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Evaluating The Effects of Signal Control Applications on Roundabout's LOS Performance Using VISSIM Microsimulation Model

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Abstract: The existence of unbalanced and high traffic flows at roundabout have resulted in poor performance and safety concerns. Past research has shown that applications of signal control at problematic roundabouts had significantly improved its Level of Service (LOS) performance. This study investigates the effects of different signal phasing plans on the roundabout's LOS performance using VISSIM microsimulation model. The findings revealed that both Approach-Signal-Control Roundabout ACSR and Two-Stop-Line Control Signalized Roundabout TSLSR signal phasing methods did not significantly improve the roundabout's entry capacities. Partial signal control applications, however, have resulted in a significant reduction in vehicle delays and higher entry capacities. The results of this study provide a good overview to local traffic practitioners on how to evaluate and implement the signal control strategy at problematic roundabouts.

Keywords: Roundabout, unbalanced flow, signalized roundabout, VISSIM microsimulation

1. Introduction

The conflict between the entry and exit flows has always occurred at roundabouts due to high traffic flow demands and the existence of unbalanced flow conditions. Oftentimes, such a phenomenon has caused massive delays and spills back to the upstream intersections. Therefore, applications of traffic signal control have been used to improve the roundabout's capacity performance. According to Al-Omari et al. [1], some safety benefits and a significant reduction in overall delays could be achieved by applying signal controls at problematic roundabouts.

Generally, the maximum capacity of a normal roundabout is approximately 6000 veh/hr (total hourly volumes from all entry approaches), while signalized intersections could handle total hourly traffic flows up to 8000 veh/hr [2]. Converting a problematic roundabout to an interchange will significantly increase its capacities. Due to cost factors, many roundabouts in Malaysia, particularly in Sarawak have been replaced with a crossed-signalized intersection that requires major geometric modifications. It is not known why signalized roundabout which does not require major reconstruction and traffic disruptions has not been considered by the local road management agencies.

As the application of signalized roundabouts has shown significant benefits in capacity improvement with lower costs, this research aimed to evaluate the effects of different signal control applications on the LOS performance of a problematic roundabout.

2. Literature Review

A roundabout is a circular intersection with the introduction of a few key features such as channelized approaches and proper geometry curvature to make sure the travel speed across the circulating lane is less than 50 km/h [3]. The

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performance of a roundabout is influenced by several factors. For instance, traffic flows, driver behavior, as well as roundabout geometry, have a significant impact on the roundabout capacity [4]. In addition, Highway Capacity Manual (HCM) [4] states that the maximum entry flow is 2400 veh/hr when there is no circulatory flow and vehicles on the entry approaches are unable to enter the roundabout when the circulatory flows reach a maximum of 3499 veh/hr.

Due to unbalanced and overloading traffic flows at one or more roundabout entry approaches, the application of traffic signal control is needed to regulate high circulatory volume inside the roundabout [5]. The signals may be operated full-time or part-time, especially during the peak morning and evening periods [6]. Fig. 1 illustrates an example of the intersection geometry for the signalized roundabout.

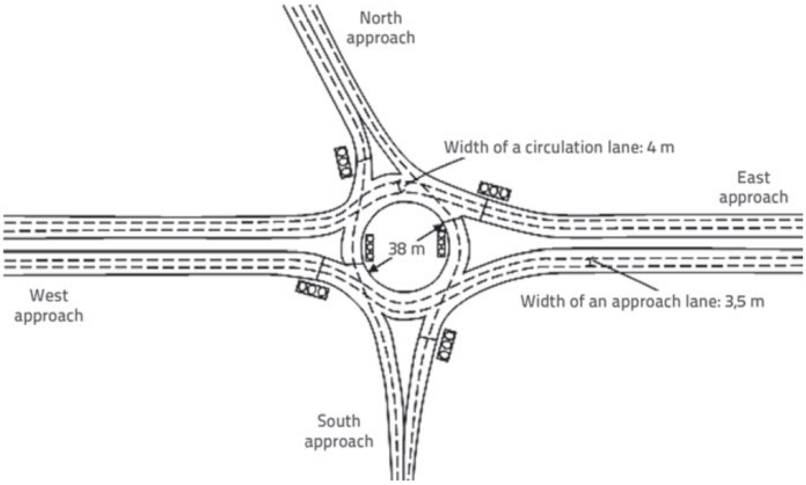

Fig. 1 - Sample of a signalized roundabout geometry [6]

