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Implementation of Shallow Underpasses at an Urban Roundabout

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ABSTRACT

Existing studies on modern roundabouts performance are mostly based on data from conventional roundabouts such as single lane or multilane roundabouts. Although there are a number of studies on roundabout treatments with traffic signals and flyover, there has been a lack of study on underpasses. With the intent of providing knowledge on the effectiveness of roundabout with shallow underpasses, a traffic study was conducted at Kipali interchange. This interchange consists of a five-legged roundabout and two sets of shallow underpasses. This research used multiple video camcorders to capture vehicle turning movements at the roundabout entrance approaches and also the underpasses. Field-measurement such as delay, and queue length were carried out. With the collected traffic data, SIDRA INTERSECTION version 6.1 was used to evaluate several performance measurements such as average delay and queue length. The software was also used to compare the performance of the before and after the construction of underpasses at the roundabout. Due to the limitation of the software, the roundabout and underpasses were designed separately. This paper will certainly provide a deeper and more comprehensive understanding of the traffic characteristics and impacts of roundabout with shallow underpasses.

Key words : Average delay, level of service, queue length, roundabout, shallow underpasses

1. INTRODUCTION

The increase in traffic volume has caused traffic congestions especially in the more densely populated area. Thus, many efforts have been made by researchers around the globe to counter this traffic problem by formulating appropriate measures for mitigation of congestion on urban roads. A large number of urban intersections particularly roundabouts are upgraded with traffic signals or grade–separation structures to alleviate traffic congestion. Many studies on roundabout with traffic signals had shown an improvement in capacity and safety [2-5]. The implementation of traffic signals on a roundabout also solved unbalanced flow patterns. Roundabout with metering signals are cost-effective [6] and reduces average delay time, queue length, and carbon dioxide emissions [7-9]. The disadvantage of traffic signals is higher noise level compared to conventional roundabout at their entries [10]. This is due to the differences in the intersection geometry, traffic parameters, flow type and management at the entries. An alternative to traffic signals installation is grade–separation structures. According to Dehnert and Prevedouros [11], the maintenance and liability cost for the structure is low. A number of studies showed that grade separation structures improved capacity, delay, traffic operation, fuel loss and vehicular emissions [12-15]. Grade separation structures are classified into flyovers or overpass (above at-grade) and underpass (below at-grade).

This paper focusses on the treatment of an urban roundabout with shallow underpasses. Shallow underpass is suggested to be constructed in urban areas because of the low density of heavy vehicles. This is a unique roundabout treatment as it is first of its kind in Kuching. The term shallow underpass is used to differentiate the vertical clearance of the underpass. A standard height underpass allows all types of vehicles to go through whereas shallow underpass is restricted to certain vehicles particularly light vehicles. This is in line with the suggestion by Dehnerts and Prevedorous [16] of which the access of shallow underpass should be limited to light vehicles only. Such limitation allows uninterrupted access that benefits traffic and emergency vehicles. As this treatment is not the norm, no guidelines are available to determine the vertical clearance of the shallow underpasses. The likelihood of crashes is reduced due to elimination of heavy vehicles in the shallow underpass. When the road width is reduced, one or more lane(s) can be retrofitted in the carriageway. Thereby, the total capacity of traffic lanes particularly at congestion hours are escalated to cater for current and future increasing traffic volumes. Higher capacity encourages smoother or free flow of traffic, increases the free flow speeds and speeds at capacity, thus reduces vehicle delay [17]. The level of safety at the intersection is thus improved [18] .

Dehnert and Prevedouros [11] estimated the cost of construction for both standard and shallow underpasses. The authors stated that a 4.8m wide and 2.4m high underpass under a six-lane, 29m arterial would likely cost $4.2 million without relocating utilities and installing alarm system. If these items were installed, the shallow underpass will cost about $5 million. A standard underpass with height 4.5m would likely to cost $8 million. This shows the cost estimates of shallow underpass that have been massively reduced by about $3 million, or 37.8% reduction in total cost.

Shallow underpass would provide an eight percent reduction in fuel consumption per business day during two peak hours, which resulted in $1.1 million fuel saving for 250 working days annually. Dehnerts and Prevedorous [16] foresaw the expected benefits of the shallow underpass would outweigh the implementation costs after two to five years of operations. In terms of delay, speed and travel time, it can be observed that the traffic conditions and pollutions can be improved with the proposed solution, which gives a significant congestion relief at the intersection.

