Dynamic Lane Configuration Treatment at Signalized Intersections in Bangkok, Thailand

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ABSTRACT

Managing traffic congestion at highly congested urban intersections has been known very challenging. In Bangkok, Thailand, where the driving-on-the-left-side-of-the-road applies, right-turn traffic is typically considered the most critical movement at intersections. Various countermeasures have been used depending on the local traffic and physical conditions. A dynamic lane configuration is among the many options that has been implemented at major intersections in Bangkok where additional right-turn lane is required during the peak hours. The dynamic lane treatment converts one through lane to a right-turn lane which results in either dual- or triple-turn lanes configuration. The operational performance and requirements of the dynamic lane application have not been known to a large degree. The aim of this study is to evaluate operational effects of the dynamic lane treatment at signalized intersections under various conditions through a simulation approach. VISSIM simulation model was used to assess performance measures in terms of the overall travel delay and the maximum queue length. Local traffic data and the intersection profile were collected at the intersection of Suk Sawat Road and Pracha Uthit Road located in suburban area of Bangkok. The analysis results suggest that the fully functioned dynamic lane application could reduce the overall intersection delay and the maximum queue length for the applied direction by up to 27.1% and 59%, respectively. In addition, it is found that a lane management for the receiving leg was the key success for the dynamic lane operations. In this study, the auxiliary lane was used to smooth out the transition between the three right-turn lanes and the two receiving lanes during the lane conversion. The known operational effects from this study can put forward recommendations for effectively implementing dynamic lane configuration as an alternative treatment at signalized intersections.

INTRODUCTION

Traffic congestion has been known as the prevailing issue in Bangkok Metropolitan area. Nearly all major roads and intersections in the city have been experiencing significant number of vehicles and resulting in extremely high travel delays. Among the various efforts to improve the congested traffic conditions in Bangkok, the dynamic lane configuration treatment has been introduced at the major intersections where right-turn traffic volume is heavy during the peak hours. The right-turn movement is considered most critical at intersections for those countries with left-hand traffic system. The dynamic lane configuration has been used during the weekday peak periods by converting one of the through lanes into a right-turn lane. The key challenge for this application is that many urban intersections usually have geometric constrains on the receiving leg that make it difficult to increase the number of lanes to match with the increased number of the right-turn lanes. As a result, some intersections are required to operate with imbalanced lanes between the approaching lanes and the receiving lanes.

The objective of this study was to investigate operational effects of the dynamic lane treatment at signalized intersections based on two configurations including the imbalanced and balanced lanes between the right-turn lanes and the receiving lanes. The study intersection is controlled by a traffic signal and located in urban transition area of Bangkok. The operational performance measures for each alternative were generated through a simulation approach using the calibrated model in VISSIM.

LITERATURE REVIEW

Access management has been considered as one of the effective strategies to manage a traffic congestion on urban roads. The capacity and traffic operations performance at intersections usually contribute to overall level of services and safety risk of a transportation network. Managing the congestions at urban signalized intersections is very challenging due to geometric constrains and the interactions between vehicles, pedestrians, non-motorized vehicles.

In attempt to overcome the congestion problem at signalized intersections, ones have developed guidelines and recommended treatments ranging from a signal retiming, a reconfiguration of lane channels, and a modification of the entire intersection. As a rule of thumb, the intersection will require dual left-turn lanes when the left-turn volume exceeds 300 vehicles per hour and triple left-turn lanes may be used where left-turn traffic exceeds 600 vehicles per hour. The operational success of the triple left-turn lanes will be based on lane distribution for the approaching leg (FHWA, 2014).

FHWA also divides alternative intersection treatment into three categories including intersection reconfiguration and realignment, indirect left-turn, and a grade separation treatment. The indirect left-turn treatment includes jug handle, median U-turn, continuous flow intersection or displaced left-turn intersection (XDL), quadrant intersection, and super-street. The displaced left-turn intersection has been used to eliminate the left-turn signal phase and increase the overall intersection capacity by 15% to 30%. However, the XDL design requires additional right-of-way and is suitable for the location where the left-turn traffic is regularly high (Esawey et al., 2007).

