Equation (16) shows the calculation of t-test.

$$\frac{X - \mu_o}{\frac{S}{\sqrt{n}}} \leq t_{(\alpha/2,\, n-1)} \qquad (16)$$

where,

    X = observed delay mean
    μ_o = theoretical delay mean
    S = standard deviation
    n = sample size

4.0 RESULT AND DISCUSSION

4.1 Traffic Data Analysis

The data of traffic flow were analysed according to the types of vehicle and also the direction of the vehicles of the observed roundabout. The composition of vehicles were classified into light vehicle i.e. car, taxi and small lorry, heavy vehicle i.e. large lorry and buses, and motorcycle. These data are crucial as it will affect the result of data analysis. Figure 4 shows the percentage of traffic flow composition at the roundabout during the data collection. The main composition at this roundabout is light vehicles with 80.29%, followed by motorcycles with 15.19% and the lowest is heavy vehicles at only 4.52%.
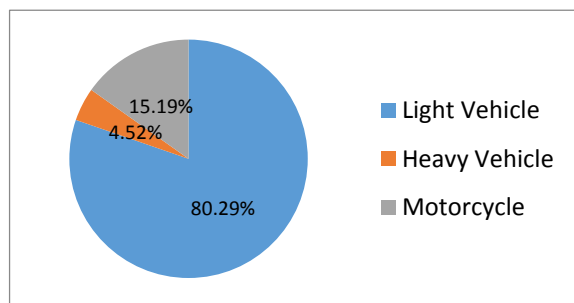

Figure 4 Traffic flow composition at the roundabout

Table 3 Traffic flow for day 1 in weekday morning peak

Direction	Traffic Flow (veh/15min)				Total Traffic Flow
	0-15 min	15–30 min	30-45 min	45-60 min	
W – N	127	143	149	127	546
W – E	312	425	432	472	1641
W – S	21	21	20	20	82
W – W	29	22	31	28	110
N – N	51	53	47	49	200
N – E	57	94	83	86	320
N – S	44	20	24	29	117
N – W	109	104	95	97	405
E – N	96	92	90	89	367
E – E	24	18	16	23	81
E – S	74	93	80	84	331
E– W	78	65	75	68	286
S – N	74	81	79	79	313
S – E	29	48	52	37	166
S – S	0	1	0	0	1
S – W	21	36	27	31	115

*W=West E=East S=South N=North

The example of traffic demand data of the roundabout for the day 1 in weekday morning session were shown in Table 3. The highest traffic demand at the roundabout were 472 veh/15min in direction of West to East, while the lowest traffic demand was 0 veh/15min in the direction of South to South. In addition, this table also shows that the traffic flow of the major road had the highest traffic demand compared to other movement. This is because the major road was connected to the residential and the township area.

4.2 Estimation of Entry Capacity

The entry capacity of the roundabout was estimated from the traffic demand on Equation (1). The example of estimation of entry capacity of the roundabout for weekday at west arm was shown in Table 4. The following geometric parameters were used; D = 75m, r = 34m, e = 18m, v = 10m, l'= 18m, and φ = 35°. The circulating flow has been converted to pcu/hr. The value for K, F, f_c, t_D, x_2, and S can be obtained by using the Equations (2) – (7) respectively.
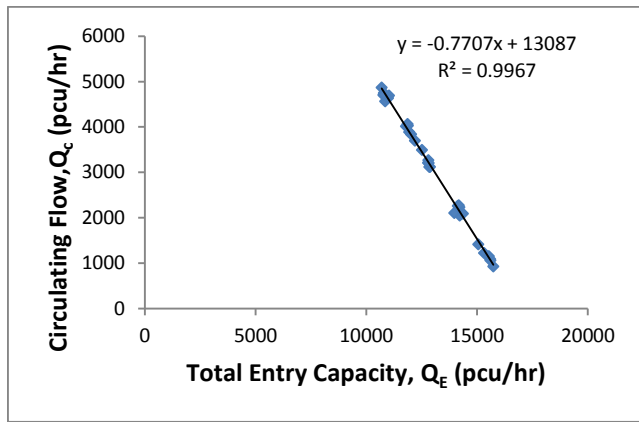
Figure 5 Effect of circulating flow on total entry capacity

Figure 5 shows the effect of circulating flow on entry capacity of the roundabout. It shows that circulating flow has a strong relationship with the total entry capacity. When the circulating flow is high, the total entry capacity is less because the vehicles need to wait for an acceptance gap to enter the roundabout. On the other hand, the total entry capacity increased when the circulating flow is low.