2. REVIEW OF EXISTING STUDIES

The entry capacities of approaches to a roundabout decreased with the increased in the number of vehicles in the circulating lane(s). Capacity refers to the capability of a road to accommodate traffic. It is also known as the maximum traffic volume that travels over a given section of a road in a certain period of time [19]. The entry capacity of roundabouts determines whether the delays and the queue lengths are small enough to ensure a good Level of Service (LOS) [20]. In fact, for capacity considerations, single-lane roundabout was extended to double-lane roundabout. In order to further extend the capacity of the roundabout, it is possible to upgrade the roundabout with grade-separation structures such as flyover and underpass.

Grade separation structure divides traffic into different flows using physical means. There are two types of grade separated structures, namely overpasses (also known as flyovers) and underpasses. These structures can increase overall capacity of roads and reduce traffic congestion, crashes, traffic delay, and ensure smoother traffic flow. Also, grade separation structures only need low maintenance and liability cost compared to signalized intersections [11]. Yousif and Zhang [15] proposed a few roundabout treatments at Kahtan Square in Baghdad city. Those treatments are: signalized intersection and flyover. The authors concluded that flyover is the better option in improving the capacity and traffic operation at the intersection. The overall LOS by converting a roundabout to signalized intersection is very poor as compared to flyover [15]. The construction of flyover over four signalized intersections in Nagpur City has brought positive impacts in terms of time delay, fuel loss, and vehicular emissions [12]. It was found that 35% of the total traffics diverted to the flyover, leading to 32% reduction in the total emission generation. In addition, drivers saved as much as 60-70% in time compared to those driving on main road.

By comparing widening of road and flyover solution, the travel time for road widening reduced by 15% whereas travel time for flyover reduced by 30% [13]. Additionally, the throughputs are increased by 7% and 16% in widening of road and flyover respectively. The installation of flyover at Hat Yai International Airport in Thailand also received positive feedback [14]. The outcomes showed 45% of traffic diverted to flyovers whereby time delay reduction by 34% over the same period. Similar study has been done by Salatoom and Taneerananon [14], the authors stated that despite flyovers ability to solve congestion problem, long queue and delay still occur at a signalized intersection and upgraded with flyover as it is controlled by fixed time control plans. Notwithstanding that there are not many papers related to underpass, the operation for grade separation structures works similarly, with exception in terms of cost. The total cost of flyover is higher than underpass by 28% [21].

According to Malaysia design's guideline, the Public Works Department (PWD) recommends the minimum clear vertical height of a standard underpass to be at least 5.4m over the entire width of traffic lanes, auxiliary lanes in the latest Arahan Teknik (Jalan) (ATJ) Pindaan 2015 [22]. Referring to another guideline, Road Engineering Association of Malaysia (REAM) suggests a slightly lower minimum vertical clearance of 5.3m [23]. As the focus of this study is situated at urban arterials, new or reconstructed underpass should provide 4.9m over the entire roadway width and the existing underpass that provides 4.3m may be retained if permitted by local statute. In the case of freeways, the vertical clearance should be at least 4.9m over the entire roadway width, including auxiliary lanes and usable width of shoulders. Concerning the cost of construction of an underpass in highly urbanized areas, attaining 4.9m would be unreasonably expensive, thus a minimum clearance of 4.3m may be used alternately [24].

3. STUDY AREA

A grade-separation structure in the form of underpasses was constructed at a roundabout in Petra Jaya, Kuching to ease traffic congestion. The intersection is known as Datuk Temenggong Abang Kipali Bin Abang Akip interchange (herein called Kipali interchange). It is the first roundabout with shallow underpasses in Kuching city and was opened to public in June 2018. Previously, most of the intersections in Kuching roundabout such as Simpang Tiga interchange (RM50millions), Third Mile interchange (RM50millions) and BDC roundabout (RM100millions) were improved using the flyover bridges concept [1]. Third Mile interchange also applies the standard underpass concept, with vertical clearance of 3.5m. The flyover bridges concept has the following disadvantages: expensive to build, causes impacts on the elevations of the existing buildings at the vicinity of the intersections, and longer disruptions to the traffics due to longer time of construction. Shallow underpasses are relatively inexpensive to construct and have far lesser impacts on the surrounding buildings and people of Kuching City. The estimated cost for the shallow underpasses was RM22millions [1].