Other alternative intersection treatments include the use of bypass lane for T-intersections and the use of auxiliary lanes to accommodate either left-turn or right-turn movements. The auxiliary lane has been used at signalized intersections to add more capacity to the receiving leg by allowing turn-on-red operations. Another benefit of the auxiliary lane is related to the increase of saturation flow rate. The previous study found that the overall width of the receiving leg is usually perceived as a visual target for the left-turning drivers. It was found that the saturation flow rate increased from 1,725 passenger cars per hour per lane (pcphpl) to 1,833 pcphpl when the total width of the receiving leg increased from 7.3–11 meters (24–36 feet) to 12–16.5 meters (40–54 feet) (TRB, 2014).

It is apparent that most of the conventional treatments are effective for intersections with unconstrained physical conditions. In many cases, a modification or a combination of treatments may be necessary depending on local conditions. The operational effects and guidelines for the dynamic lane practice have not been available for local conditions in Thailand and will need attentions at a larger degree.

METHODOLOGY

A traffic simulation modeling approach through VISSIM version 7 was used in this study. VISSIM is a microscopic simulation model used to replicate the real-world driving behavior. Three traffic parameters were used in a model calibration process. These parameters include traffic volume, speeds, and queue length. The calibration was performed based on the recommended guidelines by FHWA (Dowling et al., 2004). Three scenarios were created in VISSIM as shown in Figure 1. These scenarios include:

- Scenario 1 (No Dynamic Turn-Lane): This scenario represents the intersection operations without the dynamic lane treatment. The traffic movement #5 in Figure 1(a) traveled from two lanes to two lanes
- Scenario 2 (Dynamic Turn-Lane without Auxiliary Lane): This scenario represents the existing dynamic lane operations without the auxiliary lane on the receiving leg. The traffic movement #5 in Figure 1(b) traveled from three lanes to two lanes.
- Scenario 3 (Dynamic Turn-Lane with Auxiliary Lane): This scenario represents the dynamic lane operations with one auxiliary lane added to the receiving leg. The traffic movement #5 in Figure 1(c) traveled from three lanes to three lanes.

The operational effects of the simulated scenarios were identified through performance measures including the maximum queue length and the average travel delay based on multiple VISSIM runs. A minimum number of 10 runs per scenario was used to account for stochastic variability in the simulation model. For purpose of this analysis, the traffic signal was held constant across the scenarios to isolate the operational impacts based on the dynamic lane alone.

