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OPTIMISING TRAFFIC FLOW AT A SIGNALISED INTERSECTION USING SIMULATION

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ABSTRACT

Traffic signal lights system is a signalling device located at an intersection or pedestrian crossing to control the movement of traffic. The timing of traffic signal lights has attracted many researchers to study the problems involving traffic light management and looking for an inexpensive and effective solution that requires inexpensive changes in the infrastructures. A simple traffic lights system uses a pre-timed control setting based on the latest traffic data, and the setting could be manually changed. It is a common type of signal control and sometimes the setting was not correctly configured with the traffic data, thus leading to congestion at an intersection. Many mathematical strategies were applied to get an optimal setting. This study aims to model the traffic flow at Persiaran Kayangan and Persiaran Permai Intersection, Section 7, Shah Alam, as the case study, by using AnyLogic simulation software. The model was used to determine the best timings of traffic green lights that minimise the average time at the intersection and reduce traffic congestion. The findings showed that the best timings of traffic green lights for four directions at the intersection are 120 seconds, 75 seconds, 130 seconds and 100 seconds, respectively. These timings of green lights produced the lowest average time at the intersection (55.65 seconds).

Keywords: *Traffic Light, Intersection, AnyLogic Simulation, Optimisation.*

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1. Introduction

A traffic light system consists of three basic subsystems; the signal lights (red, yellow and green) in their housing, the supporting poles, and the electric controller. It is a signalling device located at an intersection or pedestrian crossing to control the movement of traffic.

The first traffic signal was invented in 1868 by John Peake Knight, a British railroad engineer, installed outside London's Houses of Parliament and operated manually by a traffic cop. The first three-colour signal was installed in New York in 1918, operated manually from a tower in the middle of a street. Since then, various types of traffic lights were invented and became the art of technologies (Kamran *et al*., 2017). In general, there are two types of traffic light systems (Kulanthayan *et al*., 2007); first is fixed time system (pre-timed) and second is traffic actuated system (actuation by vehicles or pedestrians using electronic detectors). Installing and operating a traffic actuated system is much more expensive than a fixed time system, and the fixed time system is always preferred.

The timing of traffic signal lights has attracted many researchers to study the problems involving traffic light management and looking for an inexpensive and effective solution that requires inexpensive changes in the infrastructures of city areas (Babicheva, 2015; Covell *et al*., 2015; Goel *et al*., 2017; Pop, 2018). A simple traffic light system uses a fixed control setting based on the latest traffic data, and the setting could be manually changed. It is a common type of signal control and sometimes it produces a glitch which differs from the original setting, thus leading to a long queue at an intersection. Many mathematical strategies were applied to get an optimal setting (Di Febbraro and Sacco, 2014; Kamran *et al*., 2017; Li and Sun, 2016; Prontri *et al*., 2015; Kou *et al*., 2018). Most of the studies consider sensitivity analysis on different factors affecting traffic flow and try to optimize traffic flow for different types of settings.

In this study, a pre-timed traffic light system at an intersection that experiences some issues such as long waiting time and long queue was considered as the case study. The objectives are to evaluate the traffic flow at the intersection using a simulation approach, and then determine the best timings of traffic green lights that would reduce the traffic congestion during rush hours. The traffic flow was modelled using AnyLogic software. The timings of traffic green lights were optimised via an optimisation engine built in the software.

2. Case Study and Methodology

2.1 The Case Study, Data Collection, and Significant of Study

A signalised intersection (fixed time three-stroke traffic light system) at Section 7, Shah Alam, Selangor was selected as the case study. The specific location is the Persiaran Kayangan and Persiaran Permai Intersection at Section 7, Shah Alam, where one of the four directions is the entrance to Universiti Teknologi MARA (UiTM).

Through observations and video recording at the intersection, the required data were collected for one week during rush hours (seven days including weekends). To build the corresponding simulation model, the following variables for each direction at the intersection must be determined; arrival rate of cars, mean duration of traffic green light, mean duration of yellow light, and mean duration of red light. The current four-phase signals plan of the traffic light system that controls the movements of cars and the factors contributing towards traffic congestion at the intersection were also observed.

Optimising the durations of traffic signal lights would be a normal approach for reducing traffic congestion at intersections. Traffic flow at Persiaran Kayangan and Persiaran Permai Intersection facing bad congestion during morning and evening rush hours as it is connected to the main roads from i-City Section 7, Section 2, Padang Jawa, and UiTM Shah Alam. The commuters spent too much time waiting at the intersection. This not only annoys the commuters, the long waiting time would trigger anxiety among them. This study would significantly contribute to the interest of all stakeholders; UiTM Shah Alam’s staff and students, Shah Alam City Council or MBSA (the local authority), and Shah Alam residents, especially in the vicinity of Section 7.