With the shallow height at Kipali interchange, it is restricted to vehicles of height below 2.2m to pass through. Poole [25] revealed that 94% of the vehicles in Kuching are passenger cars or motorcycles while the remaining 6% are heavy goods and public transport vehicles. A local consultant conducted a research at the intersection and found that almost all passenger cars and motorcycles were not higher than 2.2m, thus the concept of low clearance underpasses for the improvement of congested intersection was proposed [1]. Shallow underpasses are unique in that there are no guidelines on the vertical clearance for shallow underpasses, contrarily to most guidelines that specifies the minimum clearance to cater for all types of vehicles. Example of vehicles that are allowed to use the shallow underpasses are passenger cars of all sizes such as sport/utility vehicles (SUV), minivans, vans and pick-up trucks. All other types of vehicles are to utilize the at-grade roundabout. This should not be an issue as the proportion of large vehicles at urban arterials are typically small. PWD has classified design vehicles into four general classes: passenger cars, busses, trucks and recreational vehicles. It is stated that the passenger cars of all sizes, SUV, minivans, vans and pick-up trucks are all classified under passenger car class, but the dimensions of these vehicles are not provided in the guidelines, causing constraints to this research.

Kipali interchange adopted double-level low clearance underpasses. The shallow underpasses height clearance is 2.2m with 0.4m freeboard. Therefore, the total height clearance is 2.6m. The roundabout has five approaches and two sets of shallow underpasses: (1) South (S) approach to Northwest (NW) approach and vice versa; (2) South (S) approach to Northeast (NE) approach and vice versa. Drivers travel clockwise around the central island. Despite the changes on the layout of the interchange, the number of circulating lanes remained the same. The major alteration is on NW, NE, and S approaches. The number of entry and exit lanes on S approach increases from three lanes to six lanes on each way; whereas the number of entry and exit lanes at NW and NE approach increases from two lanes to four lanes. The diameter of the central island estimated using Google Earth is 122m (before and after construction). The lane widths for the roundabout are 3.5m. Since the shallow underpasses ramp only cater for passenger cars, the lane widths are reduced to 3.25 m. The roundabout is relatively large; therefore, the design speed is 60kph whereas the shallow underpasses ramp is 70kph [1]. Figure 1 illustrates the geometry of Kipali interchange.

4. FIELD MEASUREMENT

4.1 Video Recording

Vehicles are classified into categories, which are passenger cars, motorcycles, light vans, medium lorries, heavy lorries and busses. The recorded volumes are converted into passenger car unit per hour (pcu/h) using the conversion factors shown in Table 1**.** The results of turning movements for pre-construction and post-construction of the shallow underpasses are presented in Table 2. The morning peak hour before the completion of underpasses shows that NW entrance approach has the highest traffic volume of all the five approaches; the highest traffic volume for evening peak hour is at S entrance approach. After the construction of the underpasses, about 55% of the total traffic volumes in the morning peak hour and 60% in the evening peak hour diverted to the underpasses. The diverted traffic vehicles are light vehicles due to the height of the shallow underpasses. With the operation of shallow underpasses at the roundabout, the total traffic volumes in the morning peak hour have increased by 12.7%; whereas the evening peak hour have decreased by 9.0%. Despite the increment in the total traffic volumes of the intersection in the morning peak hour, all the entering approaches showed decreased in the number of traffic volumes except SW.