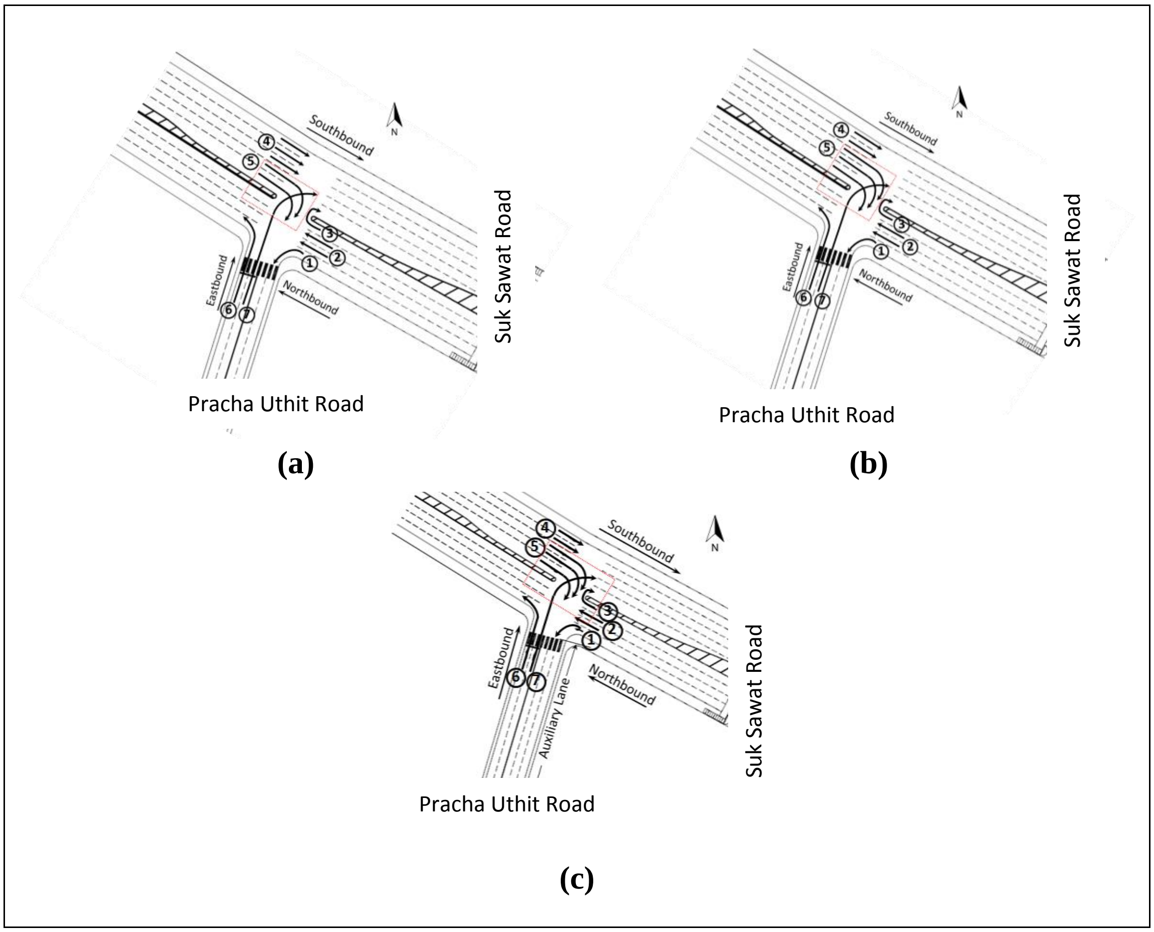


Figure 1. Study Scenarios – (a) Scenario 1, (b) Scenario 2, (c) Scenario 3

DATA COLLECTION

The study location is a signalized T-intersection of Suk Sawat Road and Pracha Uthit Road located in Thung Khru district in Bangkok. There is one adjacent intersection located at 500 meters (1,640 feet) north of the study intersection on Suk Sawat Road. The intersection has entering traffic volume of nearly 75,000 vehicles per day and more than 9,000 vehicles per hour during the peak hour (BMA, 2013). Figure 2 shows the location of the study intersection.

Suk Sawat Road is an 8-lane divided arterial traveling in the north-south direction and connecting between the downtown area of Bangkok and suburban areas. It has a travel lane width of 3.5 meters (11.5 feet) in both directions. Pracha Uthit Road is a 4-lane undivided arterial traveling in the east-west direction and serving as a collector road with a travel lane width of 3.3 meters (11 feet) in both directions. During the peak periods, the dynamic lane conversion has been operated in the southbound direction of Suk Sawat Road to convert one of the southbound through lanes to a right-turn lane, resulting in triple right-turn lanes. At present, the lane conversion has been operated manually using traffic cones.

The study intersection is controlled by a traffic signal with a protected right-turn phase for the southbound Suk Sawat Road and a split phase for the eastbound Pracha Uthit Road. The through traffic on southbound Suk Sawat can bypass the signal at all time. The intersection has a fixed cycle length of 313 seconds during the observed PM peak period and 162 seconds during the off peak periods.

The traffic data collection was performed at the study intersection for 2 weekdays in November 2015 using a video recording. The PM peak hour was selected for the analysis due to its heavy right-turn volume. The PM data collection was performed between 3.00 pm and 7.00 pm. Figure 3 shows the PM peak traffic volume for all approaches. The study intersection had the PM peak volume of 7,930 vehicles per hour with a peak direction for the southbound Suk Sawat Road (4,040 vehicles per hour). The southbound right-turn volume was 2,055 vehicles per hour.