2.2 Simulation with AnyLogic

Simulation is a probabilistic decision model (Malim *et al*., 2019). Simulation has been widely applied to solve various problems including traffic management (Halim *et al*., 2012; Jupri and Malim, 2013; Kamran *et al*., 2017).

The modelling and simulation of the case study were executed by AnyLogic. It supports agent-based, discrete event, and system dynamics simulations (Weimer *et al*., 2016). It can be used to create a virtual prototyping environment for discrete, continuous and mixed behaviour of complex systems (Yang *et al*., 2014). Its applications include control systems, traffic systems, dynamic systems, manufacturing, logistics, military, and education. AnyLogic can offer a variety of modelling methods; object-oriented, flowchart, and Java. This software is claimed as a unique tool because of the combination of system dynamics, discrete event, and agent-based modelling methods into one model development environment (Karaaslan *et al*., 2018). Shi *et al*. (2010) used the AnyLogic-based simulation to model and analyse the container terminal's service process. A passenger flow lines simulation model was established by Wang *et al*. (2018) based on AnyLogic. The software enabled them to optimise the passenger flow lines and improve the operation capacity of a high-speed railway station. In Chen *et al*. (2013), AnyLogic was used to study the layout of pedestrian walking facilities at metro stations, and a reasonable facility arrangement plan was obtained.

By default, AnyLogic considers the arrivals of vehicles follow a Poisson process. The optimisation process to determine the best timings of traffic green lights at the intersection was performed using AnyLogic OptQuest Optimisation Engine. OptQuest automatically finds the best values of variables of a model, with respect to certain constraints.

2.3 AnyLogic Model Overview

The simulation model for Section 7 intersection was built using AnyLogic Personal Learning Edition 8.3.3 software. There were several necessary steps to follow, as described below.

Step 1: Road Network Creation

First, a simulation model with the name "Intersection Section 7" was constructed on a satellite image of the intersection taken from Google Maps. For optimal results, the model must be constructed based on the image scale aligned with the AnyLogic scale. Later, the lanes on each road at the intersection were created. Each of the roads (directions) was mapped with connecting lanes and turning points according to the current four-phase plan where flow from each direction is put into a single phase avoiding all conflicts (one phase for each direction). At each junction, a line was drawn to represent the stopping line.

Step 2: Set up Arrival Rates

Car is the only agent that had been defined with the 'CarSource' block creating agent at a specified rate. This is the specific procedure for this step. The arrival rate of Car for each of the four sources (Padang Jawa, i-City, Section 2, and UiTM) was set up based on the number of vehicles arrived at the road stopping line.

Step 3: Set Up Speed

Acceleration and deceleration can be modelled by changing the speed at appropriate times. For instance, the initial speed and preferred speed for vehicles from Padang Jawa were setup at 80km/h as this is the maximum speed for that road. The agent (Car) length defined in this model is 5 meters.

Step 4: Traffic Flow Logic

Road Traffic Library in AnyLogic can be utilised by simulating and visualising the traffic flow. The library provides a specific physical-level of vehicles development. It is appropriate for road and highway traffic modelling. This library incorporates:

- Visual space mark-up to draw street systems (street, crossing point, parking, stop line).
- Driver behaviour; speed control, pick less busy lane, give way when paths merge, etc.
- Support of user-defined vehicle types with custom animation and attributes.

The traffic flow process considers the traffic stream of road lanes which are forward and backward with the following components; CarSource, CarMoveTo, CarDispose, and their logic associations (SelectOutput). SelectOutput has two or five connectors to provide the probabilities to each road at an intersection, to be customised just like in reality, depending on the number of routes that could be utilised by the vehicles. If a vehicle has the possibilities to turn right, to go straight, and to turn left, it is suitable to use SelectOutput5 with more connectors. The probability to use a specific lane has been setup based on vehicle options to follow any route. Then, every segment of the road is paired with a certain element.

Road Traffic Library consists of Car object blocks that use to control the Car. The CarSource block produces Car objects and places them within the road network at a specified location. The Car arrivals may be defined by interarrival times, arrival rate, arrival schedule, or call for injection functions. Car Dispose block eliminates Car from the model, and CarMoveTo block controls the movement of Car. When a Car enters the CarMoveTo block, it estimates the route from start location to the next destination (roads, parking, bus stop, or stop lines). If destination is a road, the Car will start moving throughout the shortest route from initial road and then move along the road till it is disposed. Otherwise, if there is no route from current location to the next destination, the Car is disposed from the block.