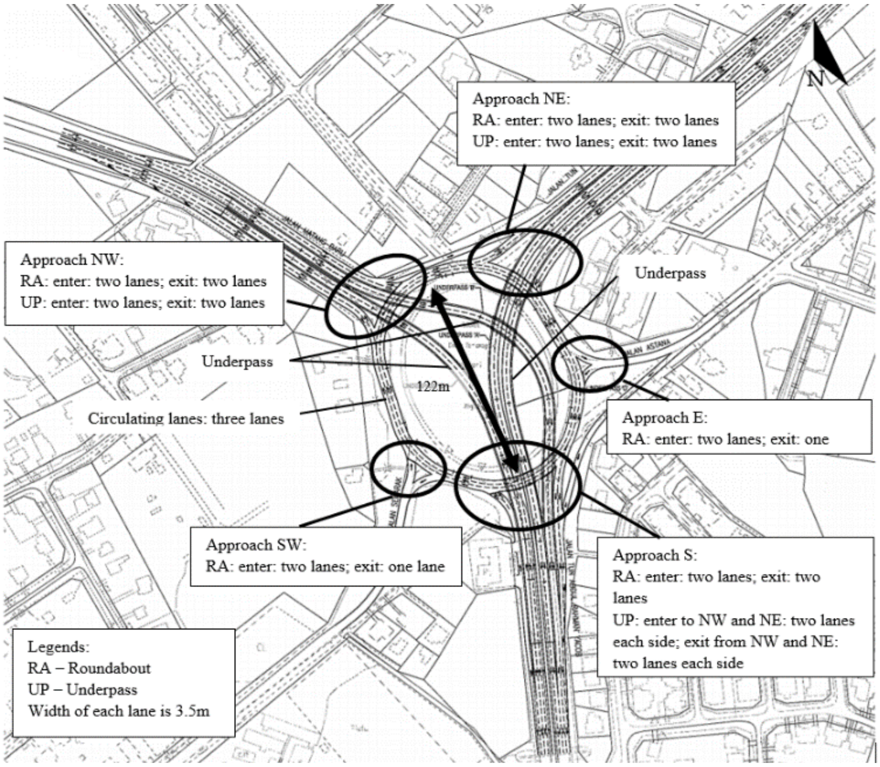

Figure 1: Geometry of Kipali Interchange [1]

Table 1: Conversion Factors [19]

Vehicle type	**Equivalent pcu value**
Passenger cars	1.00
Motorcycles	0.75
Light Vans	2.00
Medium Lorries	2.80
Heavy Lorries	2.80
Buses	2.80

Table 2: Turning Movement Volume of Morning and Evening Peak Hour at Kipali Interchange

Morning Peak Hour (pcu/hr)							
Construction	To From	SW	NW	NE	E	S	Total
Pre-construction (2015)	S	257	875	859	69	155	2215
	SW	127	51	230	25	306	739
	NW	96	188	532	32	2700	3548
	NE	160	231	61	61	563	1076
	E	74	0	297	74	592	1037
	Total						**8615**
Post-construction (2018)	S	154	0 355 (U)	35 1230 (U)	779	48	1016 1585 (U)
	SW	15	31	248	130	172	582
	NW	147	47	647	449	18 2078 (U)	1308 2078 (U)
	NE	358	454	7	21	12 1731 (U)	852 1731 (U)
	E	75	103	10	4	524	716
	Total						**9868**
Evening Peak Hour (pcu/hr)							
Construction	To From	SW	NW	NE	E	S	Total
Pre-construction (2015)	S	571	228	831	1114	343	3087
	SW	68	61	183	114	61	487
	NW	10	56	477	168	412	1123
	NE	599	83	150	83	1462	2377
	E	277	25	71	39	814	1226
	Total						**8300**
Post-construction (2018)	S	203	1 940 (U)	25 1810 (U)	201	170	600 2750 (U)
	SW	0	105	495	242	228	1070
	NW	58	51	383	256	24 680 (U)	772 680 (U)
	NE	258	282	0	22	6 1115 (U)	568 1115 (U)
	E	121	284	12	0	417	834
	Total						**7555**
*Note: The traffic volume for underpass is represented in (U).							

4.3 Delay and Queue Length Data

For the delay and queue length data, only the field measurement for post-construction of shallow underpasses were taken. Delay is measured in second (s) whereas queue length is measured in meter (m) and number of vehicle (veh). The delay data were obtained using a mobile application named 'Travel Time and Delay Study'. The purpose of the application is to track the vehicle travelling speed and time. It is done by appointing a driver in a test vehicle to travel together with other vehicles in the traffic stream. The test vehicle travels at the same speed as other vehicles within the vicinity to simulate the travelling experience of other vehicles. As the peak hours were identified, one passenger was assigned in the test vehicle and acts as an observer to record the data using the application as the vehicle travels through the road. The data collected were only obtained on the approaches that were affected by the shallow underpasses, which are S, NW, and NE approaches. This survey was conducted for a duration of one hour per session to coincide with the peak hours. Delay can be measured by comparing the data of the peak hours with the off-peak hour. The off-peak hour is the time when traffics are under free flow condition. The total time travelled during off-peak hour at S, NW, and NE approach was 170s, 131s, 130s, respectively. Since a number of runs were obtained during the period, the longest time travelled will be used to compare with the time travelled during off-peak hour. Table 5 summarizes the field measurement for delay at Kipali interchange. With the construction of shallow underpasses, delay can still be observed at the roundabout. S and NW approaches showed positive delay whereas NE approach showed negative delay. The differences are likely caused by the characteristics of the driver. The positive delay could be attributed by the higher traffic volumes during the peak hours. It was also observed that drivers tend to be driving in a rush during peak hour, and slower during off-peak hour, hence the negative delay. The study faced difficult task when following the front driver as the drivers' characteristics and origin-destination were not known.