Table 4 Entry Capacity in pcu/hr for Day 1 in Weekday at West Arm

Circulating Flow, Q_c (pcu/hr)	Sharpness of flare, S (m/m) Eq.(7)	x_2 Eq. (6)	t_D Eq. (5)	f_c Eq. (4)	F Eq. (3)	K Eq. (2)	Entry Capacity, Q_E (pcu/hr) Eq. (1)
912	0.711	13.303	1.091	0.839	4030.734	1.003	3274.815
1172	0.711	13.303	1.091	0.839	4030.734	1.003	3056.111
1128	0.711	13.303	1.091	0.839	4030.734	1.003	3093.122
1104	0.711	13.303	1.091	0.839	4030.734	1.003	3113.311
1308	0.711	13.303	1.091	0.839	4030.734	1.003	2941.712
1304	0.711	13.303	1.091	0.839	4030.734	1.003	2945.077
1244	0.711	13.303	1.091	0.839	4030.734	1.003	2995.547
1372	0.711	13.303	1.091	0.839	4030.734	1.003	2887.877

4.3 Observed Delay

Table 5 shows an example of the observed delay at the roundabout while Figure 6 to 8 show the variation of average delay for different volumes of traffic demand.

Table 5 Observed delay

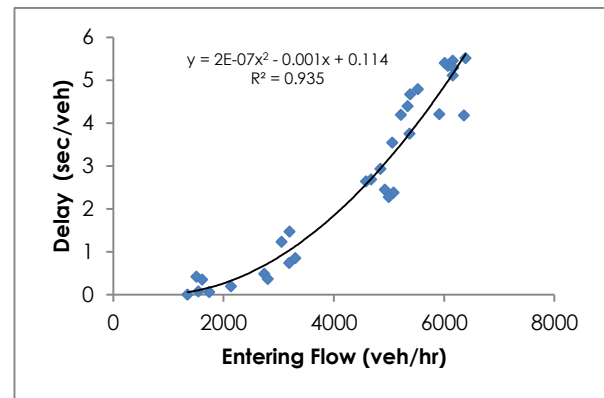| Day	Time (min)	q (veh/ 15 min)	Total Flow, q_T (veh/ hr)	Average Delay (sec/veh)
Day 1 Weekday a.m.	0-15	1146	4584	2.64
	15-30	1344	5376	3.75
	30-45	1305	5220	4.19
	45-60	1335	5340	4.39
Day 1 Weekday p.m.	0-15	1590	6360	4.18
	15-30	1540	6160	5.11
	30-45	1518	6072	5.33
	45-60	1540	6160	5.45

Figure 6 Variation of average delay for different entering flow

Figure 6 shows the variation of average observed delay at the roundabout. It shows that the delay increased when the entering flow also increased. The highest average observed delay at the roundabout is 5.51 sec/veh (standard deviation: 3.04 sec/veh, minimum delay: 1.31 sec/veh, and maximum delay: 10.98 sec/veh) with the entering flow of 6392 veh/hr. This is because increased of traffic demand would directly increase the flow of circulating. Hence, the delay will also increase due to the queuing and waiting for an acceptable gap in the circulating flow.
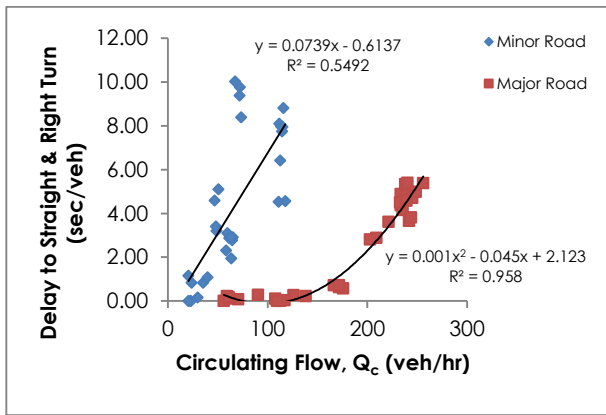
Figure 7 Variation of comparison of delay to straight and right turn for major road and minor road corresponding with circulating flow

