SIGNAL CONTROL OF A ROUNDABOUT WITH LIGHT RAILWAY TRANSPORTATION OPERATION (CASE STUDY: PHUKET LIGHT RAILWAY TRANSIT, SURIN CLOCK TOWER)

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ABSTRACT

An at-grade light rail project has been initiated in Phuket, Thailand. The line runs through the city streets with several signalized intersections and large roundabouts. The study aims to explore traffic control strategies in order to provide transit progression while minimizing delays in other vehicles. A software package, TRANSYT, was used to establish the optimized signal timing and coordination. VISSIM, a microscopic simulation software package, was also employed to simulate and evaluate the efficiency measures to recommend the best scenario. The test scenarios included 1) unsignalized control without light railway transit (LRT), 2) unsignalized control with yield, 3) unsignalized street vehicle control with actuated signal control for LRT, 4) fixed time signal and 5) signalized street vehicle control with transit actuated signal. The best traffic control scheme was found to be unsignalized street vehicle control with actuated signal control for LRT due to its short queue length and low average street delay.

KEYWORDS: LRT, at-grade intersection, actuated traffic signal, roundabout

1. Introduction

Phuket is one of the most famous tourist destinations in Thailand. Due to the expanding tourism industry, high travel demand, and severe traffic congestion, the Office of Transport and Traffic Policy and Planning (OTP) initiated a light railway transit (LRT) project in an attempt to alleviate traffic congestion, increase the city's mobility, and lower pollution caused by transportation for an eco-friendlier lifestyle and reduction of traffic congestion.

The Phuket LRT project was planned as a 58.6 km route, divided into two phases. The first phase of the project embraces a 41.7 km route from Phuket International Airport to Chalong intersection. The second phase involves an extension to the north from the intersection between Highways 402 and 4026 to Tha Nun station, which is also the future terminal station of the State Railway of Thailand (SRT) Surat Thani-Tha Nun line. The LRT network consists of 24 stations [1]. The project feasibility study was conducted in 2017, and the LRT was due to start the operation in 2021. The project was first specified as a tram system. Later in 2021, the LRT plan was replaced by Autonomous Rail Rapid Transit (ART) [2]. Thus, the design of the project had to be revised accordingly. Nonetheless, both LRT and ART share the same characteristics in that they both are operated on the at-grade "type B" right-of-way which offers an exclusive public transport lane with intermittent at-grade intersections with street traffic [3].

The LRT project in Thailand is relatively new for transport planners. The detailed study on light railway operations has not been carried out to date. One of the most challenging elements is probably the traffic signal timing and phasing which have not been prepared explicitly. The signal plan should be designed to accommodate the uninterrupted movement of transit vehicles while maintaining an acceptable level of service for street vehicles.

This study explores strategies to facilitate transit progression and minimize street vehicle delays at Surin Clock Tower which is a roundabout section included in the second phase of the project. The complex nature of the roundabout calls for special phasing coordination to prevent street gridlock over limited storage space while reserving sufficient green time for transit vehicle movement.

1.1 Physical Properties of the Roundabout

Located in a high-density residential zone of the south urban area, the roundabout has five legs and two circular lanes. The inner diameter of the roundabout is approximately 35 m. Figure 1 illustrates the plan of the roundabout and provides street views of connecting roads.

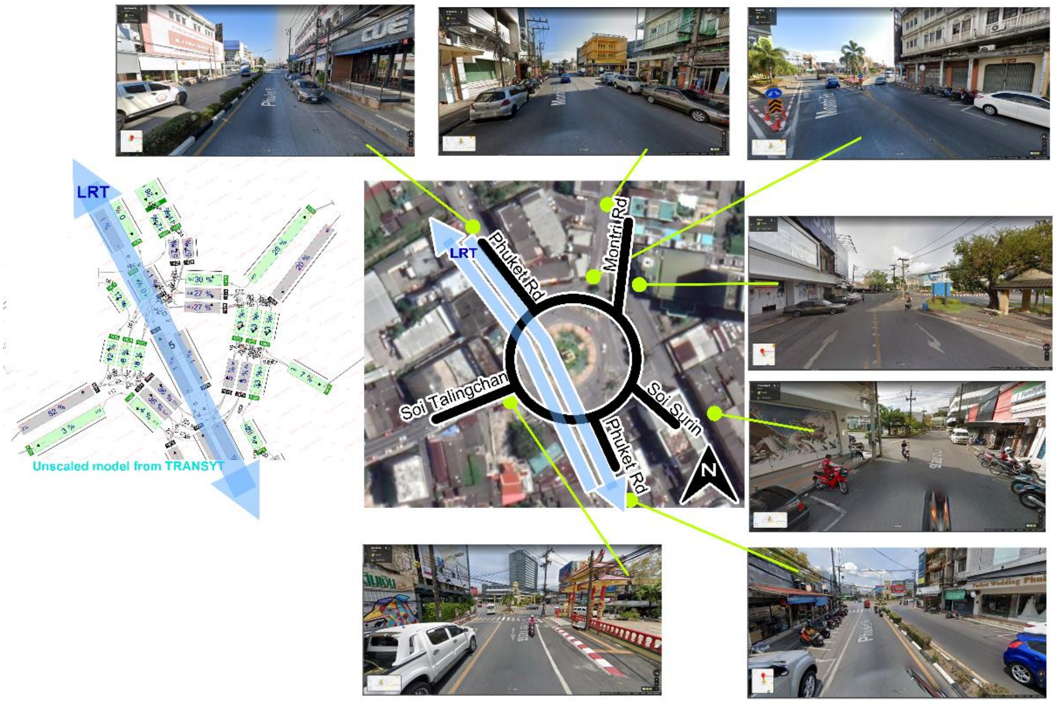


Figure 1 The plan, the TRANSYT model and the roads approaching the Surin Clock Tower roundabout [4]

The roundabout connects 4 roads. Phuket Road is a two-lane road with parking spaces in an approximate north-south direction. Montri Road is a two-lane road with curbside parking spaces connecting the roundabout on the northeast. Soi Surin is a one-way single-lane road with parking spaces and expands to a two-way, two-lane road as it approaches the roundabout on the southeast. Lastly, Soi Talingchan is a two-lane road connecting the roundabout on the west.