TrafficLight block simulates traffic lights at intersections or pedestrian crossings to control conflicting traffic flows. RoadNetworkDescriptor block allows the set up of actions for each Car in the following cases; entering network, changing lanes, entering roads, and many more. This block also allows for a road density map which shows the current traffic jams on a network of roads. A probability distribution is defined to determine turning points and directions of the Car. The function of Delay block is to keep Car meant to park during allotted time interval. The Car will later exit the environment through CarExit block when all instructions have been completed.

Step 5: Setup Traffic Lights

The logic model is then simulated for the purpose of noticing any improper function. Next is to configure the traffic lights; it is a mandatory for intersections. Let say, there were no traffic lights built in the logic model, then AnyLogic would function perfectly but a malfunction warning will be displayed.

Step 6: Optimisation of Traffic Lights

The first step in optimisation process is to determine the initial values of *variables* by running a simulation experiment using the developed model for one-hour based on the collected data. Using the initial values, an optimisation process can be performed. This process searches through all possible values of variables to find the optimal values. It is possible to have more than one set of optimal values. The optimal values are determined by a search area. If the search area gets bigger, the optimal values will be dragged. In other words, the wider the range, the more time is needed to find the optimal values in the search area.

In the optimisation process, AnyLogic software performs its mathematical reasoning. It is important to know the right mathematical formula to achieve optimal results. Currently AnyLogic has its own top place in OptQuest Optimisation Engine. It was claimed as one of the most flexible and user-friendly optimisation tools in the market. The OptQuest will search for the best values of variables of a model automatically. AnyLogic provides a convenient graphical user interface to set up and control the optimisation process. The model used in this study will not allow a vehicle to wait at the intersection. It is also assumed that the number of vehicles passing through the intersection is maximised by solving the following linear programming model from road *i* to road *j* for a fixed vertex v (Göttlich and Ziegler, 2014).

$$\text{Maximise} \quad \sum_{i\in\delta_v^{in}} \hat{f}_i \tag{1}$$

$$\text{such that} \quad \bar{f}_j = \sum_{i\in\delta_v^{in}} d_{ij}\hat{f}_i \,,\ 0 \le \hat{f}_i \le \hat{F}_i \,,\ 0 \le \hat{f}_j \le \hat{F}_j \tag{2}$$

where $\hat{f}_i := f(\hat{\rho}_i)$ and $\bar{f}_j := f(\bar{\rho}_j)$ indicate the flow of incoming and outgoing edges, δ_v^{in} is the set of incoming edges and δ_v^{out} is the set of outgoing edges, $\rho_i \in [0, \rho^{max}]$ denotes the density of cars at position $x \in [0, L_i]$, and L_i is the length of road *i*.

The optimal solution will be referred by $\left\{\hat{f}_i, i \in \delta_v^{in}\right\}$ and $\left\{\hat{f}_j, j \in \delta_v^{out}\right\}$. Under certain conditions, it is possible to solve the linear model exactly. If a unique solution exists,

$$\sum_{i\in\delta_v^{in}} d_{ij}\hat{F}_i \le \bar{F}_j \ . \quad (3)$$

The optimal solution is given by $\hat{f}_i = \hat{F}_i$, $\bar{f}_j = \sum_{i\in\delta_v^{in}} d_{ij}\hat{f}_i$. (4)

From equations (3) and (4), it is followed immediately that equation (2) is satisfied, and hence the feasible solution of equation (2) is $\left\{\hat{f}_i, i \in \delta_v^{in}\right\}$ and $\left\{\hat{f}_j, j \in \delta_v^{out}\right\}$. Let $\left\{\hat{f}_i^{\,s}, i \in \delta_v^{in}\right\}$ and $\left\{\hat{f}_j^{\,s}, j \in \delta_v^{out}\right\}$ be the second feasible solution of equation (2). Then, equation (3) induces that $\hat{f}_i^{\,s} \le \hat{f}_i$ for all $i \in \delta_v^{in}$. Since $\bar{f}_j^{\,s}$ is uniquely defined by equation (3), the second solution is only different from the first if $\hat{f}_i^{\,s} \le \hat{f}_i$ for at least one $i \in \delta_v^{in}$. This implies that $\sum_{i\in\delta_v^{in}} \hat{f}_i^{\,s} < \sum_{i\in\delta_v^{in}} \hat{f}_i$ (objective function). Consequently, $\left\{\hat{f}_i, i \in \delta_v^{in}\right\}$ and $\left\{\hat{f}_j, j \in \delta_v^{out}\right\}$ represent the unique optimal solution for equation (2).