Generally, the signal phasing plan for signalised roundabouts can be categorised into two, three or four-phased as shown in Fig. 2. The selection of the phase plan shall be based on analysis and field observations as it has significant impacts on the performance of the signal control system [7]. In the early 1980s, the approach-signal-control roundabout (ASCR) as shown in Fig. 3 is the most common signal phasing plan used for signalised roundabouts [8]. However, the ASCR signal phasing plan was found to be inefficient, which often causes traffic delays and long queues at the roundabout entry approaches [9], [10].

Sun et al. [11] discovered that the two-stop-line control signalised roundabout (TSLSR) has a larger capacity than a self-regulated roundabout. The study findings suggested that cycle length between 60s and 90s is suitable for a 2-lane roundabout that uses the TSLSR phasing plan method. In addition, Jiang et al. (2019) [12] found that the cycle length and radius of the central island affected the capacity of signalised roundabout using the TSLSR phasing plan. Thus, the selection of optimum cycle time for TSLSR should be carefully examined to avoid undesired results. A typical phasing plan for a four-phase TSLSR is shown in Fig. 4. In TSLSR, left-turning vehicles are not controlled by the traffic signal and can proceed to enter the roundabout whenever the gap in the circulating traffic flow is sufficient [11], [12].

3. Methodology

3.1 Case Study Site

In this research, a roundabout intersection, which connects Jalan Stutong and Jalan Setia Raja was chosen as the study site (Fig. 5). The selection of the intersection was made since the intersection experienced high traffic demands and the occurrence of unbalanced traffic flows during peak periods. Long queues have commonly occurred during peak hours, especially at approach B, which sometimes could cause blocking back of the incoming vehicles from the upstream roundabout (approximately 1.8km away from the studied roundabout). The studied intersection has two lanes in the circulating area with a central island diameter of approximately 95m. Overall, the lane width was taken as 3.5 m.

Traffic data collection was undertaken on the 28th of July 2020 from 7.00 am to 9.00 am for the morning peak and 4.00 pm to 6.00 pm for the evening peak. Since the traffic data collection was undertaken during the Recovery Phase, it is important to note that the analyzed data does not reflect normal traffic conditions before the occurrence of the COVID-19 pandemic. Tabulations of traffic data for the analysis are attached in Appendix A.

3.2 Optimum Cycle Time Estimation

The following equation as stated in [13] was used to estimate the optimum cycle time for signal control applications at the studied roundabout.

$$C_o = \frac{1.5L + 5}{1 - Y} \tag{1}$$

For the loss time, it was assumed to be 4s per phase as suggested by the Highway Capacity Manual [4] which consists of 2s of start-up lost time and 2s of clearance lost time. As for the ratio of demand overcapacity (Y), the critical movement ratio is 68% for the evening peak from Leg B (AM peak) and approach D (PM peak). The adopted optimum cycle time for the two signal phasing plans is shown in Table 1. Nonetheless, different cycle times ranging from 40 s to 110 s were examined in this research. For the allocation of green time, the effective green time was computed based on the proportion of traffic flow demands for the signal phasing plans evaluated.

Table 1 - Estimation of optimum cycle time

Phase design	No. of Phases	Total Lost Time (s)	Y	C_o (s)	Adopted C_o (s)
ASCR	4	16	0.68	90.625	90
TSLSR	2	8	0.68	53.125	60

