A Study of Sam Yan Intersection Traffic Signal Management Optimization

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Abstract

Traffic lights are essential tools for controlling the flow of traffic at intersections, ensuring smooth and safe movement of vehicles and pedestrians. Nowadays, the traffic volume in cities has significantly increased, resulting in traffic congestion. This congestion causes unnecessary energy waste, air pollution that harms public health, and various social and economic problems. It is crucial to find solutions to traffic congestion for the betterment of the environment and the well-being of city residents.

Developing more effective signal timing will result in positive changes in traffic flows and is key to addressing traffic congestion problems. This research project aims to study traffic characteristics and the relationship between traffic signals and traffic flows. Data was collected through field traffic observations over a period of several months and analyzed using Anylogic modeling software, which simulates various traffic scenarios.

The study found that altering the green light duration affects overall traffic flow and delay. For instance, optimizing the green light duration based on real-time traffic conditions significantly improved traffic flow and reduced delays at intersections. However, the optimal duration may vary depending on factors such as time of day, traffic volume, and intersection design.

The results of this study can be useful for temporary or permanent improvement of traffic signals at intersections and can also serve as valuable information for traffic officers in the area. Future research could explore the impact of other traffic management strategies, such as adaptive signal control technologies and traffic demand management techniques, to further alleviate traffic congestion in cities.

Keywords: Traffic Signal Optimization, Anylogic, Transportation Engineering

1. Introduction

Traffic congestion is a major issue for many cities around the world. The problem causes negative impacts to the environment and society, including air pollution, waste of energy, social issues, health and mental issues, etc. [1]. Since road transport is a crucial means of transportation involving the movement of freight and people, the volume of road traffic tends to increase with time. Therefore, related infrastructure must be designed to support such increasing demands or be improved to alleviate the occurring issues. One strategy that is implemented to improve road traffic is adjusting traffic light timing. Proper signal timings can help reduce traffic congestion and improve flows [2-3].

Most of the time, traffic signal timing is designed in accordance with the traffic data at the intersection [4]. However, on some occasions, manually operated signaling may be required [5]. Even though the primary objective of changing signal timing is to reduce traffic congestion, altering the timing randomly may lead to even more congestion or confusion. There are also some disadvantages of adjusting traffic signals. Since traffic data is a crucial part of the system, failure to provide or constantly update traffic data may lead to even more congestion. Moreover, when taking other nearby intersections into account, the system can be more complex, resulting in more difficult and requiring extensive resources to conduct such analyses. Also, frequent changes on traffic signals may confuse road users and may unintentionally cause accidents. In this regard, the operator should understand how the timing changes affect vehicle flows.

This research aims to study the impact of signal timing change at the intersection. Therefore, the research question has been raised: "How does traffic signal timing change affect road traffic congestion at an intersection". In this research, related study and theory are discussed in section 2. Section 3 presents the methodology used in this study. The result of the study and summary section are followed in section 4 and 5.

2. Literature review

2.1 Signal Control

McShane [7] stated that traffic control systems are the most visible element of the urban infrastructure [6]. The systems are utilized in every mode of transportation differently. For road transportation, traffic signals can be one of the most effective ways to control vehicle traffic at the intersection. However, the design of signal timing can either eliminate or increase conflicting traffic depending on the suitability of the design.

In general, traffic signals are found to consist of three different colors, red, yellow, and green, which refer to stop, prepare to stop, and go (or proceed). These colors are changed according to the fixed or variable plans. The time required for one complete color sequence for all movement directions is referred to as a *cycle*. A *phase* is defined as the green, change, and clearance intervals in a cycle assigned to specified movement of traffic [8].

In signalized intersections, signal timing controls whether to go or to stop, therefore, it causes waiting reflecting delay at the intersection. Gao et al. [9] explored the relationship between signal timing and the traffic at the intersection, focusing on vehicle speed. They stated that the changes of signal timing affect vehicle's average travel speed. They also simulate the relationship between the original cycle, fixed cycle, and variable cycle which fluctuate by the demand of the traffic. The result shows that by decreasing cycle time and green time, vehicle's speed tends to increase from approximately 6 to 13%. However, this model is limited by its assumption that the queue length of the vehicle remains constant. In this regard, even though the vehicle speed shows signs of improvement, the flow of the traffic is not elaborated.