1.2 Traffic Management and Transit

At present, the roundabout is unsignalized. Traffic flows clockwise as the left-hand driving rule applies. Priority is given to vehicles in the roundabout over those entering it. As the roundabout geometric design permits, the yield control rule is applied instead of stop control. When LRT is in operation, priority shall be offered to transit vehicles first.

The 2017 feasibility study estimates that the LRT will serve up to 70,000 passengers per day in the opening year 2021 (2564 BE). With the recent proposal for the new system, the railway transit vehicle model for the project has not yet been decided. This study still assumes that traditional electric trams will be used as transit vehicles. The tram specifications define the car length of 30-40 m and the car width of 2.40 or 2.65 m with a capacity of 200 passengers. Tramcars will be driven manually by line-of-sight operation. The service runs at an average speed of 20-40 kph in the Phuket town area and a maximum speed of 80 kph in the outer part of the town. The operation has been flexibly planned to allow coordination with other future projects such as one-way street arrangement and transit-oriented development. The LRT will initially run with an average frequency of 6 cars/hr (headway of 10 minutes) in the town area. The tram will run through Surin Clock Tower Roundabout in both directions of Phuket Road in the first phase of operation.

2. Literature Review

Transit Signal Priority (TSP) gives the transit vehicles priority, which is beneficial to transit cars and results in lower delay. TSP can be categorized into passive, active and adaptive types. Passive signal priority relies on static signal planning and requires no interaction between the traffic signal system and transit vehicles [5]. Active signal priority applies some communication between the traffic signal system and transit vehicles [6]. Adaptive signal priority collects real-time data and adjusts the signal control according to traffic situations.

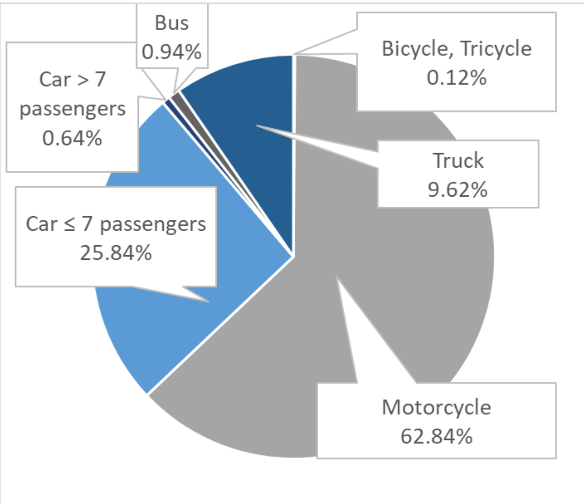
Passive signal priority is generally carried out at a lower cost since there is no need to install vehicle detectors. On the other hand, active signal priority requires the detection of vehicle presence, speed, and density. The location and alignment of the detectors also affect the performance of the signal at various flow levels. At a higher flow rate, and the further the detector from the intersection, the active setting could better clear queues and lower transit delays [7].

Passive signal priority in the urban area is usually designed to maximize bandwidth for transit vehicle progression. Active signal priority could interrupt the offset of the signal, which could result in negative impacts on the network. There are methods to recover to the original settings, for example, compensating in the next cycle [8]. However, the active signal priority might have downside effects on the non-prioritized side streets, especially under high flow situations. Delays on side streets would likely increase due to residual queues [9]. The effect on side streets could also be taken into account using a passenger-based approach [10].

3. Materials and Methods

3.1 Data Collection and Management

Traffic volume statistics were collected during morning peak hours over 5 weekdays. Four cameras were set up. The traffic volumes entering and leaving the roundabout at each leg were recorded with the traffic composition as shown in Figure 2. These traffic volumes were then converted into Passenger Car Units (PCU) using the passenger car equivalent (PCE) factors given by OTP, as shown in Table 1. The design turning movement count (TMC) volumes of street vehicles were analyzed as shown in Figure 3. The TMC volumes were distributed proportionally to each traffic node. Table 2 shows traffic volume balancing in the origin-destination matrix (OD matrix). The most critical movement was found to be the north-south movement from nodes 1-10 to nodes 14-16, with a traffic volume of 515 PCUs/hr.



Vehicle Class	Percentage
Bicycle, Tricycle	0.12
Motorcycle	62.84
Car ≤ 7 passengers	25.84
Car > 7 passengers	0.64
Light Bus	0.25
Medium Bus	0.45
Heavy Bus	0.24
Light Truck	8.99
Medium Truck	0.64

Figure 2 Composition of collected traffic data

Table 1 Passenger Car Equivalent (PCE) Factor [11]

Vehicle Class	PCE factor			
	Urban	Rural	Roundabout	Signalized Intersection
Private Car, Taxi, Light Truck	1.00	1.00	1.00	1.00
Motorcycle	0.75	1.00	0.75	0.33
Medium to heavy truck	2.00	3.00	2.80	1.75
Heavy bus	3.00	3.00	2.80	2.25

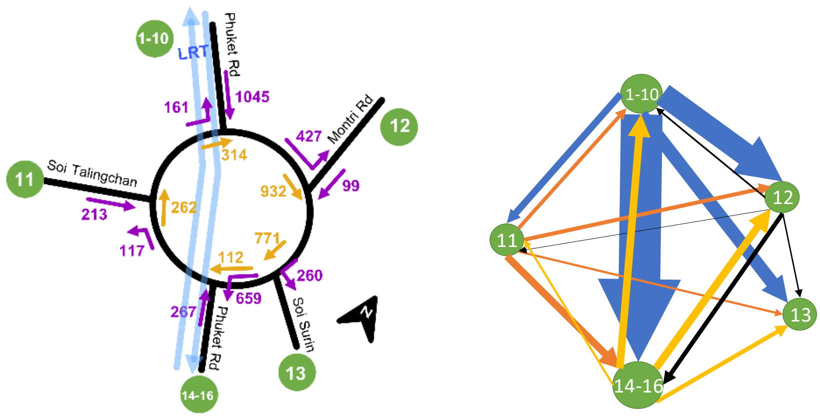


Figure 3 Turning movement counts (TMC) and the desire lines of the volume assigned to Surin Clock Tower Roundabout in PCUs

Table 2 OD matrix (PCUs/hr)

Origin \ Destination	1-10	11	12	13	14-16	Sum
1-10	0	84	284	162	515	1045
11	46	0	50	28	89	213
12	21	6	0	17	55	99
13	0	0	0	0	0	0
14-16	94	27	93	53	0	267
Sum	161	117	427	260	659	

3.2 Assumptions and Scenarios

To simulate traffic operations, assumptions were made as follows:

1) The time period of the simulation is within the first ten years of operation

2) Transit vehicles run on the median with an exclusive lane (left-hand side)

3) Transit drivers drive on sight and are responsible for the safe operation of the vehicle, i.e., keeping a safe distance between vehicles, respecting radio instructions from the control center, driving at a safe speed and being able to stop safely according to environmental conditions, speed restrictions, LRT signaling color aspects and other operating instructions.