Queue length data were measured using a measuring tape at every 15-minutes interval during the peak hours. In every fifteen minutes, the longest queue from the yield line was recorded at S, NW and NE approaches, regardless of which lane (refer Table 5). When measuring the queue length survey, it was observed that most of the vehicles did not stop completely and tend to advance slowly towards the roundabout, thus causing a challenge in the data collection. Besides that, as the roundabout was not congested, larger gaps were observed between vehicles in the queue.

5. ANALYSIS WITH SIDRA

Signalized and Un-signalized Design and Research Aid (SIDRA) is used to design, analyze, and evaluate traffic operations at various types of intersections. It can also design and evaluate individual intersections and networks of intersections. Although SIDRA were first developed in Australia, it is still applicable in Malaysia as both Malaysia and Australia practice driving on the left-hand side of the road. Furthermore, roundabouts are common and many high-capacity roundabouts exist in these countries. Many researchers have used this software to help them to study intersections' performance [26-30].

In this study, SIDRA Intersection version 6.1 was used to study the performance of roundabout with and without underpasses. The number of circulating lanes at Kipali interchange remained the same after the construction of the shallow underpasses. Before the intersection was upgraded, traffic wardens are needed to regulate the traffic flows particularly during peak hours. This caused congestion in the circulating streams. SIDRA, nonetheless, did not take into consideration of other factors such as the existence of traffic wardens nor allow traffics queueing in the circulating lanes. Therefore, the results from SIDRA as presented in Table 3 and Table 4 are overestimated. From the table, the average delay and queue length improved drastically with the implementation of shallow underpasses. It can be observed that the approaches with shallow underpasses improved around 90% as a result of the light vehicles being diverted to the underpasses instead of using the roundabout. This also matched with the field observation where there was no congestion on the intersection. Vehicles were advancing slowly towards the roundabout with minimal stops. The underpasses also showed no queues at all during peak hours during the observation (see Table 6 for shallow underpasses performance from SIDRA).

There were several issues encountered when modelling the intersection mainly due to differences in local drivers' behavior. With large roundabouts such as Kipali, the local drivers tend to make lane change in the circulating lanes to exit to their desirable leg. SIDRA does not take into consideration of vehicles that may be subjected to lane changing on the circulating lane. Another issue encountered was that SIDRA assigns the vehicle's movement according to the lane disciplines in Lane Geometry tab. The software does not distribute the volume of vehicles equally on the approaching lane according to the movement class. The movement class must be specified on different lanes in SIDRA for it to allocate the volumes equally. In reality, the local drivers will queue on any lane that they deem to be faster in the approaching lane before the yield line, and depart to any exit they want. Based on the field observation, vehicles were most likely to queue on the left-side of a two-lane lane. This caused unbalanced traffic volume on the approach. This traffic movement data collected only considered the traffic volumes that left at the yield line of the roundabout, the number of vehicles on a specific lane was ignored.

5.1 Layout of Kipali Interchange

SIDRA Intersection can only design at-grade intersection as presented in Figure 2**.** In the design of roundabout with underpasses, the traffic volumes for the underpasses are not input in the software as they neither circulate nor affect the performance of the roundabout. A separate model was done to investigate the performance of the underpasses. The underpasses were designed in NW, NE, S, and SE approach.

5.2 Average Delay and Queue Length

The average delay shown in Table 3 is measured in seconds. Without underpasses, the longest delay for morning peak hour occurred at entering approach E, followed by NE, NW, S, and SW. In the morning peak hour, traffic wardens regulated the traffics at approach NW and NE. This causes high traffic volumes in the circulating lanes, and eventually congestion occurred at other approaches. Following the implementation of the underpasses, average delay at S approach decreased by 95.6%; SW decreased by 98.9%; NW decreased by 80.3%; NE decreased by 99.2%; and E decreased by 99.7%. For evening peak hour, traffic wardens were also seen at S and NW approaches before the underpasses were completed. Some approaches see decrease in average delay: S (95.4%); NW (81.5 %); NE (99.6%); E (17.6%). SW approach showed an increment in average delay by 45.1%.