At present, there are 4 types of traffic control system; fixed time signal control, vehicle actuated signal control, adaptive signal control, and coordinated signal control. The objective of these signal controls is similar, to reduce the average delay of all vehicles and reduce probability of crashes [7]. However, each system has different pros and cons, according to Prasert (2015) [10-13].

- Fixed time signal controls require less maintenance and design effort than other intelligent systems. However, the system may not work efficiently at every timeframe, traffic demands, or special circumstance.
- Vehicle actuated signal controls vary phase duration depending on the vehicle or pedestrian request. This type of system performs better than the fixed time signal controls, especially at the intersection involving both vehicle and pedestrian traffic. The cons of this control type include higher budget requirements and higher maintenance costs. Moreover, the effectiveness of the system may be indifferent from the fixed time controls during the rush hours as all traffic direction heavily request signal service at the same time.
- Adaptive signal controls alter phase duration, and may include signal strategy, depending on the current traffic demands. The adjusted phase duration should be suitable for the traffic situation at the time; therefore, it should alleviate traffic congestion the most, theoretically. The challenges incorporate with this type of control include high costs, technological restrictions, equipment securities, etc. [14-15]
- Coordinated signal controls cover multiple intersections and connect them altogether. Each intersection communicates with one another and transfer traffic data to the processing unit to adjust signal or to implement the most suitable strategy for the current situation. This type of system performs the best at the network level. However, the system requires extensive data and analysis to work. Also, the budget is higher than the other systems as it includes several intersections rather than individual components [10].

2.2 Signal timing using the Webster Method

Webster Method can be applied to determine *optimum cycle length* for the intersection that minimize vehicle delays. The Webster Method equations are as follow:

$$C_0 = \frac{1.5L + 5}{1 - \sum_{i=1}^{\phi} Y_i} \quad (1)$$

where;

C_0 = optimum cycle length (sec)

L = total lost time per cycle (sec)

Y_i = maximum value of the ratios of approach flows to saturation flows for all lane groups using phase i

ϕ = number of phases

q_{ij} = flow on lane groups having the right of way during phase i

S_j = saturation flow on lane group j

While the *allocation of green time* can be determined by:

$$G_{te} = C - L = C - (\sum_{i=1}^{\phi} \ell_i + R) \quad (2)$$

where;

C = actual cycle length used

G_{te} = total effective green time per cycle

The total effective green time should be distributed among the different phases in proportion to their Y values to obtain the effective green time for each phase.

$$G_{ei} = \frac{Y_i}{Y_1 + Y_2 + \ldots + Y_\phi} G_{te} \quad (3)$$

the actual green time for each phase can be determined as follow;

$$G_{a1} = G_{e1} + \ell_1 - \tau_1 \quad (4)$$

$$G_{a2} = G_{e2} + \ell_2 - \tau_2 \quad (5)$$

$$G_{ai} = G_{ei} + \ell_i - \tau_i \quad (6)$$

$$G_{a\phi} = G_{e\phi} + \ell_\phi - \tau_\phi \quad (7)$$

Webster method is capable of estimating optimum cycle length for the intersection. However, according to Calle-Laguna et al. (2019), the error tends to increase with an increase in the level of congestion [16]. In this regard, some researchers proposed the developed model to produce more accurate results in the different scenarios.

2.3 Intersection performance measures

As reducing vehicle total delay is the primary objective of signal timing change, the performance measures in this research include:

2.3.1 Vehicle delay

The definition of vehicle delay in this research is adhered from [17] which defines delay as "the difference between actual travel time and ideal travel time".

$$delay = actual\_travel\_time - ideal\_travel\_time$$

2.3.2 Vehicle traffic flow

Vehicle traffic flow is defined as the number of vehicles passing a specific point per unit of time (vehicle per hour).

2.3.3 Intersection level of service

Level of Service or LOS is a popular method of measuring transportation service conditions. It can be determined by various traffic indicators, including density, speed, volume to capacity ratio, service flow rate, control delay, etc. [18]. According to the Highway Capacity Manual [19], Control delay and volume-to-capacity (V/C) ratio are used to characterize LOS for the intersection. Where delay quantifies the increase in travel time due to traffic signal control, and V/C ratio quantifies the degree to which a phase's capacity is utilized.