Table 1 shows vehicle classifications at the study intersection. There were 5 vehicle types including motorcycles, passenger cars, small buses, regular buses, and trucks observed at the study intersection. Similar to a typical traffic composition in Bangkok, motorcycles were dominant in the traffic stream, with more than 50 percent of the total traffic volume for nearly all approaches. The passenger cars were observed at a range between 33.2 and 46.4 percent while the share of all buses and trucks was about 4.7 to 9.1 percent. Southbound Suk Sawat Road had the highest proportion of all buses and trucks in the traffic stream.

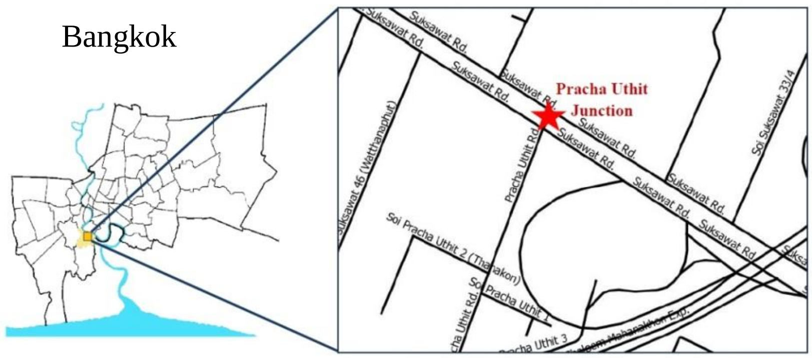


Figure 2. Study Area Map.

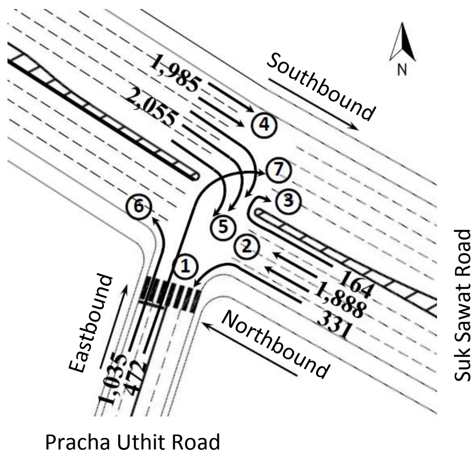


Figure 3. PM Peak Traffic Volume (vehicles/hour).

Table 1. Traffic Volume by Vehicle Classification (AM Peak).

Vehicle Type	Suk Sawat/Pracha Uthit Intersection		
	Northbound (1)+(2)+(3) (Inbound)	Southbound (4)+(5) (Outbound)	Eastbound (6)+(7) (Minor)
Motorcycle	51.3	44.5	59.6
Passenger car	44	46.4	33.2
Small bus	0.6	3.8	6.3
Regular bus	2.8	2.3	0.8
Trucks	1.3	3.0	0.1
Total	100	100	100

MODEL CALIBRATION

The model calibration was performed by comparing between the model performance results and the field measurements for traffic volumes and speeds. Driving behavior parameters were adjusted until the resulting volumes and speeds are within acceptable criteria (Dowling et al., 2004). The GEH Statistics was used for the traffic volumes comparison and it was computed as follows:

$$GEH = \sqrt{\frac{(E-V)^2}{(E+V)/2}} \tag{1}$$

Where:

E = model estimated volume, (veh/hr.)
V = field count, (veh/hr.)

For the acceptable model, it is recommended that the GEH Statistics should be less than 5 for individual link volume for more than 85% of the cases. Difference between the estimated speeds and the actual speeds should be less than 20%. The model calibrations results are shows in Tables 2 and 3 respectively for volumes and speeds.

Table 2. Calibrated Model Results for Traffic Volumes.