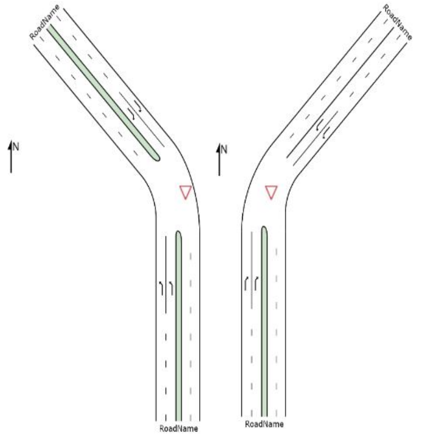

Figure 2: Layout of Kipali Interchange from SIDRA

The queue length presented in Table 4 is measured in meters. The queues decreased significantly after the construction of the underpasses. The length for morning peak hour at S approach improved by 94.3%; SW by 95.5%; NW by 97.6%; NE by 97.8%; and E by 98.8%. The length for evening peak hour at S approach improved by 97.8%; NW by 69.9%; NE by 99.6%; and E by 5.1%. SW approach showed an increment in queue length by 247.1%.

The field measurement data are compared with SIDRA software as presented in Table 5. For the SIDRA analysis, the gap acceptance parameter was adjusted until it is comparable with the field-measured queue length. After the adjustment, it was found that the delay of the field-measured data and SIDRA results are different. This could be due to lack of information on drivers' behavior. The duration of the survey was only one hour, therefore only few runs were carried out due to limited number of surveyors. The maximum number of runs can be conducted during the survey was seven runs or seven samples of vehicles only. Some drivers drove over the speed limit while some drove very slowly, creating some degree of inconsistencies. At the NE approach, the queue length in the evening peak hour was noticeably shorter in SIDRA result when compared to the field-measured data. Also, the number of vehicles in the queue are not the same. Observations from the recorded videos show large gaps were between vehicles in the moving queue. Long and large trucks were also noticed causing the queue to be longer. Furthermore, the collection of traffic movement data and queue length data were conducted on different weeks, hence the types of vehicles may have varied during the survey.

Table 3: Comparison of Average Delay Before and After the Construction of Shallow Underpasses

Entering Approach	Before Construction (s)		After Construction (s)		Percentage Difference (%)	
	AM	PM	AM	PM	AM	PM
S (U)	629.2	355.6	27.4	16.3	-95.6	-95.4
SW	505.5	18.2	5.5	26.4	-98.9	+45.1
NW (U)	1459.3	55.7	31.1	10.3	-97.9	-81.5
NE (U)	1804.4	2489.0	15.3	9.8	-99.2	-99.6
E	1808.1	23.3	4.6	19.2	-99.7	-17.6
*Note: (U) denoted underpass						

Table 4: Comparison of Queue Length Before and After the Construction of Shallow underpasses

Entering Approach	Before Construction (m)		After Construction (m)		Percentage Difference (%)	
	AM	PM	AM	PM	AM	PM
S (U)	1626.8	1861.3	92.9	40.2	-94.3	-97.8
SW	857.0	38.4	38.5	133.3	-95.5	+247.1
NW (U)	5311.6	135.7	126.8	40.8	-97.6	-69.9
NE (U)	2597.4	6996.9	55.9	26.1	-97.8	-99.6
E	2296.0	97.7	26.9	92.7	-98.8	-5.1
*Note: (U) denoted underpass						

Table 5: Comparison on Field-Measured Data and SIDRA Analysis

Entering Approach	Measurement	Field-measured		SIDRA		Percentage Difference (%)	
		AM	PM	AM	PM	AM	PM
S	Delay (s)	21.0	141.0	27.4	6.8	+30.5	-95.2
	Queue length (m)	97.4	42.8	92.9	40.2	-4.6	-6.1
	Queue length (veh)	11.0	6.0	13.3	5.7	+20.9	-5.0
NW	Delay (s)	56.0	47.0	31.1	29.0	-44.5	-38.3
	Queue length (m)	135.6	40.8	126.8	40.8	-6.5	0.0
	Queue length (veh)	15.0	5.0	18.1	5.8	+20.1	+16.0
NE	Delay (s)	14.0	30.0	15.3	9.9	+9.3	-67.0
	Queue length (m)	45.5	58.4	55.9	26.1	-22.9	-42.6
	Queue length (veh)	5.0	7.0	5.5	3.7	+10.0	-47.1

5.3 Shallow Underpasses

The performance of the shallow underpasses (see Table 6) showed minimal average delay that ranges between 4.6-5.6 seconds. These values are small and can be insignificance. Besides that, no queue length is shown on the underpasses indicating that there is a free-flow traffic pattern at the underpasses. This is to be expected for grade-separated structures to provide free-flowing movement and the average delays are due to geometric delay.