Five scenarios were assigned with the same design volumes. All vehicles run at the cruise speed of 30 kph. The transit vehicles run with a frequency of 6 cars/hr. The five scenarios are set as follows:

3.2.1 SC1: Unsignalized control without LRT

This scenario replicates the base network when the LRT project has not been executed. The street vehicles yielded when entering the roundabout.

3.2.2 SC2: Unsignalized control with yield

This scenario was treated as the base scenario. There is no traffic signal control in the conflict areas. All entering vehicles must yield to vehicles already in the roundabout. Both entering and roundabout vehicles must always yield to the transit vehicles.

3.2.3 SC3: Unsignalized roundabout with actuated signal control for LRT

Street vehicle traffic would run with a green signal with yield in the base scenario. However, LRT vehicles had priority to pass the intersection using the actuated signal. The expressions were as shown in Table 3. The detectors were placed 80 m upstream before the stop. The distance from the detector to the stop was calculated using the LRT speed of 30 kph, intergreen (i.e., yellow plus red time) time of 5 s and LRT deceleration rate of 1.2 m/s^2. The logic file was created using VISVAP, as shown in Figure 4. Two stages were assigned: Stage 1 for street vehicles and Stage 2 for transit vehicles. When the individual upstream sensor detected a vehicle, it would trigger a request for a transit priority signal.

The signal only changes when all the LRT vehicles that enter the intersection have safely passed the downstream detector.

Table 3 Expressions for VAP logic for SC3

EXPRESSIONS	Contents	Comment
DetNB_UP	Occupancy(501) > 0	Northbound Upstream detector
DetNB_DWN	Occupancy(502) > 0	Northbound Downstream detector
DetSB_UP	Occupancy(503) > 0	Southbound Upstream detector
DetSB_DWN	Occupancy(504) > 0	Southbound Downstream detector

3.2.4 SC4: Fixed Time signal

The signal timing was set to run repeatedly regardless of traffic volume variations. Signal timing was designed using TRANSYT with the focus on reducing transit delay. This is equivalent to the passive transit signal priority where transit delay is minimized by the signal progression. However, if an LRT vehicle arrives during the red time, it must wait for the signal to complete the cycle until the green is given.

3.2.5 SC5: Signalized Street vehicles control with transit actuated signal

The logic file, as shown in Figure 5, was coded based on the existing study [12] and a Vissim tutorial [13]. The expressions were as shown in Table 4. In this scenario, if there was no LRT vehicle approaching the intersection, the signal plan would be the same as in the fixed time signal scenario. If the LRT vehicle approaches the intersection, it runs over the detector placed upstream of the intersection. The upstream detector then sends a signal to actuate the signal control of the intersection. The signal controller gives arriving LRT vehicles priority over other street vehicles to pass the intersection or roundabout by calling the signal stage accommodating LRT movement (Stage 4) after finishing the minimum green time of the current stage. “NEXT” indicates the next stage after finishing Stage 4. The “Excess4” variable stores the excess green time of Stage 4 of the current cycle to compensate by giving more time for other stages by reducing the green time of Stage 4 in the next cycle. After the LRT vehicle has passed the downstream detector, the signal shifts to the stage specified by NEXT.