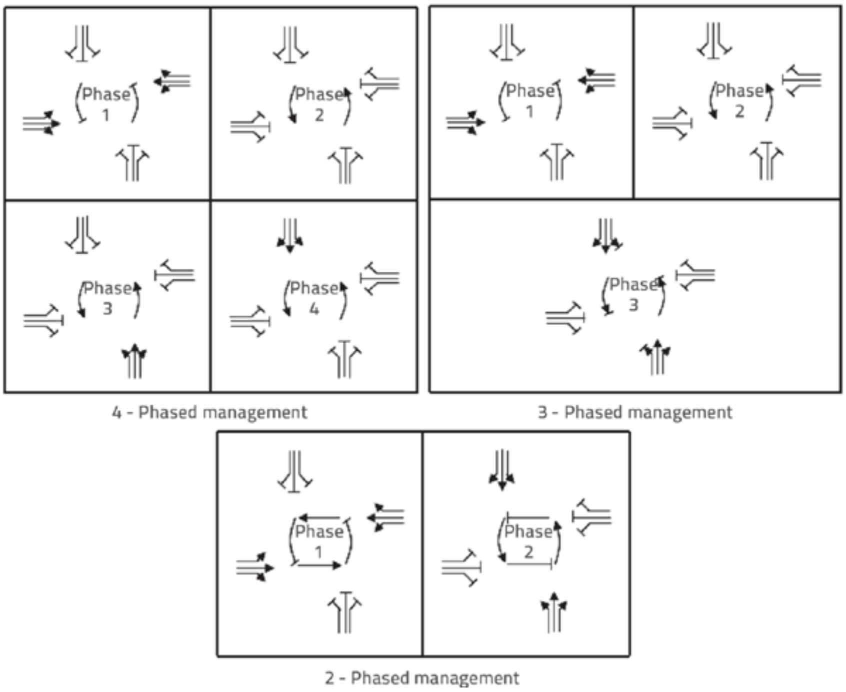

Fig. 2- Sample phase plan for signalised roundabouts [7]

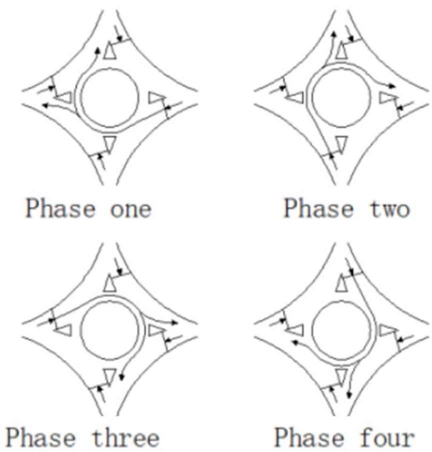

Fig. 3 - Approach-signal-control roundabout (ASCR) signal phasing plan [8]

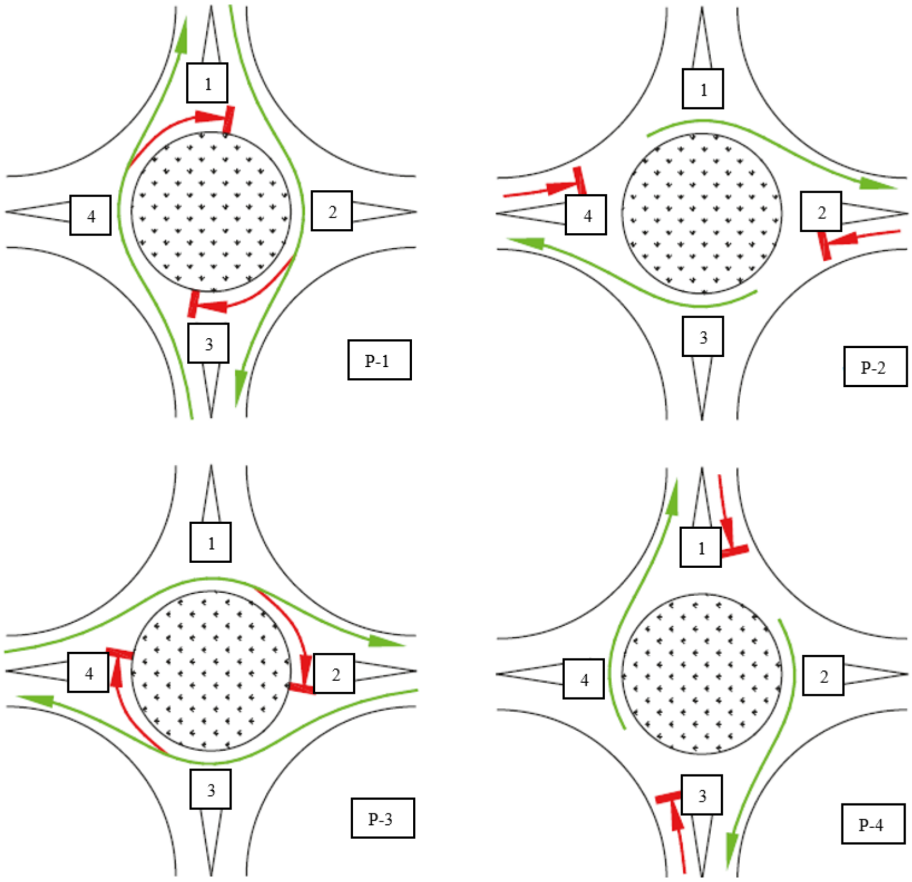

Fig. 4 - TSLSR signal phasing plan [11], [12]