Collection Points	Volume (vph.)		GEH	Logical Test
	Model	Observed		
1	2,382	2,383	0.02	Accepted
2	4,039	4,040	0.02	Accepted
3	1,042	1,035	0.22	Accepted
4	468	472	0.18	Accepted
5	308	331	1.29	Accepted
6	1,868	1,888	0.46	Accepted
7	161	164	0.24	Accepted
8	2,146	1,985	3.54	Accepted
9	1,836	2,055	4.97	Accepted
10	1,047	1,035	0.37	Accepted
11	452	472	0.93	Accepted
12	2,919	2,923	0.07	Accepted
13	2,144	2,316	3.64	Accepted
14	2,757	2,621	2.62	Accepted
Total	23,569	23,720	0.98	Accepted

Table 3. Calibrated Model Results for Speeds.

Collection Points	Speed (kph.)		%Diff	Logical Test
	Model	Observed		
1	5	5	9.14	Accepted
2	40	38	-6	Accepted
3	10	10	3.19	Accepted
4	60	57	-4.76	Accepted
5	20	19	-3.46	Accepted
6	40	33	-12.50	Accepted
7	30	34	12.66	Accepted

OPERATIONAL RESULTS

This section presents the operational results for all simulated scenarios. Maximum queues and travel delays were used as the performance measures to indicate how well the dynamic lane treatment operated relative to the normal operations. The maximum queues are reported for the entire approach while the travel delays are reported for individual movement and for the entire intersection.

Scenario 1 – No Dynamic Turn-Lane

In Scenario 1, the intersection operated at overall delay of 90.3 seconds per vehicle. With the limited capacity for the southbound dual right-turn lanes on Suk Sawat Road, the maximum queue generated in this direction spilled back into the upstream intersection. Table 5 presents the simulation results for Scenario 1.

Table 4. Results for Scenario 1

Approach	Movement	Average Speed within Intersection (kilometers/hour)	Maximum Queue length (meters)	Travel Delay (seconds/ vehicle)
Northbound	LT (1)	18	224	110.5
	TH (2)			109.9
	UT (3)			103.2
Southbound	TH (4)	51	568	17.6
	RT (5)			194.3
Eastbound	LT (6)	33	99	15.8
	RT (7)			88.3
Intersection	All	34		90.3

Note: LT = left turn movement, TH = through movement, UT = u-turn movement, RT = right turn movement.

Scenario 2 – Dynamic Turn-Lane without Auxiliary Lane

Table 5 presents the simulation results for Scenario 2, where the dynamic lane was applied to the southbound Suk Sawat Road without the auxiliary lane. In this scenario, the southbound approach of Suk Sawat Road had the maximum queue length of 495 meters (1,624 feet) that did not spill back to the upstream intersection. The overall intersection delay was 107.2 seconds per vehicle with the maximum delay of 266.1 seconds per vehicle for the southbound right-turn movement from Suk Sawat Road to Pracha Uthit Road.

Table 5. Results for Scenario 2

Approach	Movement	Average Speed within Intersection (kilometers/hour)	Maximum Queue length (meters)	Travel Delay (seconds/ vehicle)
Northbound	LT (1)	18	225	111.0
	TH (2)			109.9
	UT (3)			103.3
Southbound	TH (4)	38	495	16.7
	RT (5)			266.1
Eastbound	LT (6)	33	98	15.8
	RT (7)			90.6
Intersection	All	30		107.2

Note: LT = left turn movement, TH = through movement, UT = u-turn movement, RT = right turn movement.

Scenario 3 Dynamic Turn-Lane with Auxiliary Lane

In Scenario 3, the dynamic lane application with the auxiliary lane could reduce the maximum queue on southbound Suk Sawat Road by nearly half and significantly reduce travel delay for the right-turn movement by 93.8 seconds per vehicle compared to without the dynamic lane. The overall intersection delay reduced by 24.5 seconds per vehicle compared to the normal operations in Scenario 1.