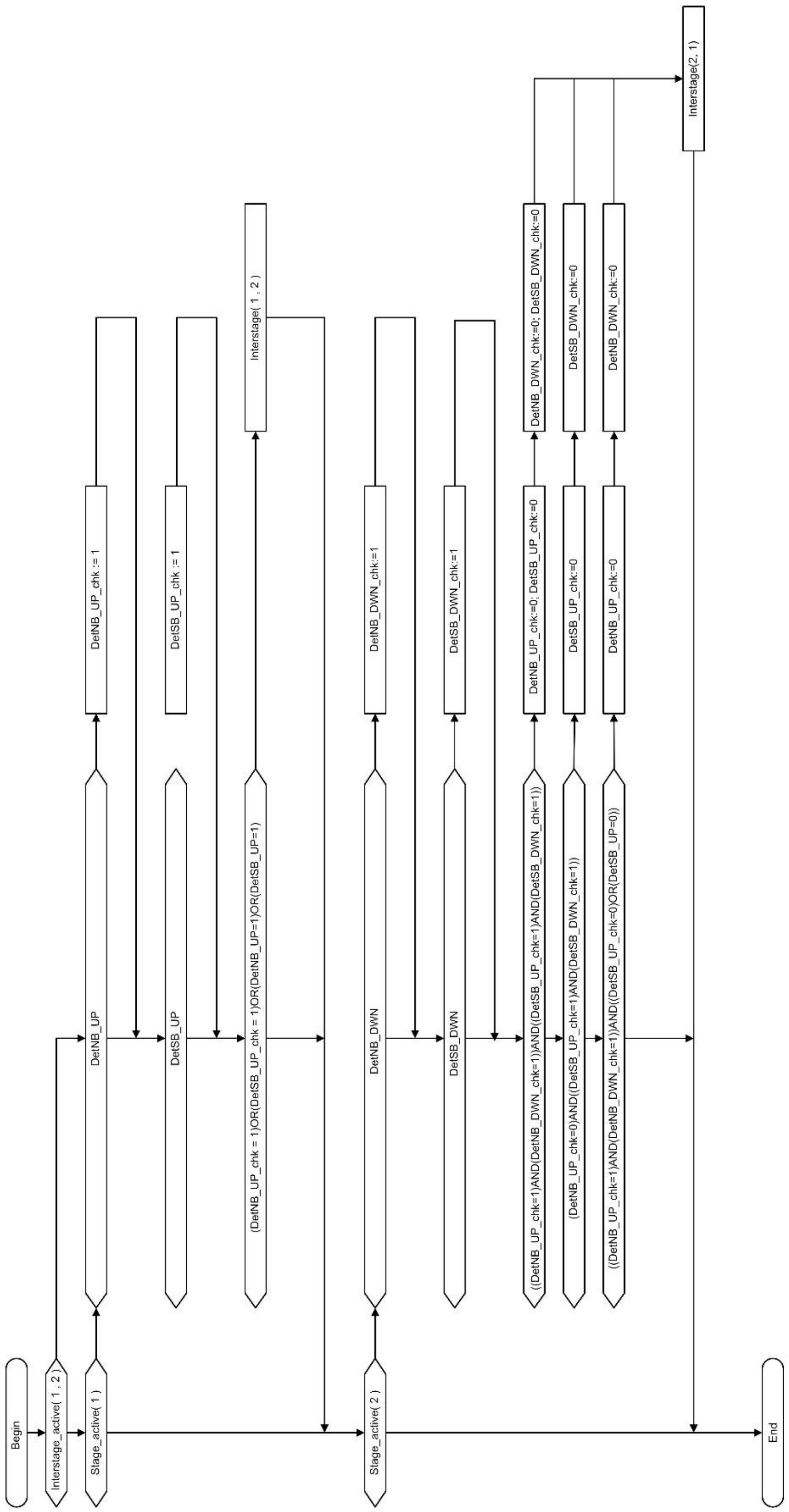


Figure 4 Unsignalized street vehicle control with actuated signal control for transit signal logic

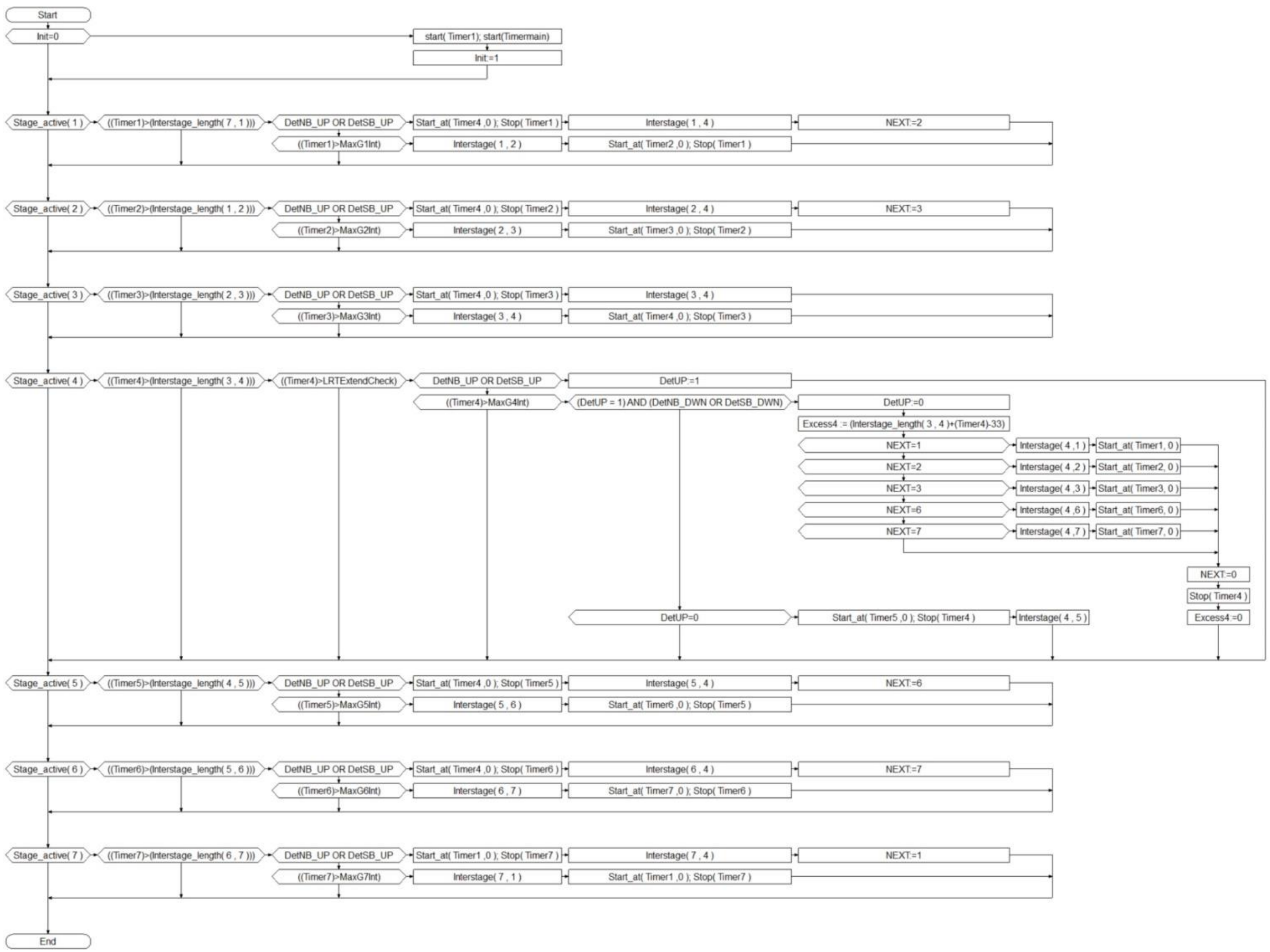


Figure 5 VAP logic of the signalized street vehicle control with tram-actuated signal control (SC5)

Table 4 Expressions for VAP logic for SC5

EXPRESSIONS	Contents	Comment
DetNB_UP	Occupancy(501)>0	Northbound Upstream detector
DetNB_DWN	Occupancy(502)>0	Northbound Downstream detector
DetSB_UP	Occupancy(503)>0	Southbound Upstream detector
DetSB_DWN	Occupancy(504)>0	Southbound Downstream detector
MaxG1Int	(Interstage_length(7 , 1)+G1)	Interstage5s+G1
MaxG2Int	(Interstage_length(1 , 2)+G2)	Interstage5s+G2
MaxG3Int	(Interstage_length(2 , 3)+G3)	Interstage5s+G3
MaxG4Int	(Interstage_length(3 , 4) +Excess4+G4)	Interstage5s+ExcessG4formerG4 +G4
MaxG5Int	(Interstage_length(4 , 5)+G5)	Interstage5s+G5
MaxG6Int	(Interstage_length(5 , 6)+G6)	Interstage5s+G6
MaxG7Int	(Interstage_length(6 , 7)+G7)	Interstage5s+G7
LRTExtendCheck	(Interstage_length(3 , 4) +G4-LRTtoStop)	Interstage5s+G4-ApproachingLRTtime:10s