Fig. 5 - Selected study roundabout

3.3 PTV VISSIM Microsimulation Modelling

PTV VISSIM 2020 was used to model and evaluate the performance of signalised roundabouts under different signal phasing plans. In this study, the Conflict Area Module is chosen over the Priority Rules Module as it provides a more accurate observation assessment [14]. VISSIM model for the base case (without traffic signal application) is shown in Fig. 6. The lane width for each of the entry approaches was taken as 3.5 m. For the speed control, desired speed distributions were created in the speed reduction areas. A speed reduction area was set at 50m before the exit of each leg, which imitates vehicles slowing down when approaching the exit. Vehicle routing for left, straight and right turn movements for each leg was predicted and placed in the model to identify the relative traffic flow. Priority rules were placed before the exit to prioritize the flow in the roundabout.

For ASCR, the VISSIM model is shown in Fig. 7, in which traffic signal controls were applied for all the approaches. ASCR allocated green time is shown in Fig. 8. The VISSIM model for TSLSR is shown in Fig. 9, while the allocated green time is shown in Fig. 10.

Fig. 6 - The base model for the studied roundabout

Fig. 7 - ASCR VISSIM model

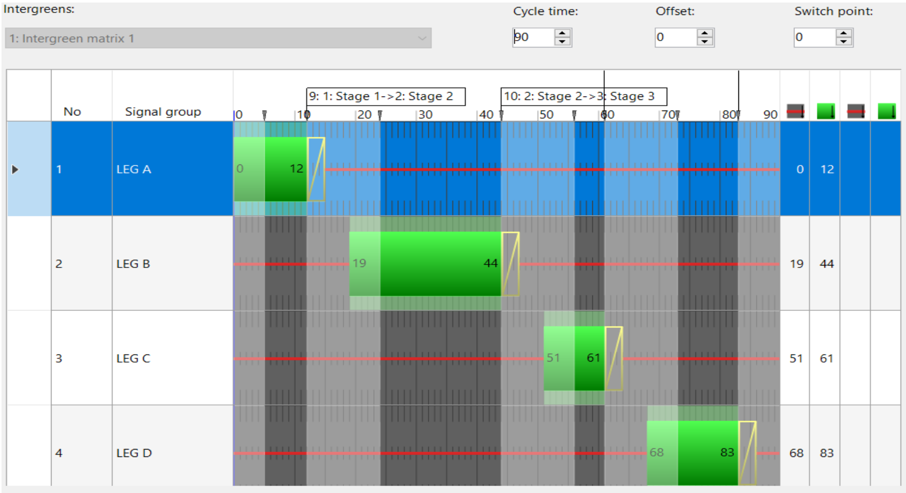

Fig. 8 - ASCR allocated green time

Fig. 9 - Two stop line signal roundabout network

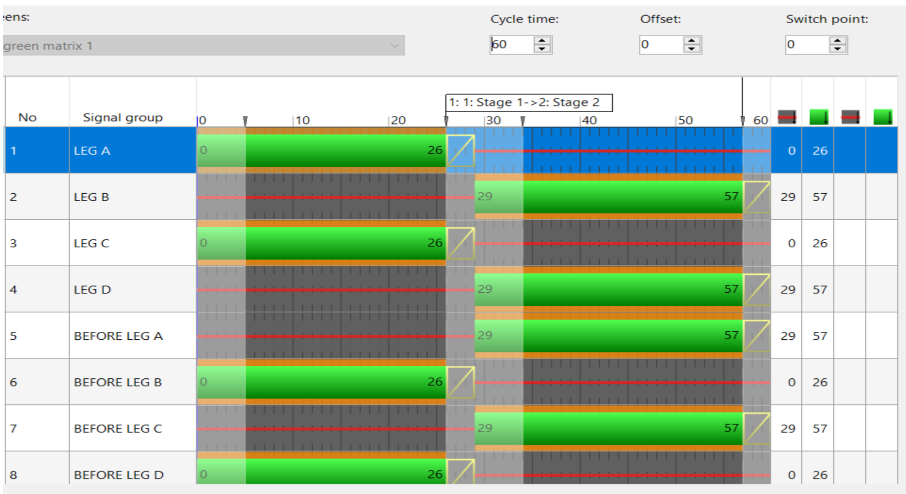

Fig. 10 - TSLSR allocated green time

3.3 Model Calibration and Validation

The current modern roundabout model was calibrated to ensure the traffic output of the model is representing the actual traffic condition of the roundabout. The model was calibrated and validated using Geoffrey E. Havers (GEH) statistics. For both AM and Pm peak volumes. GEH statistics compare the modelled traffic volume with the measured traffic volume on-site [15]. A GEH value below 5 is a good fit and above 10 is unacceptable. The parameters that were used to calibrate the model are the reduced speed of the speed zones and deceleration, and the desired speed decisions. GEH statistics are calculated using Eq. (2).

$$\text{GEH} = \sqrt{\frac{2\left(c-m\right)^2}{c+m}} \tag{2}$$

where c is the modelled traffic volume in veh/hr and m is the measured traffic volume on-site in up. It was found that the volumes were within the requirements (+/- 20%). At approach A (PM peak), the maximum difference occurred by 18%.

4. Results and Discussion

4.1 Base Case Scenario