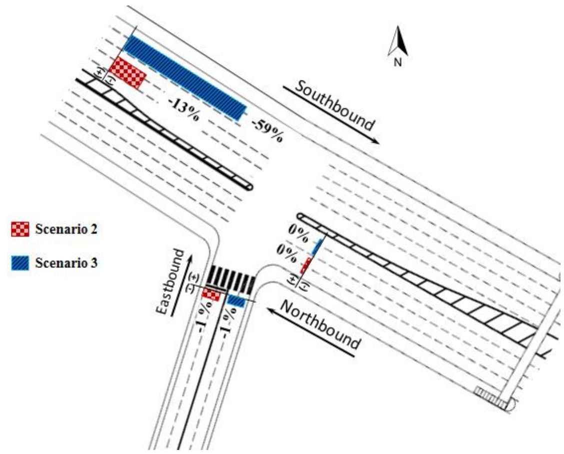
Table 6. Results for Scenario 3

Approach	Movement	Average Speed within Intersection (kilometers/hour)	Maximum Queue length (meters)	Travel Delay (seconds/ vehicle)
Northbound	LT (1)	18	224	110.5
	TH (2)			109.5
	UT (3)			103.5
Southbound	TH (4)	48	233	6.9
	RT (5)			100.5
Eastbound	LT (6)	33	98	16.0
	RT (7)			88.4
Intersection	All	33		65.8

Note: LT = left turn movement, TH = through movement, UT = u-turn movement, RT = right turn movement.

RESULTS COMPARISION

The key comparison performed in this section focuses on the operational performances of the dynamic lane configuration with and without the auxiliary lane relative to without the dynamic lane. Figure 4 presents the maximum queue length comparison by approach. The dynamic lane application could reduce the maximum queue length for the southbound Suk Sawat Road by 13% and 59%, respectively without and with the auxiliary lane. The queues in all other approaches did not significantly change due to no direct impacts from the dynamic lane operations.



Positive sign = longer queue, negative sign = shorter queue

Figure 4. Approach Queue Change Compared to No Treatment

Figure 5 presents a percent change of the approach delay for the southbound Suk Sawat Road and Figure 6 presents a percent change of the intersection delay. When compared to without dynamic lane, the dynamic lane application without auxiliary lane would result in higher delays for both the southbound Suk Sawat Road and the entire intersection by 33.3% and 18.7%, respectively. By operating with the auxiliary lane, it effectively reduced the delays by 48.0% and 27.1%, respectively for the southbound Suk Sawat Road and the entire intersection.

Figure 7 presents a comparison for the vehicle throughputs for the right-turn movement of the southbound Suk Sawat Road. The dynamic lane application with the auxiliary lane showed higher throughputs by 6.4% compared to without dynamic lane. However, the application of the dynamic lane without the auxiliary lane did not show improvements for the throughputs.

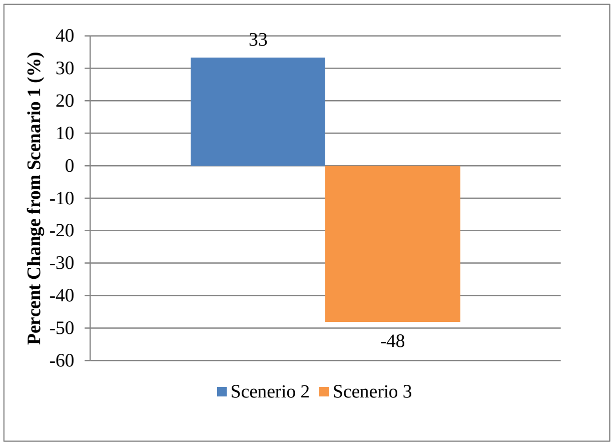


Figure 5. Approach Delay Change for the Southbound Suk Sawat Road Compared to No Dynamic Lane