3.3 TRANSYT and Vissim

To develop signal timing plans using TRANSYT, network inventory data (e.g., number of lanes, length, route alignments), traffic stream characteristics (e.g., traffic counts, speed, route decision) and traffic control (e.g., right of way, signal controllers and signal groups) were required. Subsequently, TRANSYT would provide signal timing along with other measurements (e.g., progression, delay) based on those inputs. The Vissim simulation could be started by coding with the same input data used in TRANSYT and signal timing from TRANSYT. The simulations were run, then the average measurements of each run, such as delay, travel time and queue length, were obtained. Each scenario was run with varied transit headways and proportionally varied street traffic volumes.

3.4 Signal Phasing and Timing

The signal control of the roundabout was planned as a series of three intersections that were closely located under the same controller. Seven possible movements were placed into three groups, as shown in Figure 6. The traffic signal stages could be arranged as shown in Figure 7, aiming to achieve traffic progression for all legs and prevent spillback.

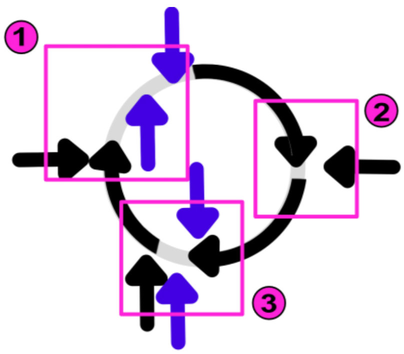


Figure 6 Signal head groups

Considering the width of the intersections within the roundabout, the intergreen and minimum green times were set to 5 and 7 seconds, respectively. For the cycle time of 40 seconds, these were set to 4 and 6 seconds to satisfy the cycle time limit.

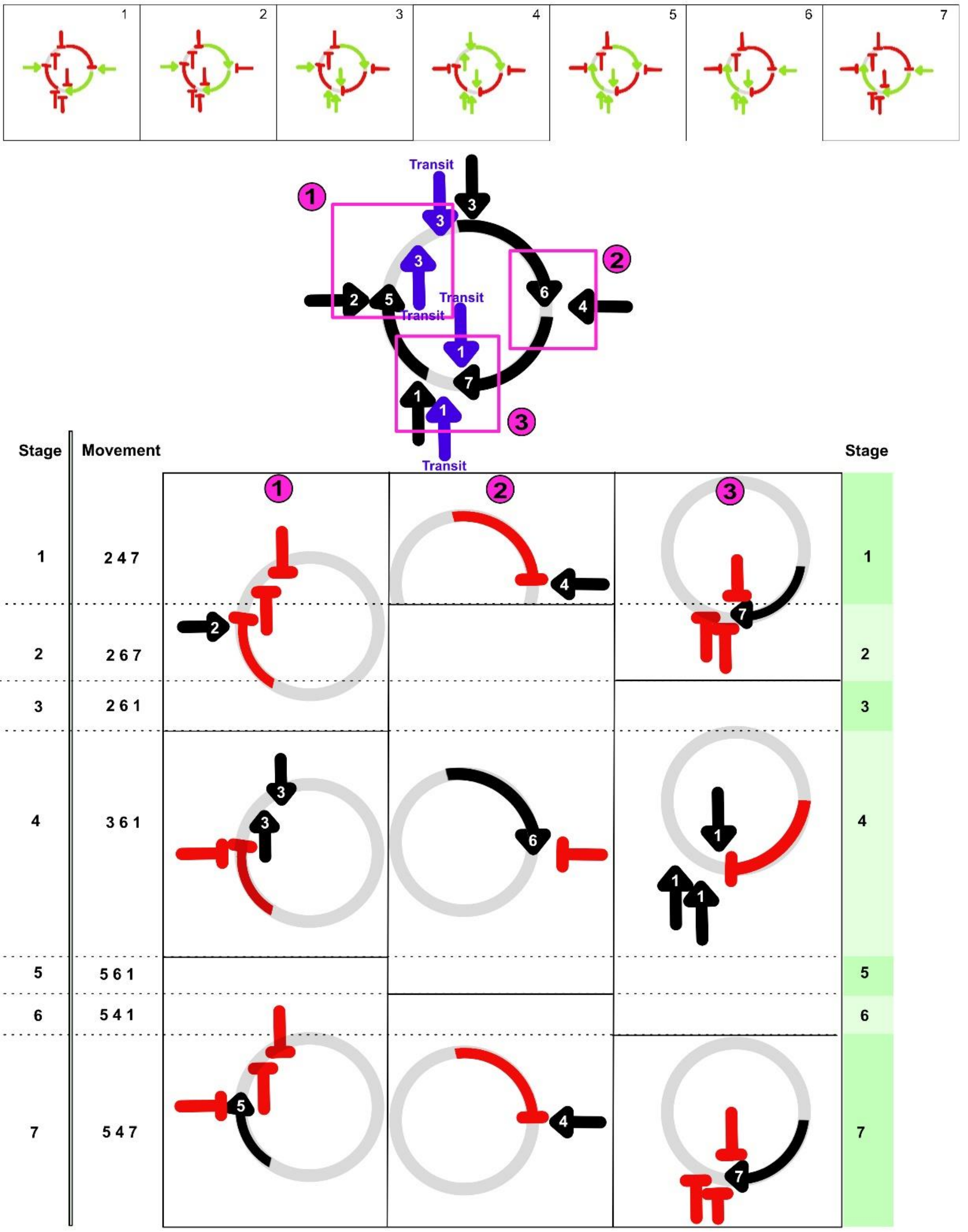


Figure 7 Signal control stages

4. Results and Discussion

The results from TRANSYT and Vissim were collected using different tools. TRANSYT allows the user to collect both total network and individual link performance. The results from Vissim were collected using the Vehicle Travel Time and Queue Counters tool placed on the network.