From the results in Table 1, the existing roundabout is having a LOS of F. **Error! Reference source not found.**At morning peak only A is operating within the desired LOS (B). However, a similar approach experienced the worst LOS in the evening peak (F) while other approaches were operating within the desired LOS. The longest queue (107 m) occurred on approach C in the morning peak while approach A experienced the longest queue (106 m) in the afternoon peak.

Table 1 - LOS of the existing roundabout (without traffic signal application)

Approach	Queue Length (m)	Average Delay (s)	LOS
A	26 (160)	12 (99)	B (F)
B	86 (24)	55 (20)	E (C)
C	107 (37)	95 (29)	F (C)
D	89 (30)	64 (20)	F (C)

Note: PM peak results in the parentheses

4.2 Approach Signal Control Roundabout (ASCR)

ASCR approach is similar to the split-cycle timing plan for the cross signalised intersection, in which only one approach will receive the green signal while other approaches remain stopped. The VISSIM results for the ACSR simulation are shown in Table 1 for the morning peak while Table 2 provides the results for the evening peak.

In general, ACSR did not produce better results as compared with a base case scenario, both for morning and evening peak hours. The intersection LOS remains F with a significant increment in vehicle queueing and delays. The performance did not improve, although different cycle times were applied under ASCR. For example, under 110 s cycle time, by comparing ASCR with the base case scenario (considering the worst-case scenario), the delay on approach C has increased by 43% in the morning peak while approach an experienced an increment in delay by 16% for the evening peak. The results clearly show that the ASCR signal phasing plan is not suitable for the studied roundabout.

Table 2 - VISSIM results for ASCR model (AM peak)

Cycle time	Queue Length (m)			Average Delay (s)			LOS		
	70s	90s	110s	70s	90s	110s	70s	90s	110s
Approach A	152	150	147	386	237	248	F	F	F
Approach B	180	172	167	89	67	91	F	E	F
Approach C	151	149	147	375	311	271	F	F	F
Approach D	149	148	144	274	212	197	F	F	F

Table 3 - VISSIM results for ASCR model (PM peak)

Cycle time	Queue Length (m)			Average Delay (s)			LOS		
	70s	90s	110s	70s	90s	110s	70s	90s	110s
Approach A	146	141	137	168	150	137	F	F	F
Approach B	199	195	192	205	195	192	F	F	F
Approach C	155	151	148	498	315	267	F	F	F
Approach D	146	141	137	171	146	139	F	F	F

4.3 Two Stop Line Signal Roundabout (TSLSR)

For the TSLSR model, this research adopted the two-stop line method as stated in Jiang et al. [12] since four-phase TSL signal control produced a longer delay. VISSIM simulation results are tabulated in Table 4 (AM peak) and Table 5 (PM peak).