Figure 7 shows that when the circulating flow at the roundabout increase, the delay will also increase. It also shows that the delay for minor road is higher than the major road. This is because, although the traffic flow in major road is higher but once there is an acceptance gap to enter the roundabout, most of the queuing vehicles will enter together at that moment. When the vehicles from major road enter the roundabout together, the headway time is lesser, therefore the acceptance gap for minor road's vehicles to enter roundabout will be lesser too. Hence, the delay at minor road is dependent on circulating flow at the roundabout and also the traffic demand at major road.

Figure 8 shows the variation of comparison delay between straight and right turn, and left turning corresponding with the circulating flow. The delay for left turning at the roundabout is lesser than the delay for straight and right turn in the roundabout. This shows that the circulating flow has less impact to the left turning flow. This is because the road is designed with diverging tapers whereby for those vehicles that are turning left do not need to wait for acceptance gap in the circulating flow. Hence, the delay of left turning is less affected by the circulating flow in the roundabout.
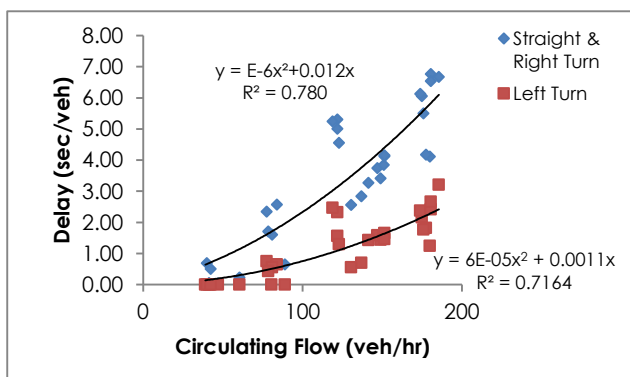

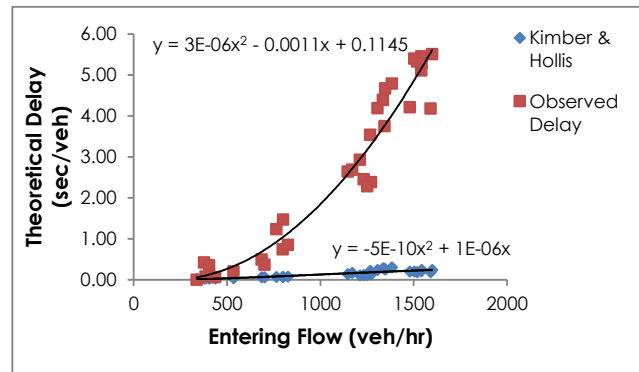**Figure 8** Variation of comparison of delay to straight and right turn, and left turn corresponding with circulating flow

Figure 9 Variation of comparison of Kimber & Hollis theoretical delay and observed delay

4.4 Theoretical Delay

The delays that are calculated or estimated from the theoretical model which are Kimber & Hollis theory, Akcelik & Troutbeck theory, and CETUR formula in this study are termed as theoretical delay. The data collected for the roundabout is used to estimate the delay based on each of these models.

(i)   Kimber & Hollis's Model

The theoretical average delay of Kimber & Hollis theory was calculated using the Equation (8). Table 6 shows the example of the theoretical delay data of Day 1 in weekday for Jalan 19/8 to Jalan Universiti.

The C value is equals to 1 because the roundabout is estimated as a random arrivals and service. L_o is the length of queue at start of time interval. The interval time period for the data collection was 15 minutes, therefore the value of t is equal to 900sec. The capacity defined as the entry capacity for each arm and is estimated using the equation (1). The value of F and G can be obtained by using the Equations (9) and (10) respectively.