4.1 Results from TRANSYT

The signal timings are as shown in Table 5. The green time (G) is the difference between the starting green time (G_S) and the ending green time (G_E). Figure 8 shows an example of a signal timing plot at the cycle length of 90 seconds. The horizontal axis represents time and the vertical axis represents signal group/movement.

Table 5 Signal Timing from TRANSYT (s)

Cycle Time (s)	Time in a Cycle	Signal Group/Movement						
		1	2	3	4	5	6	7
40	G_S	33	23	38	13	8	28	18
	G_E	14	34	4	24	19	9	29
	G	21	11	6	11	11	21	11
50	G_S	14	2	20	39	33	8	45
	G_E	40	15	28	3	47	34	9
	G	26	13	8	14	14	26	14
60	G_S	35	22	41	9	3	29	15
	G_E	10	36	58	24	17	4	30
	G	35	14	17	15	14	35	15
70	G_S	18	5	24	57	51	12	68
	G_E	63	19	46	7	70	52	13
	G	45	14	22	20	19	40	15

Table 5 Signal Timing from TRANSYT (s) (continued)

Cycle Time (s)	Time in a Cycle	Signal Group/Movement						
		1	2	3	4	5	6	7
80	G_S	16	74	22	56	50	10	66
	G_E	61	17	45	5	69	51	11
	G	45	23	23	29	19	41	25
90	G_S	16	1	23	68	62	10	81
	G_E	76	18	57	5	86	63	11
	G	60	17	34	27	24	53	20
100	G_S	5	88	14	68	62	99	78
	G_E	73	9	57	94	83	63	100
	G	68	21	43	26	21	64	22
110	G_S	3	88	9	65	59	107	78
	G_E	73	4	54	102	83	60	108
	G	70	26	45	37	24	63	30
120	G_S	58	42	73	21	15	52	32
	G_E	27	68	10	47	37	16	53
	G	89	26	57	26	22	84	21

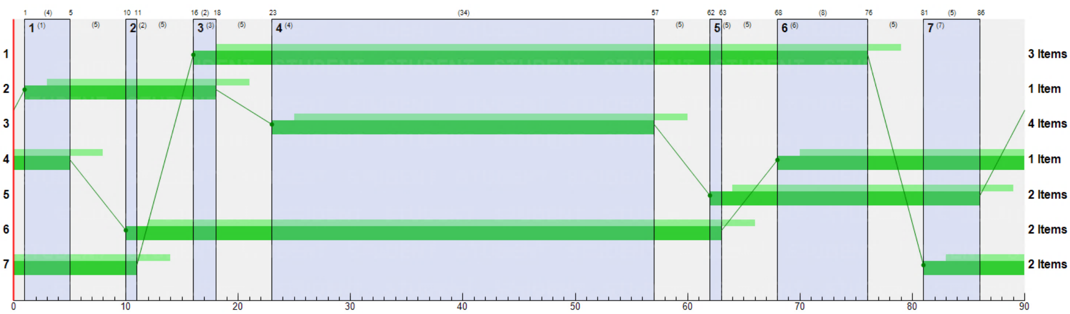


Figure 8 The signal design at cycle length = 90 s from TRANSYT

The network was coded in TRANSYT. The saturation flow rate of each lane was estimated and varied by its turning operation. The exclusive left turn, right turn and through lane had saturation flow rates of 1425, 1600 and 1675 PCUs/hr/lane. The left-through and right-through shared lanes had saturation flow rates of 1600 and 1625 PCUs/hr/lane, respectively.

For the fixed time scenario, various cycle times were tested under prevailing traffic conditions. The signal timings were evaluated using data from TRANSYT. Measures of effectiveness include v/c ratio, delay and bandwidth efficiency and attainability, as shown in Figure 9. Other parameters were external maximum queue length on the roundabout and average delays of southbound, northbound and LRT cars, as shown in Figure 10.

From the evaluation results, a cycle time of 90 seconds was chosen in actuated signal scenarios. The selected cycle time resulted in a low average delay for both street and transit cars, v/c ratio and external max queue length. This cycle time also yielded high bandwidth efficiency.

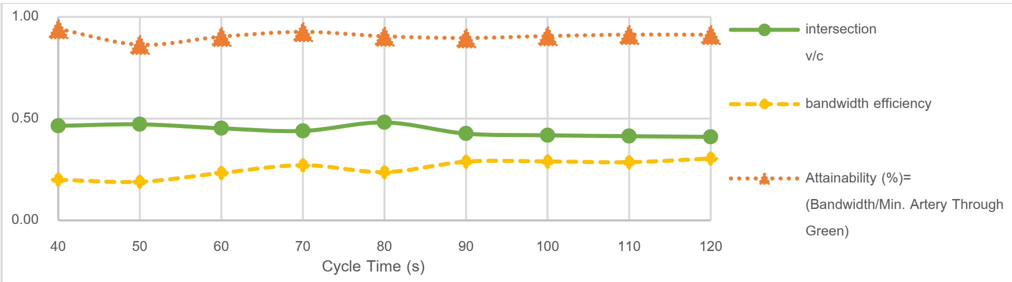


Figure 9 The relationship between v/c ratio, bandwidth efficiency, attainability and cycle time of fixed time scenario

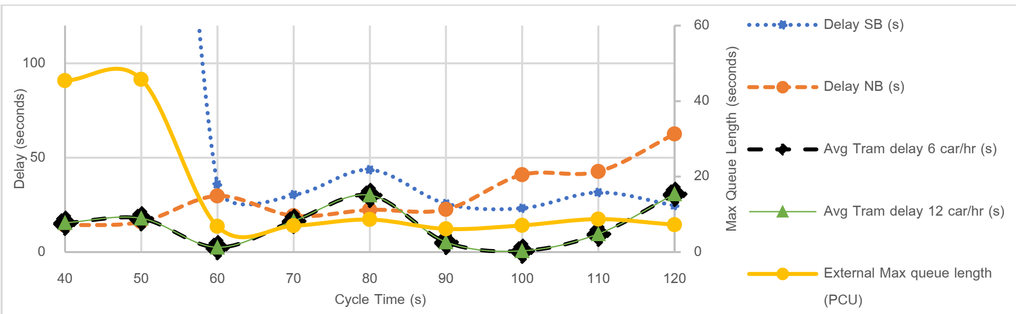


Figure 10 The relationship among average delay, external max queue length and cycle time of the fixed time scenario

4.2 Results from Vissim

Each scenario was simulated with multiple runs with the same set of seeds. The total runtime of each simulation was 4,500 seconds, with the initializing period of 900 seconds or 15 minutes to bring the traffic to the steady state. The statistical data were collected in the next 3,600 seconds or 60 minutes. After the simulation runs had been completed, the average indicators from 5 runs were taken using the queue counter and travel time measurement tool in Vissim for key movements as shown in Figure 11a. The average delay of the roundabout was the result of the weighted mean delay from all movements as shown in Figure 11b. The total and average delay was as shown in Table 6.