Table 4 - VISSIM Results for TSLR Model (AM Peak)

Cycle time	Queue Length (m)			Average Delay (s)			LOS		
	40s	60s	80s	40s	60s	80s	40s	60s	80s
Approach A	21	24	104	44	50	191	D	D	F
Approach B	95	123	152	45	56	116	D	D	F
Approach C	139	147	144	187	291	420	F	F	F
Approach D	6	9	25	22	28	76	C	C	F

For AM peak hour, it can be seen that TSLSR optimum cycle time is 40s. When compared with the base case results, the only improvements (reduction in delay) achieved are for approach B and approach D by 10% and 49% respectively. LOS for approach C remains F while LOS for approach A has decreased from B to D.

VISSIM simulation results for PM peak indicate that the optimum cycle for TSLSR is similar to AM peak, i.e., 40 s. While no change in the LOS (C) for approach B and C, the LOS performance for approach C has decreased from C to F, in which the delay increased by 68%. In addition, LOS for approach A remains unchanged (F) with an increment in delay by 7%. It appears that TSLSR produced a comparable performance with the base case scenario.

Table 5 - VISSIM results for TSLR model (PM peak)

Cycle time	Queue Length (m)			Average Delay (s)			LOS		
	40s	60s	80s	40s	60s	80s	40s	60s	80s
Approach A	139	134	131	113	111	128	F	F	F
Approach B	20	109	160	28	55	90	C	E	F
Approach C	11	15	21	31	39	54	C	D	E
Approach D	137	130	133	105	111	143	F	F	F

4.4 Partially Signal Control

As the fully signal control application for all the entry approaches did yield the desired results, this research has further examined the possibility of applying partial signal control for the studied roundabout. In this regard, a combination of at least two signalised entry approaches were investigated). With several combinations, multiple simulations were undertaken under similar traffic flow conditions in which the cycle time was set at 40 s. The results for partial signal control application are presented in Table 6 (AM peak) and Table 7 (PM peak). From the AM simulation results, the roundabout overall LOS performance was best improved under partial signal control application at approach A and approach C. LOS performance for approach C and approach D has been considerably reduced from F to B and C respectively. In addition, the LOS performance for approach B was reduced from E to B, however, a slight increment in LOS occurred at approach A.

Table 6 - VISSIM results for partial signal control model (AM peak)

Signalised approaches	Queue Length (m)						Average Delay (s)						LOS					
	AB	AC	AD	BC	BD	CD	AB	AC	AD	BC	BD	CD	AB	AC	AD	BC	BD	CD
Approach A	18	21	19	3	2	1	28	28	29	23	25	16	C	C	C	C	C	B
Approach B	98	22	17	98	55	55	28	24	34	30	38	42	C	C	C	C	D	D
Approach C	19	17	148	16	142	142	23	17	206	21	170	172	C	B	F	C	F	F
Approach D	36	20	6	15	6	6	45	27	13	26	16	13	D	C	B	C	B	B

Table 7 - VISSIM results for partial signal control model (PM peak)

Signalised approaches	Queue Length (m)						Average Delay (s)						LOS					
	AB	AC	AD	BC	BD	CD	AB	AC	AD	BC	BD	CD	AB	AC	AD	BC	BD	CD
Approach A	129	77	25	149	148	141	90	51	25	143	144	96	F	E	C	F	F	F
Approach B	20	135	22	21	19	60	17	67	22	22	19	44	B	C	C	C	B	B
Approach C	28	11	26	10	10	11	38	23	41	17	26	15	D	D	B	B	C	C
Approach D	127	97	120	22	50	38	83	66	72	26	38	29	F	E	F	C	D	D

From the results in Table 7, it appears that although signal control application at approaches A and C produces the best overall results, the overall LOS performance however is no better than the base case scenario. Thus, a further investigation was undertaken to examine the effects of lower cycle time on the performance of partial signal control application at approaches A and C. The results are presented in Table 8. It can be seen that an application of 35 s cycle time yielded the best performance for PM traffic flow conditions. Under such a signal control phasing plan, the overall LOS performance of the studied roundabout has been significantly reduced from F to E. However, the LOS performance for approach C has slightly increased from C to D.

