International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075, Volume-8 Issue-5S March, 2019

Road Traffic Congestion Solution using Discrete-Event Simulation

Muhammad Zulqarnain Hakim Abd Jalal, Wan Laailatul Hanim Mat Desa, Mohd Kamal Mohd Nawawi, Ruzelan Khalid, Razamin Ramli, Waleed Khalid Abduljabbar

Abstract: ***The increasing number of vehicles in developing areas indirectly become one of the causes for road traffic congestion (RTC) to occur. RTC can also be caused by a temporary obstruction, a permanent capacity bottleneck in the network itself, stochastic fluctuation in demand within a network, leading to spillback and queue propagation. Inefficient management of traffic light control (TLC) to the existing system in term of cycle time contributes to the RTC in a developing town in Malaysia, Changloon, especially during peak hours that lead to environmental pollution and long average waiting time. This situation negatively affects the road users and the people surrounding. A discrete-event simulation (DES) model was developed using ARENA software to represent the real TLC system condition during peak hours. From the simulation model, the TLC which causing the bottleneck was identified. The total of three scenarios were developed with modification on elements such as road structure and cycle time of TLC. All scenarios recorded with improvement for total average waiting time and average number in queue. The findings of this study can be used as a guideline for authorities to improve road traffic at Changloon town during peak hours.***

Keywords: Cycle time; discrete-event simulation; road traffic congestion; traffic light control; waiting time

I. INTRODUCTION

Basically, there are two types of road transportation. The first type is private transportation and the other one is public transportation. In Malaysia, people more favor to use private transportation instead of public transportation. This is due to many factors including poor services' quality of public transportation [1]. This situation occurs not only in big cities but also in a small town like Changloon. Statistics provided by Road Transport Department, Malaysia [2] prove that the total registered vehicles from 2010 to 2015 is increasing drastically as shown in Figure 1.

Revised Manuscript Received on March 08, 2019

Muhammad Zulqarnain Hakim Abd Jalal, School of Quantitative Sciences, Universiti Utara Malaysia, 06010 UUM Sintok, Kedah, Malaysia

Wan Laailatul Hanim Mat Desa, School of Quantitative Sciences, Universiti Utara Malaysia, 06010 UUM Sintok, Kedah, Malaysia

Mohd Kamal Mohd Nawawi, Institute of Strategic Industrial Decision Modelling (ISIDM), School of Quantitative Sciences, Universiti Utara Malaysia, 06010 UUM Sintok, Kedah, Malaysia. mdkamal@uum.edu.my

Ruzelan Khalid, Institute of Strategic Industrial Decision Modelling (ISIDM), School of Quantitative Sciences, Universiti Utara Malaysia, 06010 UUM Sintok, Kedah, Malaysia

Razamin Ramli, School of Quantitative Sciences, Universiti Utara Malaysia, 06010 UUM Sintok, Kedah, Malaysia

Waleed Khalid Abduljabbar, School of Quantitative Sciences, Universiti Utara Malaysia, 06010 UUM Sintok, Kedah, Malaysia

Hence, with raging growth in private vehicle purchase and practice, this will lead to road traffic congestion (RTC).

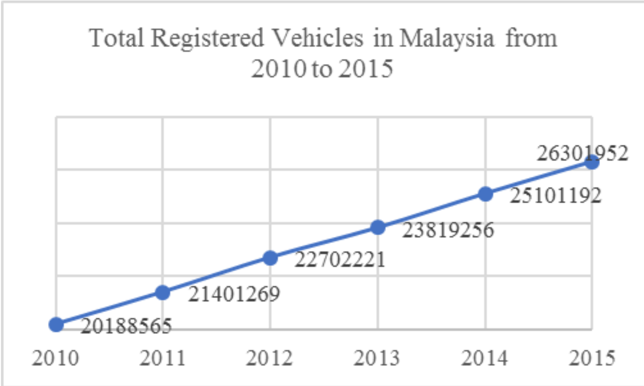

Fig. 1 Total registered vehicles in Malaysia up to year 2015 [2]

RTC can occur at anywhere and it can either be predictable or unpredictable. There is nothing can be done with unpredictable event as it happened outside the expectation while not for predicted event which occurs at the main road, and mostly controlled by traffic light system. Traffic light control (TLC) optimization have received special attention in recent years. From the previous studies, most of RTC closely related to weak traffic control system or more precisely an inefficient TLC system [3]–[7]. Therefore, research in reducing RTC by optimizing TLC system is relevant to be studied where the focus of this study is at Changloon main road traffic system in Malaysia.