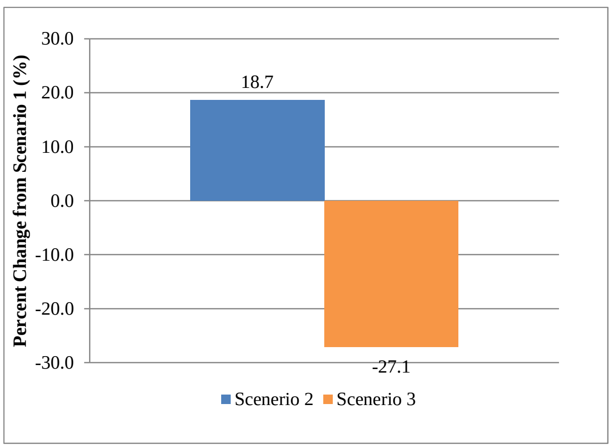


Figure 6. Intersection Delay Change Compared to No Dynamic Lane

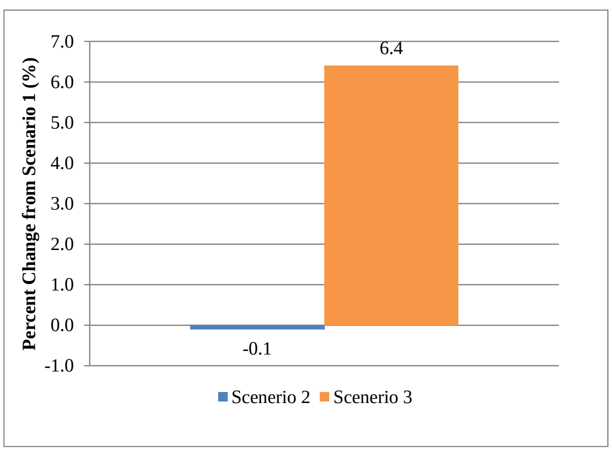


Figure 7. Movement Throughput Change for Southbound Suk Sawat Road Right-Turn Compared to No Dynamic Lane

CONCLUSIONS

The evaluation results of the dynamic lane operations suggest that this application can be efficiently used at the signalized intersections where a full intersection widening is not always feasible and excessive number of turn lanes is not required at all time. For the selected study intersection, triple right-turn lanes were warranted during the peak hours and the dynamic lane treatment has been used to accommodate the temporary need. The analysis results suggest that the dynamic lane treatment could be used to manage the queue length for the heavy turning movement, but it showed mixed results on the delay improvement depending on the lane configuration throughout the intersection.

The key success for the dynamic lane application will rely on the physical geometry of the intersection. The limitation that has been addressed in this study involves the conditions where the initial turn lanes already occupy all lanes of the receiving leg. The dynamic lane application will result in lane imbalance between the increased number of right-turn lanes and the number of receiving lanes. It was found that this condition did not provide improvement on the delays, but could help reduce the queue to some degrees. It is recommended that the departure lanes treatment shall be applied to maintain the lane balance throughout the intersection and provide safe environment for the turning vehicles. One of the treatment options used in this study was the auxiliary lane application. The dynamic lane operations with balanced lanes conditions could significantly reduce the queue and the delays for the applied direction.

It is also recommended that, when the departure auxiliary lane is used, a sufficient length shall be provided to ensure efficient operations while minimize the construction cost. Longer auxiliary lane will increase efficiency of the dynamic lane operations, but will require more investment on the right-of-way acquisition and the construction. Efficient strategies that have been used include the reduction of travel lane width to fit in the extra lane or the use of hard shoulder as a part-time travel lane. In addition, the dynamic lane treatment should be used in caution that every additional turn-lane may have consequent effects on safety performance of the intersections.

REFERENCES

Dowling R., Skabardonis A. and Alexiadis V. "Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Software." Federal Highway Administration, Washington, D.C., USA, 2004, 1-132.

Esawey, M. E. and Sayed T. "Comparison of Two Unconventional Intersection Schemes Crossover Displaced Left-Turn and Upstream Signalized Crossover Intersections." Transportation Research Record: Journal of the Transportation Research Board,No. 2023, Transportation Research Board of the National Academies, Washington, D.C., 2007, 10–19.

Federal Highway Administration. "Signalized Intersections: Informational Guide." Technical Report FHWA-HRT-04-091, Aug. 2004.

National Cooperative Highway Research Program. "Design Guidance for Intersection Auxiliary Lanes." Report 780, Transportation Research Board of the National Academies, Washington, D.C., August 2014.

Traffic Statistic, Bangkok Metropolitan Administration (BMA), Thailand, 2013.