Table 8 - Effects of different cycle times on partial signal control application at A and C (PM peak)

Cycle time	Queue Length (m)			Average Delay (s)			LOS		
	30s	35s	40s	30s	35s	40s	30s	35s	40s
Approach A	21	42	25	20	32	25	B	C	C
Approach B	13	28	22	18	24	22	B	C	C
Approach C	33	57	26	43	61	41	D	D	D
Approach D	140	68	120	95	48	72	F	E	F

4.5 Discussion

Based on the study results, the ASCR method was proven not suitable for the studied roundabout. The application of signal control based on ASCR has worsened the performance of the existing roundabout performance, both for AM and PM peak traffic flow. The findings support the conclusion made by earlier studies [9], [10] which deduced that ASCR is not suitable for huge traffic volume since the method could not utilise the circulating storage lanes.

Contrary to expectations, this study did not find a significant improvement to the roundabout LOS performance upon applying the TSLSR method, although Sun et al. [11] discovered that TSLSR is suitable for a 2-lane roundabout with cycle length between 60s and 90s. The present study found that TSLSR is more suitable for a 3-lane roundabout because such a geometric arrangement provides more vehicle storage in the circulating areas. Nonetheless, this study found that the application of 40s cycle for TSLSR has improved the roundabout LOS performance as compared with higher cycle time as recommended by the past study. The selection of lower optimum cycle time, however, must be carefully examined as traffic congestion will quickly build up when the application of optimum cycle time is too short. This is because the application of shorter traffic signal cycle time under high traffic volume oftentimes results in more cumulative loss time and vehicle delays.

Since ASCR and TSLSR did not yield the desired results, the present study has investigated the application of partial signal control for the studied roundabout. Based on several partial signal control applications on the roundabout approaches, it was found that signal application on approaches A and C produced the best results for the roundabout performance improvement. For AM peak traffic flows, the optimum cycle time was found to be 40 s, whereas, for PM peak traffic flows, 35s was found to be selected. From site investigation, it was observed that the high proportion of U-turn traffic from approach A (approximately 40%) hampered the vehicles from other approaches to enter the roundabout. As such, applying traffic signal control at approaches A and C, provided the entry gaps for other vehicles to manoeuvre into the roundabout. Under unbalanced flow conditions, the application of a partial signal control strategy with an optimum cycle time less than 60s resulted in lesser vehicle queuing in the circulating lanes and ensure no blockage occurs at any of the roundabout entry approaches [15].

The fact that the total hourly traffic flows at the studied roundabout were still below the maximum capacity as stated in [2] (i.e., 4361 veh/hr for AM peak and 5260 veh/hr for PM), this could be a possible explanation as to why the application of TSLSR did not produce overall significant improvements. The most interesting finding was that the application of partial signal control at the studied roundabout showed significant achievement in improving the LOS performance. This finding, while preliminary, provides a good overview of the methodology for assessing and selecting the application of partial signal control at roundabouts.

5. Conclusion

This study investigates the effects of different signal phasing plans (ASCR, TSLSR and partial control) to improve the LOS performance of a problematic roundabout using VISSIM microsimulation model. Results from the study confirmed that ASCR is not suitable as an alternative to improve the LOS performance of problematic roundabouts. In addition, while the application of TSLSR showed some minor improvements, these results, however, did not contribute to significant improvement of the studied roundabout's overall LOS performance.

One of the more significant findings to emerge from this study is that the exploration of partial signal application at any two of the entry approaches has considerably improved the roundabout's LOS performance under the circumstance when the total hourly traffic demands at the roundabout are approaching its maximum capacity. Based on the methodology used in this study, industrial practitioners could adopt it to assess end design signal control application for any problematic roundabouts before considering any major reconstruction to replace them with higher capacity intersections such as cross signalised intersections and grade-separated interchanges (e.g., overpass or underpass).

Acknowledgement

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Appendix A: Traffic data

Table A1 - Traffic data at Jalan Stutong roundabout for AM peak) (Veh/hr)

Approach	Direction	Straight	Turn Left	Turn Right	U-turn	Total
A	North	232	251	131	409	1023
B	East	1045	262	461	2	1770
C	South	361	285	321	2	969
D	West	399	603	158	39	1199

Table A2 - Traffic data at Jalan Stutong roundabout for PM peak (Veh/hr)

Approach	Direction	Straight	Turn Left	Turn Right	U-turn	Total
Leg A	North	457	149	834	115	1555
Leg B	East	713	225	113	0	1051
Leg C	South	373	337	294	2	1006
Leg D	West	606	458	399	185	1648

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