Table 6: Performance of Shallow Underpasses

Entering Approach	AM		PM	
	Average Delay (s)	Queue length (m)	Average Delay (s)	Queue Length (m)
S	5.0	0.0	4.6	0.0
NW	4.5	0.0	5.6	0.0
NE	5.5	0.0	5.6	0.0
S (to NE)	5.6	0.0	4.4	0.0

5. CONCLUSION

In order to mitigate road traffic congestion at an urban roundabout, the Sarawak State government has taken up initiatives to construct shallow underpasses. This unique roundabout treatment option only allows light vehicles to flow through its two shallow underpasses. Before the construction of the underpasses, traffic wardens are required to regulate the traffics especially in the morning and evening peak hours. After the underpasses were constructed, the traffic volumes seem to increase in the morning peak hour but decrease in the evening peak hour. However, the increase in the traffic volumes does not affect the performance of a treated roundabout. The underpasses have greatly improved the performance of the roundabout in terms of average delay and queue length. The number of vehicles diverted to underpasses causing lesser number of vehicles at the roundabout. Nonetheless, the performance of SW entering approach in the evening peak hour dropped slightly due to the increasing traffic volumes. For the shallow underpasses, the performances is as expected with minimal delay and no queue length. This concluded that underpasses or shallow underpasses are an effective treatment in solving traffic congestion at a roundabout. This research suggests further study on major downstream that are connected with the shallow underpasses of Kipali interchange. Besides, parameters such as gap acceptance should also be a concern and relevant in future studies.

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REFERENCES

[1] Jurutera Jasa (Sarawak) Sdn Bhd, "Expression of interest to provide engineering consultancy services for the improvement of traffic junctions in Kuching City using shallow underpasses," p. 19, 2013.

[2] Y. Bai, K. Xue, and T. Wang, "Association of signal-controlled method at roundabout and capacity," in *ICCTP 2009: Critical Issues In Transportation Systems Planning, Development, and Management*, 2009, pp. 1-12. https://doi.org/10.1061/41064(358)191

[3] Y. Bie, S. Cheng, S. M. Easa, and X. Qu, "Stop-line setback at a signalized roundabout: a novel concept for traffic operations," *Journal of transportation engineering*, vol. 142, no. 3, p. 05016001, 2016. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000829

[4] A. Munawar and S. Haryanto, "Optimizing signalized roundabout by computer simulation (case study: Pelem Gurih roundabout, Yogyakarta)," in *Traffic and transportation studies 2010*, 2010, pp. 357-364. https://doi.org/10.1061/41123(383)32

[5] J.-z. Zuo, L.-j. Xu, and L.-h. Ni, "An Optimization Method of Signal Control for a Four-leg Roundabout Based on the Single Release Method," *Journal of Highway and Transportation Research and Development (English Edition)*, vol. 8, no. 1, pp. 78-83, 2014. https://doi.org/10.1061/JHTRCQ.0000367

[6] R. Akçelik, "Roundabout metering signals: capacity, performance and timing," *Procedia-Social and Behavioral Sciences*, vol. 16, pp. 686-696, 2011. https://doi.org/10.1016/j.sbspro.2011.04.488

[7] R. Akçelik, "Capacity and performance analysis of roundabout metering signals," in *TRB National Roundabout Conference, Vail, Colorado, USA*, 2005, pp. 22-25.

[8] H. K. An, W. L. Yue, and B. Stazic, "Estimation of vehicle queuing lengths at metering roundabouts," *Journal of Traffic and Transportation Engineering (English Edition)*, vol. 4, no. 6, pp. 545-554, 2017. https://doi.org/10.1016/j.jtte.2017.04.002

[9] M. Martin-Gasulla, A. García, and A. T. Moreno, "Benefits of Metering Signals at Roundabouts with Unbalanced Flow: Patterns in Spain," *Transportation Research Record: Journal of the Transportation Research Board*, no. 2585, pp. 20-28, 2016. https://doi.org/10.3141/2585-03

[10] W. Gardziejczyk and M. Motylewicz, "Noise level in the vicinity of signalized roundabouts," *Transportation*

Research Part D: Transport and Environment, vol. 46, pp. 128-144, 2016.
https://doi.org/10.1016/j.trd.2016.03.016

[11] G. Dehnert and P. D. Prevedouros, "Reducing Congestion with Low-Clearance Underpasses at Urban Intersections: Investigation and Case Study," *Institute of Transportation Engineers. ITE Journal,* vol. 74, no. 3, p. 36, 2004.