2.4 Intersection Section 7 Simulation

The Intersection Section 7 simulation model was developed with AnyLogic 8.3.3 software using Road Traffic, Analysis, Presentation, Agent, Process Modelling, and Statechart libraries. The simulation was performed for a period of 3600 seconds. There are four different sources of cars (Section 2, Padang Jawa, i-City, and UiTM), as shown in Table 1. The average number of cars per hour (arrival rate or traffic flow rate) from Section 2 is 900 cars, Padang Jawa is 1300 cars, i-City is 1350 cars, and UiTM is 115 cars. The numbers of cars were generated based on the traffic flow rates of the corresponding sources.

Table 1. Traffic Flow Rate, Speed and Flow Density

Source	**Traffic Flow Rate, *q* (cars/hour)**	**Speed, *v* (km/h)**	**Flow Density (*k* =*q/v*)**
Section 2	900	80	11.25
Padang Jawa	1300	80	16.25
i-City	1200	30	40
UiTM	115	20	5.75

According to the fundamental traffic flow theory (Disbro and Frame, 1992), the relationship between density, flow and speed is $k = q/v$, where k = flow density (cars/km/lane), q = traffic flow rate (cars/hour/lane), and v = speed (km/hour). As calculated in Table 1, the flow densities for Section 2, Padang Jawa, i-City, and UiTM are 11.25, 16.25, 40, and 5.75 cars per km per lane, respectively. Hence, i-City has the highest flow density due to low speed, whereas UiTM has the lowest flow density due to low flow rate and speed.

3. Simulation Results and Discussion

3.1 Data Collection and Analysis

On weekends, the data were recorded from 5.00 to 6.00 pm (considered as weekends rush hours). The number of vehicles recorded from Padang Jawa was the highest due to high density of traffic from Federal Highway and Padang Jawa. The lowest number of vehicles was recorded from UiTM due to most students have no lectures and UiTM offices are closed during the weekends. On weekdays, the data were collected during morning and evening rush hours (7.00 to 8.00am and 5.00 to 6.00pm), and also during lunch break (1.00 to 2.00pm).

The yellow light at each stop line was pre-timed at a constant of three seconds. The red light for Padang Jawa stops line has the shortest duration of 3.3 minutes (198 seconds). For other three stop lines (Section 2, i-City, and UiTM), the same duration of 3.45 minutes (207 seconds) were recorded for the three red lights. The green light changes for Padang Jawa, i-City and UiTM stop lines were measured, on average, as 14 times per hour. However, the green light changes for Section 2 stop line was slightly lower as 13 times per hour.

The four-phase plan of the traffic light system currently adopted at the intersection is the most simple and trivial phase plan where flow from each direction is put into a single phase avoiding all conflicts. The factors contributing towards traffic congestion at the intersection were observed as follows; too many cars on the roads especially during rush hours, traffic signal lights out of sync many times on purpose or occasionally when the controllers were malfunctioning, and the timings of traffic signal lights were not significant.

3.2 AnyLogic Simulation Results

The average durations of green lights for four stop lines after running the simulation experiment for one hour (3600 seconds) based on the collected data were obtained as follows; p1 (Section 2) = 90 seconds, p2 (Padang Jawa) = 75 seconds, p3 (i-City) = 120 seconds, and p4 (UiTM) = 40 seconds, as shown in Table 2 (*Before Optimisation*). These are as the initial values of variables for optimisation process. The average time in system (at the intersection) is 67.98 seconds.

Table 2. Summary of Simulation Results

	Before Optimisation	**After Optimisation**
Speeds (km/h)	Section2: 80; Padang Jawa: 80; i-City: 30; UiTM: 20.	
Values of Variables in seconds	p1=90sec, p2=75sec, p3=120sec, p= 40sec	p1=120sec, p2=75sec, p3=130sec, p4=100sec
No. of Cars Arrived	2512	2488
Count/Dispose (cars)	2381	2425
Cars Remained in System	131	63
Mean (sec)	67.98	55.65
Max (sec)	1602.462	870.46
Min (sec)	2.7	2.7
Std. Deviation (sec)	149.46	118.23

Next, the initial values of variables (durations of green lights at four stop lines) were optimised by running the simulation model with OptQuest Optimisation Engine on all possible values of the four variables. The range of values for each variable was set up between 10 seconds and 200 seconds with steps of 5 seconds. All variables were converted to discrete values. The travelling speed from i-City was considered as 30 km/h, from both Section 2 and Padang Jawa were 80 km/h, and from UiTM was 20 km/h (the speed limit inside UiTM campus).