Table 6 Kimber & Hollis theoretical delay for Jalan 19/8 to Jalan Universiti

C	t (sec)	L_o (m)	Capacity, μ (pcu/hr)	Demand, q (pcu/hr)	$P = q/\mu$	F	G	Delay (sec/veh)
1	900	0	3275	516	.16	346	258	0.19
1	900	0	3056	584	.19	312	286	0.23
1	900	0	3093	612	.19	313	298	0.24
1	900	0	3113	536	.16	327	254	0.19
1	900	0	2942	596	.20	295	296	0.25
1	900	0	2945	636	.21	291	312	0.27
1	900	0	2996	640	.22	294	324	0.27
1	900	0	2888	476	.16	304	234	0.19

Figure 9 shows the variation of comparison of Kimber & Hollis theoretical average delay and observed delay at the roundabout. It shows that the Kimber & Hollis theoretical delay is lower than the observed delay at all time. The highest delay at roundabout for observed delay is 5.51 sec/veh while Kimber & Hollis's model shows that there is a slight delay at the roundabout that can be ignored as the highest delay is 0.31 sec/veh. This shows that the Kimber & Hollis's model is not a consecutive theory in estimating the delay at roundabout.

(ii) Akcelik & Troutbeck's Model

The theoretical delay based on Akcelik & Troutbeck's model was calculated using Equation (11). Table 7 shows the example of theoretical delay for Jalan 19/8 to Jalan Universiti of the roundabout for Day 1 in weekday. For Figure 10, it shows the variation of comparison of Akcelik & Troutbeck theoretical average delay and observed delay at the roundabout. The capacity of movement, $c_{m,x}$, is obtained using Equation (12).
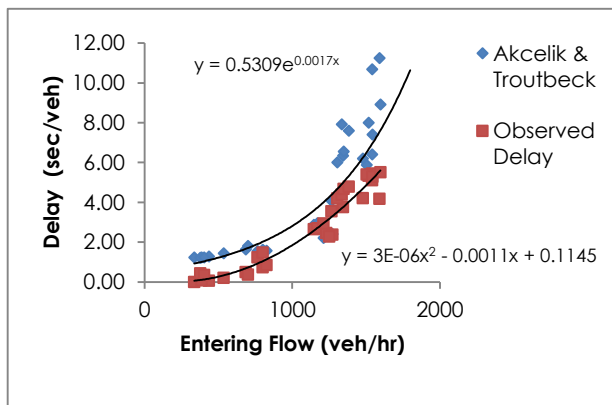

Figure 10 Variation of comparison of Akcelik & Troutbeck theoretical delay and observed delay

Table 7 Akcelik & Troutbeck theoretical delay for Jalan 19/8 to Jalan Universiti

V_{cx} (veh/15min)	t_c (sec)	t_f (sec)	v_x (veh/hr)	T	$c_{m,x}$ (veh/hr)	Delay, d (sec/veh)
272	1	1	508	0.25	3083	1.40
294	1	1	572	0.25	3044	1.46
284	1	1	596	0.25	3062	1.46
277	1	1	508	0.25	3074	1.40
325	1	1	592	0.25	2989	1.50
328	1	1	624	0.25	2984	1.53
314	1	1	648	0.25	3008	1.52
332	1	1	468	0.25	2977	1.43

Figure 10 shows the variation of comparison of Akcelik & Troutbeck theoretical average delay and observed delay at the roundabout. It indicates that Akcelik & Troutbeck theoretical delay is slightly higher than the observed delay when the entering flow is rising. The highest delay at roundabout using Akcelik & Troutbeck theoretical model is 11.25 sec/veh while for observed delay the highest delay is only 5.51 sec/veh. The lowest delay using Akcelik & Troutbeck theoretical model is 1.22 sec/veh while for observed delay is 0 sec/veh. Estimated delay should be higher than the actual delay in roundabout design because it will bring comfort to the drivers whereby the drivers will have less delay when using the roundabout. However the different between both delays in this theory is slightly higher and can contribute to overdesign.