In this research, intersection V/C ratio can be calculated by

$$V/C = N_v / N_{max} \quad (8)$$

where, N_v is the spatial mean volume, and N_{max} is the maximum number of vehicles that a segment is able to contain as the capacity [20-21]. The LOS of the intersection can be determined by the tables below.

Table 1 LOS by Control Delay (s/veh) [18, 19].

Control Delay	LOS Class	Traffic State and Condition	V/C Ratio
≤ 10	A	Free flow	0 – 0.06
> 10-20	B	Stable flow with unaffected speed	0.61 – 0.07
> 20-35	C	Stable flow but speed is affected	0.71 – 0.80
> 35-55	D	High-density but the stable flow	0.81 – 0.90
> 55-80	E	Traffic volume near or at capacity level with low speed	0.91 – 1.00
> 80	F	Breakdown flow	> 1.00

*** For approach-based and intersectionwide assessments, LOS is defined solely by control delay*

Normally, LOS indicates general acceptability of delay to drivers. Therefore, the interpretation might be acceptable in one city but not for another. Also, the current LOS methods are formulated for traditional traffic flow. The combination traffic of motorcycle, e-bike, bicycle, pedestrian crossing, etc. is not integrated with the model [22].

3. Methodology

This research was conducted as the following process – selecting performance measures, selecting study location, gathering onsite traffic data, creating simulation model, conducting trial and error analysis by creating scenarios, and analyzing result.

3.1 Performance measures

In this research, the researchers aim to study the effect of signal timing change. Since the objective of the traffic signal is to minimize delay (and reduce crashing probability), the performance measures include total delay, intersection flow, and intersection level of service as described in section 2.3.

3.2 Study location

In order to study the effect of signal timing change, the researchers chose Sam-Yan intersection in Bangkok, Thailand as a study area due to its importance and predictable daily traffic pattern. The researcher created the simulation model using Anylogic Simulation Software. The implication of the physical Sam-Yan intersection was mapped in the software. This virtual model was prepared and ready for data input and analysis. Necessary output display, such as vehicle count, average time spent in the system, and number of cars in the system were also included in the model.

3.3 Data collection

In order to obtain necessary information, field data gathering was conducted. The researchers collected traffic data at the intersection in every approach at the same timeline. The researchers considered morning peak (7am to 9am), day off-peak (9am to 4pm), and evening peak (4pm to 7pm). The number of cars on each approach was monitored and collected at the specific timeframe. The researchers also verified observed data with the recorded traffic data provided by Bangkok Traffic and Transportation Department (TTD). It was found that the traffic data ratio between each timeframe was relevant, hence, the observed was assumed to be valid.

The researchers also obtained the current signal phase timing information from Bangkok TTD for Sam-Yan intersection. Moreover, the researchers also obtained the information of the actual practice of manually operated signal timing from the local traffic police officers. The researchers found that the officer may operate signal timing manually when the traffic becomes heavily congested or if an accident occurs.

3.4 Simulation modeling

The researchers created a computer model replicating the physical Sam-Yan intersection in Anylogic simulation software platform. Because of the limitation of the software, the replication of lane assignment can be copied, but the physical appearance of the left turning ramps is restricted.

Then the researchers created the logic for vehicles appearance. The arrival rate and default signal timing are provided by Bangkok Traffic and Transportation Department incorporate with the gathered field data.

The mechanism of the system logic is that the arrival vehicles are generated from the module 'carSource'. The vehicle will be assigned randomly to an approaching lane on the virtual road.

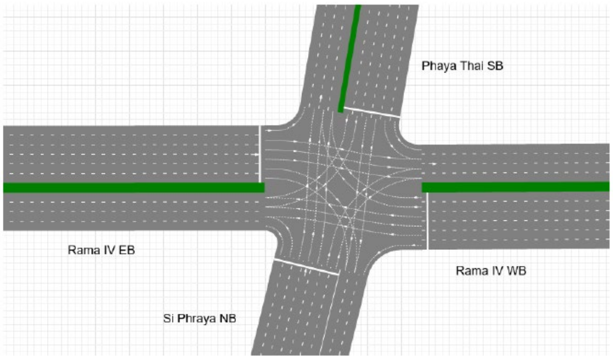

Fig. 1 Anylogic model replication of Sam-Yan intersection

After that, the vehicle chooses a destination which is determined by the probability ratio proportioned to traffic turning data. The vehicle moves along the road and turns as assigned. Finally, the vehicle departs from the road. The timer feature is set to start since the vehicle is introduced to the system and the timer ends when the vehicle finishes its trip. The counter feature is placed at the stop line, so that the turning and through vehicles can be counted at the intersection.