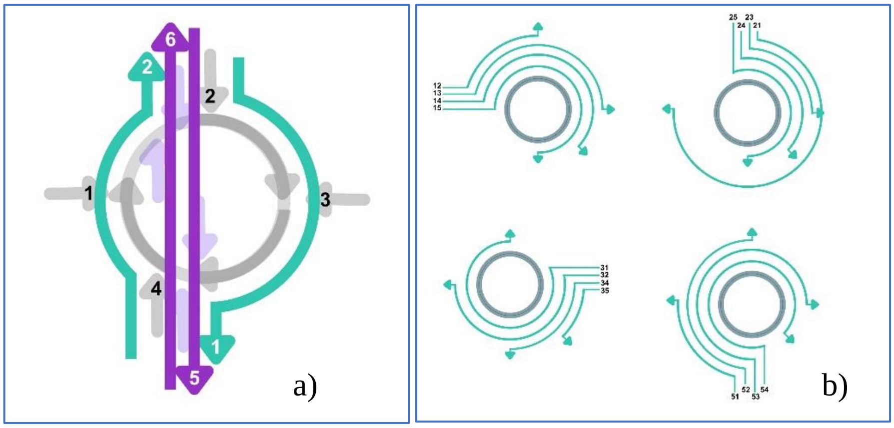


Figure 11 The Vissim Travel Time tool placements a) legs and LRT, b) traffic going through the roundabout

Table 6 The Average Road and LRT Delay Results from Vissim

Scenarios	Avg. Road Delay (s)				Avg. LRT Delay (s)			
	Headway (min)				Headway (min)			
	10	7.5	6	5	10	7.5	6	5
SC1	8.12				5.91			
SC2	7.04	6.66	6.98	6.85	0.04	0.01	0	0
SC3	5.85	5.78	5.78	5.96	1.21	1.21	1.26	1.25
SC4	33.92	33.92	33.92	34.38	16.11	8.76	8.83	16.19
SC5	35.42	34.45	35.18	33.55	11.74	0.78	0.78	8.45

Figure 12 shows that the unsignalized street vehicles control scenarios (SC1, SC2 and SC3) had significantly lower average street vehicles delay compared to the signalized control scenarios (SC4 and SC5). This may be true if the street volumes were not so high and these vehicles were able to maneuver around one another perfectly. Introducing signalized control would inevitably generate additional delay while ensuring a higher level of safety. The street vehicle delay from the actuated signal control scheme (SC5) was slightly higher than that from the fixed-time control (SC4). However, using actuated transit priority control cut down the LRT delay in SC5 approximately by half compared to SC4 as shown in Figure 13. Transit headways ranging from 6 to 7.5 minutes resulted in similar LRT delays for SC2, SC3, and SC5 schemes.

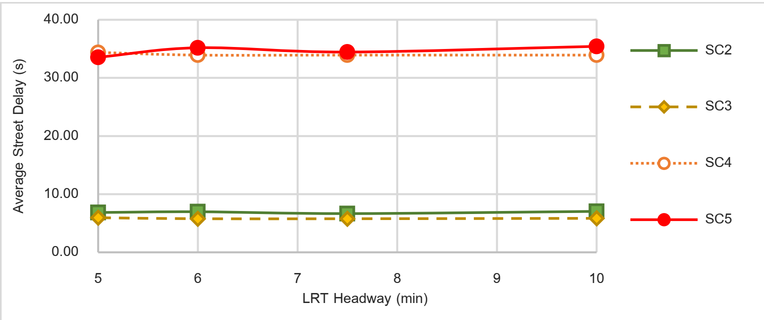


Figure 12 The relationship between average street delay and LRT Headway

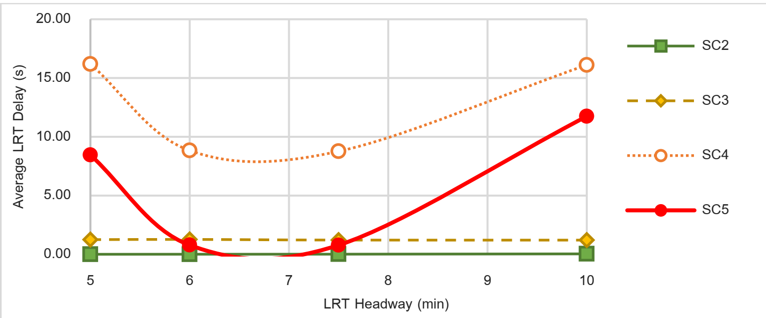


Figure 13 The relationship between average LRT Delay and LRT headway

It is always difficult to claim a good estimate of future traffic volumes with limited data. Instead, different volume growth rates were tested in this study to understand their impacts on street delay, average queue length and maximum queue length, as shown in Figure 14,

Figure 15, and Figure 16. In the morning peak hours, the approach with the heaviest traffic, hence the longest queue, was the southbound direction entering the roundabout.

This southbound leg was considered the critical approach where the delay and queue length were measured. The unsignalized control with transit actuated phase (SC3) showed the lowest delay. The other two unsignalized control schemes (i.e., SC1 and SC2) also showed low street delays but there was a sharp climb when the street volumes increased by 20% and 30%. The street delays from SC4 and SC5 were higher for the current traffic conditions but increased with lower rates at the higher traffic volume. At higher volumes, SC5 with signal control actuation tended to have average shorter queues compared to SC4 as in the previous study [7]. The average queue length presented the same trend for all five scenarios. The maximum queue lengths for unsignalized control schemes, however, increased sharply with street volumes. The delays from these three scenarios almost matched those from signalized schemes when street traffic volume increased by 30%. With extremely unbalanced travel demand, especially the southbound movement, the signal design that based on maximizing bandwidth for vehicle progression was proved to have severe negative effects on side streets for both delay and queue length as in the previous study [9].