(iii) CETUR formula

The theoretical delay for CETUR formula was calculated based on Equation (13). Table 8 shows the example theoretical delay for Jalan 19/8 to Jalan Universiti of the roundabout for Day 1 in weekday. Figure 11 shows the variation of comparison of CETUR formula theoretical average delay and observed delay at the roundabout. The value of Q_s', Q_g and entry capacity, C are obtained using Equations (14) and (15) respectively. From Figure 11, it shows that the CETUR formula theoretical delay has a huge difference compared to the observed delay. The highest delay at roundabout using CETUR formula theoretical model is 2.26 sec/veh while for observed delay the highest delay is 5.51 sec/veh. The lowest delay of roundabout using CETUR formula theoretical model is 1.47 sec/veh while for observed delay is 0 sec/veh. This model is not suitable in estimating delay in the roundabout for the purpose of design. This is because, when the entering flow is low, the estimating delay is over estimate and when the entering flow is high, the estimating delay is still low. Hence, this shows that CETUR formula is a non-consecutive theoretical delay.

Table 8 CETUR formula theoretical delay for Jalan 19/8 to Jalan Universiti

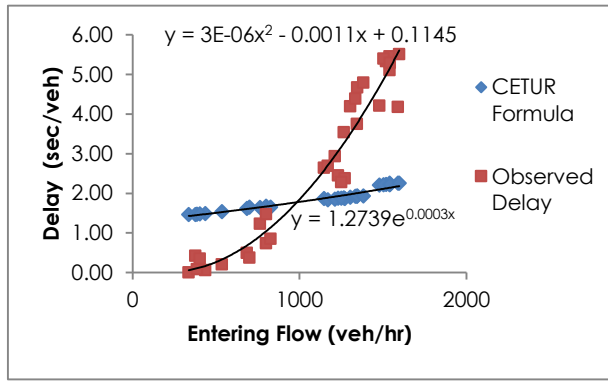| Width of circulating Flow, l_a (m)	Q_s'	Circulating Flow, Q_c (veh/ 15min)	Entering Flow, Q_e (veh/ 15min)	Impeding Flow, Q_g (veh/ 15min)	Entry Capacity, C (veh/ 15min)	Average Delay, t, (sec/veh)
15	0	272	127	110.16	1408.20	1.73
15	0	294	143	119.07	1400.78	1.78
15	0	284	149	115.02	1404.15	1.78
15	0	277	127	112.19	1406.51	1.74
15	0	325	148	131.63	1390.31	1.82
15	0	328	156	132.84	1389.30	1.84
15	0	314	162	127.17	1394.03	1.83
15	0	332	117	134.46	1387.95	1.79

Figure 11 Variation of Comparison of CETUR formula Theoretical Delay and Observed Delay

4.5　Evaluation of Observed Delay and Theoretical Delay

The observed delay and theoretical delay has been compared using the t-test as described in Equation (16). Table 9 shows the comparison of observed delay with three theoretical models.

Table 9 shows that all of the three formula's have significant different between the observed delay as the t-test at 95% confident level is in the reject region with t-critical$_{(0.25, 31)}$ = 2.042. These differences may cause by the different parameter included in the design of the roundabout adopted in the theory as compared to selected site or the bigger sample size should be collected at site in order to achieve more accurate result as compared to theoretical models.

Table 9 Evaluation of observed delay and theoretical delay

Theoretical Models	Theoretical Delay Mean, μ_o	Observed Delay Mean, X	Standard Deviation, S	n	t-test	Remark
Kimber & Hollis's	0.15	2.73	1.98	32	7.37	Reject H_o
Akcelik & Troutbeck's	4.25	2.73	1.98	32	-4.32	Reject H_o
CETUR formula's	1.85	2.73	1.98	32	2.51	Reject H_o

4.6　Evaluation with Level of Service Criteria

The evaluation of observed delay and theoretical delay with the level of service (LOS) criteria was identified based on the specification in Table 1. When refer at

Table 10, the LOS of both observed and theoretical delay has no big different in term of classification.