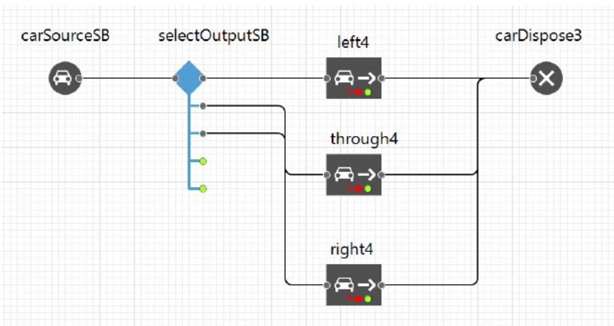

Fig. 2 Model mechanism for the study

The researchers created the mechanism for every approaching direction. Then a traffic light module is created. The feature consists of red, yellow, and green time duration with lane assignment adjustable. The default information is assigned to the module.

As of the current, the model can provide each vehicle's travel time, number of the vehicle pass the intersection, and number of vehicles generated on the road, which can be used to calculate the performance measures mentioned in section 3.

3.5 Trial and error input

To study the effect of signal timing change, the researchers tried several signal timing strategies, which includes using Webster Method, increase or decrease phase timing, etc. The researchers monitored the result from the simulation and then compared with each strategy.

4. Results

The researchers found that the maximum traffic volume is found in evening peak during 4pm to 7pm. Since this is the most congested timeframe, the researchers will discuss the result based on the experiment on this timeframe.

Based on Webster Method, the optimum timing is presented as follow

Table 2 Current cycle timing (Bangkok Traffic and Transportation Department) and Webster optimum cycle timing.

Approach	Current Timing (s)	Optimum (s)
WB	40	21
EB	50	19
NB	30	8
SB	30	25

The researchers also monitored the change of increase /decrease green phase timing for each direction by 5, 10, and 15 seconds.

The intersection LOS result shows that there are 9 strategies that can improve partially, or overall intersection LOS as presented in figure 3. There are 3 strategies that clearly improve overall LOS. Figure 3 also illustrates the negative impact from increasing green phase only strategies (plus 5, 10, 15 seconds).

Approach	Default	plus 5	plus 10	plus 15	minus 5	minus 10	minus 15
NB	D	E	E	E	D	E	D
EB	D	E	D	F	D	C	C
SB	C	D	D	E	C	C	E
WB	F	F	F	F	F	F	E

Approach	Default	Optimum	Opti +5	Opti +10	Opti +15	Opti -5
NB	D	D	D	E	E	D
EB	D	C	D	F	F	D
SB	C	B	B	B	C	B
WB	F	E	F	F	F	F

Approach	Default	Best EB	Best WB	Best NB	Best SB	Best All
NB	D	D	D	D	D	F
EB	D	F	C	B	D	C
SB	C	C	C	B	D	B
WB	F	F	F	C	F	F

Fig. 3 Intersection LOS result from different strategies.

For the comparison on total delay and intersection flow, the researchers would like to point out the 3 highlighted strategies as shown in figure 4 and 5.