The optimisation experiment aims to determine the best values of variables that optimise the objective function; i.e., minimise the mean time of a Car in the system (at the intersection). Replications were used to support the optimisation under uncertainty. The optimisation process was performed for 200 iterations and 600 seconds (10 minutes) of simulation time. After 200 iterations, the best timings (durations) of traffic green lights were obtained; p1 (Section 2) = 120 seconds, p2 (Padang Jawa) = 75 seconds, p3 (i-City) = 130 seconds, and p4 (UiTM) = 100 seconds. These values were generated at 178th iteration. The optimised simulation results are summarised in Table 2 (*After Optimisation*). The average time in system (at the intersection) has reduced to 55.65 seconds.

3.3 Discussion

As summarised in Table 2, the minimum time a car spent at the intersection for both experiments is 2.7 seconds. For the first experiment (before optimisation), the initial values of variables are p1 = 90 seconds, p2 = 75 seconds, p3 = 120 seconds, and p4 = 40 seconds. The total number of cars passed through the green lights is 2381, and the number of cars arrived at the intersection is 2512; thus, 131 cars remained at the intersection. The mean and maximum times a car spent at the intersection are respectively 67.98 seconds and 1602.46 seconds with a standard deviation of 149.46 seconds.

Meanwhile, for the optimisation experiment, the best values of variables are p1 = 120 seconds, p2 = 75 seconds, p3 = 130 seconds, and p4 = 100 seconds. The total number of cars passed through the green lights is 2425, and the number of cars arrived at the intersection is 2488; thus, 63 cars remained at the intersection. Hence, the number of cars remained at the intersection after optimisation is lower compared to before optimisation. The mean and maximum times a car spent at the intersection are respectively 55.65 seconds and 872.53 seconds with a standard deviation of 99.96 seconds (both are lower than before optimisation).
Based on the results, it can be concluded that the best timings of traffic green lights at the intersection that would minimise the average waiting time and maximise traffic flow are p1 (Section 2) = 120 seconds, p2 (Padang Jawa) = 75 seconds, p3 (i-City) = 130 seconds, and p4 (UiTM) = 100 seconds.

4. Conclusion

Traffic light system plays an important role in managing traffic congestion at intersections. The intersection considered in this study, Persiaran Kayangan and Persiaran Permai Intersection at Section 7, Shah Alam, is a crowded area adjacent to the Federal Highway with high traffic flow. This study provides a better understanding of the traffic light system at the intersection and has successfully produced better timings of green lights that would significantly reduce the waiting time and hence reduce traffic congestion at the intersection.

According to MBSA (Shah Alam City Council), the traffic light system at the intersection was set up based on a typical cycle which is about 120 sec (2 minutes). However, it was observed that the waiting time was between two minutes to four minutes. As the consequence, there were complaints from commuters regarding traffic congestion at the intersection; some have to wait for five minutes or longer. The main objective of this study is to model traffic flow at the intersection during rush hours for the purpose of determining the best values of variables (green light durations) that minimise the average waiting time and maximise traffic flow.

Using the data collected at the intersection, the traffic flow at the intersection was modelled using AnyLogic simulation software. The simulation model was run for one hour to determine the average timing of green light at each of the four stop lines at the intersection. These average durations revealed that the average waiting time at the intersection was 67.98 seconds; i.e., a commuter would wait 67.98 seconds to pass through the intersection.

For optimisation process, using the average timings obtained earlier as the initial values, the simulation model was run for 200 iterations and 600 seconds. The best values of variables were searched using OptQuest Optimisation Engine built in AnyLogic simulation software. The best values of variables were obtained at 178th iteration; p1 = 120 seconds, p2 = 75 seconds, p3 = 130 seconds, and p4 = 100 seconds. In other words, the best durations of traffic green lights for four stop lines at the intersection that minimise the average waiting time and maximise traffic flow are 120 seconds for Section 2, 75 seconds for Padang Jawa, 130 seconds for i-City, and 100 seconds for UiTM. These durations are expected to bring significant reduction in traffic congestion.

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