The LOS for observed delay, Kimber & Hollis's model, Akcelik & Troutbeck's model, and CETUR formula is Level A which define as has little or no delay. The following findings can be drawn from the study:-
i.　The traffic volume during weekday peak hour is higher than weekend peak hour. This might be due to the different activities of people during weekday and weekend. During weekday, traffic volume is higher due to working and also schooling.
ii.　The delay at roundabout is depends on the traffic demand at the major road. If the traffic demand at the major road is increased, the delay of the minor road will also increase. This is because the vehicles that queuing at the major road will enter the roundabout together for that moment of acceptance gap while the vehicles from the minor road had to wait for an acceptance gap to enter the roundabout due to high traffic flow.
iii.　The delay of doing left turning is lesser than entering roundabout. This is because the vehicle that takes left turning can just turn using the taper lane of the roundabout without interrupted the flow of circulating flow.

The delay of roundabout is arising when the traffic flow in roundabout is high due to queuing delay, waiting for acceptance gap and also delays when crossing the roundabout.

Table 10 Evaluation of observed delay and theoretical delay with LOS

Observed Delay Ave. Delay (sec/veh)	LOS	Kimber & Hollis theory Ave. Delay (sec/veh)	LOS	Akcelik & Troutbeck theory Ave. Delay (sec/veh)	LOS	CETUR formula Ave. Delay (sec/veh)	LOS
2.64	A	0.00	A	2.87	A	1.87	A
3.75	A	0.00	A	6.34	A	1.92	A
4.19	A	0.00	A	6.01	A	1.90	A
4.39	A	0.00	A	7.93	A	1.92	A
4.18	A	0.00	A	11.25	B	2.26	A
5.11	A	0.00	A	6.40	A	2.21	A
5.33	A	0.00	A	8.00	A	2.22	A
5.45	A	0.00	A	10.69	B	2.25	A
2.69	A	0.00	A	2.95	A	1.84	A
3.54	A	0.00	A	4.08	A	1.89	A
4.67	A	0.00	A	6.55	A	1.93	A
4.79	A	0.00	A	7.59	A	1.93	A
4.21	A	0.00	A	6.20	A	2.21	A
5.40	A	0.00	A	5.87	A	2.21	A
5.29	A	0.00	A	7.41	A	2.22	A
5.51	A	0.00	A	8.91	A	2.26	A
0.06	A	0.00	A	1.29	A	1.49	A
0.20	A	0.00	A	1.43	A	1.54	A
0.49	A	0.00	A	1.64	A	1.62	A
0.37	A	0.00	A	1.81	A	1.65	A
2.45	A	0.00	A	2.38	A	1.87	A

2.38	A	0.00	A	2.40	A	1.87	A
2.93	A	0.00	A	2.22	A	1.85	A
2.28	A	0.00	A	2.46	A	1.88	A
0.00	A	0.00	A	1.23	A	1.47	A
0.08	A	0.00	A	1.22	A	1.47	A
0.42	A	0.00	A	1.22	A	1.47	A
0.35	A	0.00	A	1.24	A	1.48	A
1.23	A	0.00	A	1.55	A	1.64	A
1.47	A	0.00	A	1.62	A	1.67	A
0.74	A	0.00	A	1.59	A	1.66	A
0.85	A	0.00	A	1.57	A	1.65	A

5.0 CONCLUSION

This study has shown the delays for the roundabout were assessed. The delay that assessed is total delay. The total delay at the roundabout increased when circulating flow increased. Besides, the delay to enter the roundabout at minor road is higher than major road due to high traffic demand from major road.

The evaluation of observed delay and theoretical delay were made by t-test evaluation. Among three theoretical models used, only one of them was agreed with the observed delay. Hence, this shows that not every theoretical delay model can be applied in evaluation of roundabout performance. The implication of observed delay and theoretical delay were evaluated with Level of Service (LOS). The Level of Service obtained at the roundabout was LOS A and it is acceptable because in roundabout the drivers are able to proceed without waiting for traffic signal to change.

Since this study had only focused on Bulatan Rothmans, it is recommended that further studies be carried out on other roundabout in order to obtain and establish more accurate result. Furthermore, further study could also explore more location in different state and town in Malaysia. Besides, seven days of data collection will also increase the accuracy of result.

There are a lot of theoretical delay model that can be used to estimate the delay in roundabout. Therefore, it is suggested using different types of delay model to compare. Lastly, the evaluation of observed delay and theoretical delay can also use other types of statistic distribution to test the result.

Acknowledgement

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