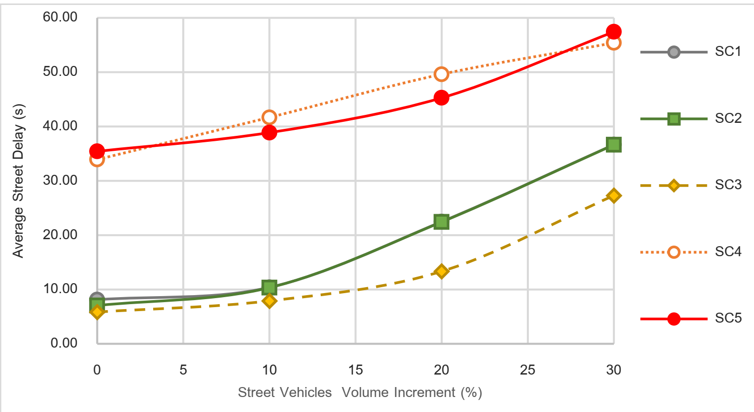


Figure 14 The relationship between average street delay and street vehicles volume increment percentage

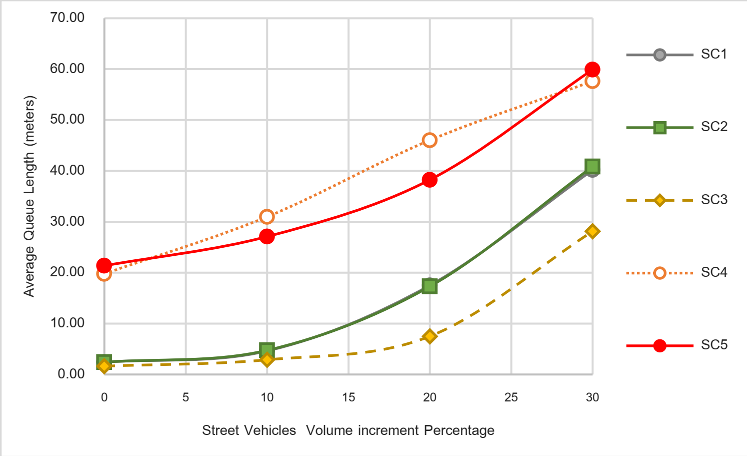


Figure 15 The relationship between average queue length and street vehicles volume increment percentage

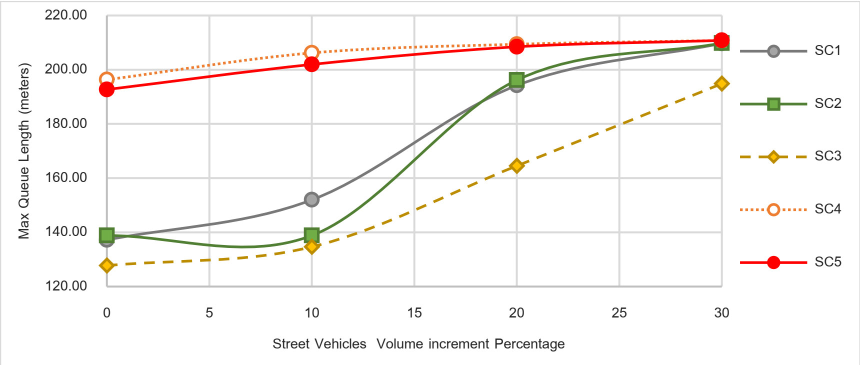


Figure 16 The relationship between max queue length and street vehicles volume increment percentage

5. Conclusion and Recommendation

Surin Clock Tower Roundabout currently accommodates a medium range of traffic demand during peak hours and is expected to carry a much larger volume in the future. The critical movement is necessarily southbound through traffic where the traffic demand is highest and long queues are often observed. However, under the current scheme where the LRT is not in place, the roundabout will be able to accommodate future traffic with reasonably low delays and acceptable queue lengths for all approaches. LRT installation and operation will adversely affect traffic condition. The optimum roundabout control scheme is needed to balance the trade-off between the street traffic delay and public transport progressive movement. This study investigated and compared four improvement schemes for roundabout control using some measures of effectiveness obtained from microscopic simulations.

Undoubtedly, the unsignalized control with yield scheme (SC2) resulted in the lowest street vehicle and LRT delay as it did not require either to stop or yield unless absolute movement conflicts occurred. The unsignalized roundabout with actuated signal control scheme (SC3) yielded equally low street delay and queue length. This scheme has a slight advantage because it allowed part of the critical southbound street movement to freely enter the roundabout simultaneously with the LRT. Thus, this scheme would receive less delay from this approach and queues could be cleared more easily. Under the actuated public transport priority signal control, the LRT would experience similarly good progression and minimal delay as for the unsignalized control scheme. The fixed-time signal control (SC4) produced by far the worst outcome in terms of both street vehicle and LRT delays as it continually gave green to all approaches regardless of vehicle absence. SC5 which applied the optimum fixed-time signal planning on street vehicles only and inserted an actuated phase for LRT proved to be much more effective in reducing delays to the LRTs although the street vehicle delay was not significantly improved.

For Phuket LRT operations, this study would suggest using SC3: Unsignalized street vehicle control with transit actuated signal control due to its low average street delay, transit delay and queue length. The actuated signal control could provide safer operations while providing necessary transit priority. The automatic physical barrier could be installed at the at-grade intersection to ensure traffic safety. When the street traffic volumes increase in the future, by more than 30% of the current condition, signalized control with transit priority could be considered to minimize the impact of queue length and spillback to the upstream intersection.

This study necessarily focused on transit signal priority through the roundabout in the north-south direction. For future research, the comparison with signal designs on the roundabouts with different characteristics could be implemented. The effects on side streets could also be considered and managed, for example, using the adaptive traffic control system. Moreover, the scope of the study included only an isolated roundabout. Further research could consider a larger part of the network involving traffic signal progression through the nearby intersections. Other roundabouts could be selected for comparative studies and alternative signal timing strategies could be tested.

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