[12] S. Goyal, S. Goel, and S. Tamhane, "Assessment of environmental benefits of flyover construction over signalized junctions: a case study," *Environmental monitoring and assessment,* vol. 148, no. 1-4, pp. 397-408, 2009.
https://doi.org/10.1007/s10661-008-0170-4

[13] D. Murshed, "Micro-Simulation Modeling of Traffic to Evaluate Two Congestion Relief Options: Roadway Widening and HOT Lane Direct Connections," in *Traffic and Transportation Studies*, 2008, pp. 248-259.
https://doi.org/10.1061/40995(322)22

[14] N. Salatoom and P. Taneerananon, "An Evaluation of Flyover-Improved Intersections: A Case Study of Airport Intersection," *Journal of the Eastern Asia Society for Transportation Studies,* vol. 11, pp. 2028-2040, 2015.

[15] M. A. Yousif and Z. Zhang, "Evaluation and Improvement of Traffic Operations at Roundabout Intersection," in *ICTE 2011*, 2011, pp. 210-216.
https://doi.org/10.1061/41184(419)36

[16] G. Dehnerts and P. D. Prevedorous, "Reducing Congestion with Low-Clearance Underpass at Urban Intersection: Investigation and Case Study," *ITE Journal,* Peer-Reviewd vol. 74, no. 3, pp. 36-47, 2004.

[17] K. A. Small and C. F. Ng, "When Do Slower Roads Provide Faster Travel?," *ACCESS Magazine,* vol. 1, no. 41, 2012.

[18] X. Yu, "Comprehensive method for evaluating signalized intersections treatments: left turn prohibition and partial grade separation," The Degree of Doctor of Philosophy, Graduate Division University of Hawai'i At Mānoa, Michigan, 2013.

[19] *A guide on geometric design of roads*, 2002.

[20] A. Polus, S. S. Lazar, and M. Livneh, "Critical gap as a function of waiting time in determining roundabout capacity," *Journal of Transportation Engineering,* vol. 129, no. 5, pp. 504-509, 2003.
https://doi.org/10.1061/(ASCE)0733-947X(2003)129:5(504)

[21] D. K. Mohapatra, "Seismic Reponses Of Metropolitan Bridges and Flyovers–A Comparative Study and The Need For A Renewed Strategy," in *IABSE Symposium Report*, 2004, vol. 88, no. 6, pp. 163-169: International Association for Bridge and Structural Engineering.
https://doi.org/10.2749/222137804796291610

[22] *A guide on geometric design of roads.* Kuala Lumpur: Jabatan Kerja Raya, 2015.

[23] *A guide on geometric design of roads*. Selangor: Road Engineering of Association of Malaysia (REAM), 2002.

[24] *A policy on geometric design of highways and streets*, 6 ed. Washington DC: American Association of State Highway and Transportation Officials (AASHTO), 2011.

[25] R. Poole. (2016, viewed 5 April 2016). *Innovative Underpass Project in Malaysia.* Available: http://reason.org/news/show/surface-transportation-news-147

[26] E. Macioszek and R. Akçelik, "A comparison of two roundabout capacity models," 2017.

[27] V. P. Sisiopiku and H.-U. Oh, "Evaluation of roundabout performance using SIDRA," *Journal of Transportation Engineering,* vol. 127, no. 2, pp. 143-150, 2001.
https://doi.org/10.1061/(ASCE)0733-947X(2001)127:2(143)

[28] E. R. Russell, M. Rys, and G. Luttrell, "Modeling traffic flows and conflicts at roundabouts," 2000.

[29] E. Chung, W. Young, and R. Akcelik, "Comparison of roundabout capacity and delay estimates from analytical and simulation models," in *Proceedings-Australian Road Research Board*, 1993, vol. 16, pp. 369-369: Australian Road Research Board ltd.

[30] M. Al-Ghandour, B. Schroeder, B. Williams, and W. Rasdorf, "Conflict models for single-lane roundabout slip lanes from microsimulation: Development and validation," *Transportation Research Record: Journal of the Transportation Research Board,* no. 2236, pp. 92-101, 2011.
https://doi.org/10.3141/2236-11