5. Conclusion and Discussion

5.1 Conclusion

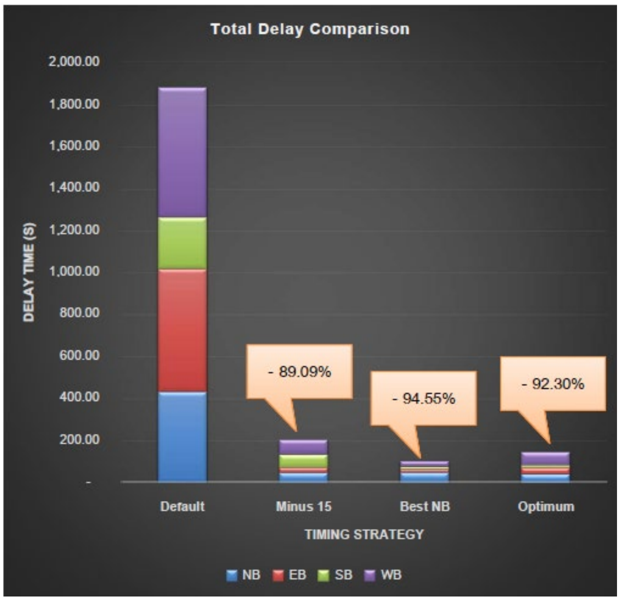

Fig. 4 Total delay comparison

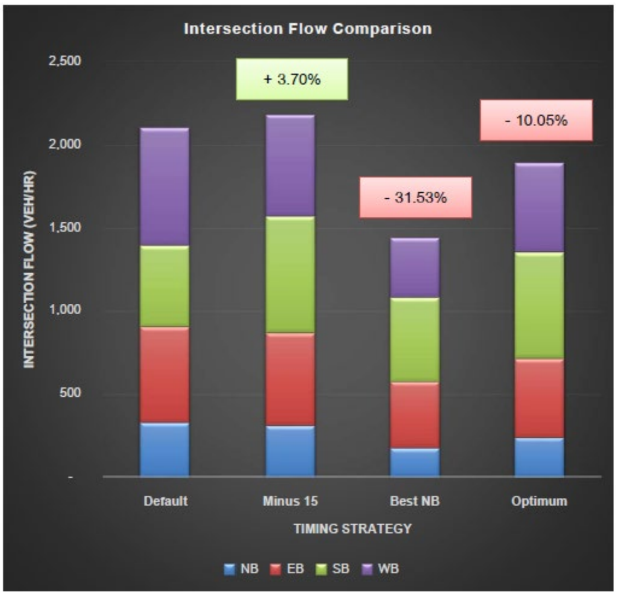

Fig. 5 Intersection flow comparison

From the result shown in this study, it can be implied that increasing green light time does not always increase traffic flow nor decrease vehicle delays. In fact, the signal timing matching with the traffic demand results in LOS improvement at the intersection.

Figures 4 and 5 show the improvement of the strategies from the simulation. However, using the best Northbound timing and Webster optimum timing reduce vehicle flows despite the improvement in total delay from the default. This reflects the difficulties of the vehicles passing the intersection in such a short period of time.

5.2 Discussion

The result from this model has not been tested in the actual environment which could significantly improve model accuracy and lead to practical use of the result. The next phase of this study is to improve the simulation model and get verified from the field.

Also, Anylogic is a powerful simulation software which is capable of multi-method simulation which greatly benefits the future study consisting of more complex techniques, such as reinforcement learning or system dynamic related study. However, to determine the best signal timing strategy for an intersection, a dedicated intersection analysis software may produce more accurate results.

5.3 Application

From this research, it can be seen that increasing green time may not result in a better traffic flow for a specific direction, instead, proper signal adjustment would be capable of relieving traffic congestion. From the simulation, the best strategy to improve the intersection for the time being is to reduce green time by 15 seconds in all directions for Sam-Yan intersections. However, for more accurate results, on-site verification is required. According to the study, vehicle behaviors such as, acceleration, braking, lane changing, and green light responsiveness, can change the outcome of the simulation. In this study, a model agent represents a vehicle on the road. In the model, the researchers set the vehicle behaviors mentioned before as default, however, the setting may be different from the time the Webster Method was developed and may be different from the real-world behavior at the studied intersection as well. These issues, including road design accuracy the software's package has provided so far, are the limitation for this research. Nevertheless, Anylogic software is a versatile tool that may incorporate even deeper or more specific details for the agent, therefore, in the future with adequate data input, the agent can reflect real-world behavior better than the simple traffic analysis software. After monitoring traffic on-site during the data gathering process, the researchers found that matching traffic demand in real-time and changing signal timing adaptively may lead to driver's confusion caused by frequent timing changes. Moreover, accidents and disruptive events may be out of the system capability to effectively analyze traffic demands for the signal timing change. For future research, this model can be more precise by incorporating more data on vehicle's behavior, pedestrian demand on-site, and more accurate road replication in the model. The signal timing change study can be more useful for the cities, however, to sustainable eliminate overall traffic congestion issues, traffic demand management, such as promoting transit while demoting personal car use, may lead to sustainable solution for traffic congestion in the long run.

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