The main objective for this paper is to control road traffic congestion at Changloon major road. There are four sub-objectives need to be completed, to achieve the main objective. The sub-objectives of this study are; to develop a model to simulate current road traffic at Changloon main road, to identify which TLC causing RTC at Changloon main road, to construct what-if analysis with the aim to reduce RTC at Changloon main road, and finally to provide alternatives for the improvement of Changloon's main road traffic conditions.

II. LITERATURE REVIEW

RTC is no more an odd problem and continues to become a major global problem. Mobility necessity turns transportation systems as an essential element in lives and the amount of vehicles roaming on the street and road strikingly increase from year to year [8]. This problem is deteriorating when it comes to a fast developing areas or commercial areas [9]. As the outcomes from this issue, it can cause massive delays, increased fuel wastage and monetary losses [10]. According to Downie [11], the growing economy and higher living standards are the reason which made activity getting around the city ridiculously difficult. Driven from RTC, there are many negative impacts on the society and environment.

Factors contribute to road traffic congestion

According to Jain et al. [10], RTC can be caused by weak traffic management which involves unplanned cities development with poorly built roadways, bad driver attitudes whose unable to follow lane discipline, archaic management with unmannered traffic junction which allowing drivers to drive recklessly, and tighter budget to improve traffic management.

Other than that, the absence of traffic light to rule the junction also can be one of the main cause for traffic congestion to happen. Kamrani et al. [4] studied on two adjacent T-junctions located at Jalan Universiti in the city of Skudai, Malaysia. The non-existence of traffic light to control the traffic at the junctions during rush hours is the main reason of the RTC which occurred almost every single day. Substantial improvement resulted after manipulating the model with the addition of traffic light to control the junctions.

For this paper, the focus is only on RTC caused by the absence or poorly managed of traffic light control (TLC). Table 1 provides the literatures on the factors that lead to RTC.

Table. 1 Factors lead to road traffic congestion

Author(s)	Factor Explored
Jain et al. [10]	Poor traffic management
Kamrani et al. [4]	Absence of traffic light control/poorly managed traffic light control
Qi et al. [5]	Temporary obstruction, permanent capacity bottleneck, stochastic fluctuation in demand
Su et al. [12]	Accident and natural phenomenon

Traffic Light Control System (TLC)

TLC system can be categorised into several types of control systems [13], [14]. The first type of control system uses pre-set cycle time to control the light changes which is fixed cycle time. On the other hand, the second type of control is a combination of the first type and proximity sensors which could manipulate the cycle time or the signal lights. The sensors work in such situation when the street seems to have less occupied vehicles, obviously it may not need a normal cycle for green light, and automatically change the cycle to street where vehicles present.

TLC serves to control the vehicles flow on the road so that the flows are smooth and convenient for the road users [15]. The signal displayed by TLC mostly consist of three different lights which are red, amber and green which carries a certain sign and cyclically changes with a suitable timing and control mechanism.

Computer Simulation

Computer simulation is a powerful tool for analysing complex and dynamic scenarios [16]. It offers a reliable approach to deal with repetitive process. Simulation helps decision makers identify alternative by analysing enormous amounts of data. With that kind of specialities, computer simulation seems to be the most suitable to analyse traffic flow patterns and signal light timing. A model built can be considered as the imitation of the real system. From there, not only the modeller but also other parties can get an clear understanding about the overall system performance.

According to Maidstone [17], computer simulation provides a method which possible to approximately imitate the real system for certain problem, and hence can be used for scenario testing. There are several simulation techniques being used nowadays which are discrete-event simulation (DES), system dynamics (SD), and agent-based simulation (ABS). Whether it is DES, SD or ABS, it is hard to tell which one is better because each of these techniques has its own benefits and disadvantages. Depends on the situation, one of these approaches can suit well when working on queuing problem, and one can suit perfectly when it comes to network flows.

As for road traffic operation, a lot of studies conducted using DES technique. Thus, to deal with traffic light control problem, DES seems to be the most suitable technique. According to Nawawi et al. [18], most DES software comes with a package of advantages which can improve the quality of analysis, reduce analysis time, user friendly, and easy to understand. In addition, the changes of variables or any input data does not require the developer to reformulate and recalculate to get the new result. By simply adjust the input data or adding specific module, the model can run different kind of scenarios without needing a coding specialist. Above all, the most important feature about DES is, its key element which adapt well with problems involving queuing.

III. SYSTEM DESCRIPTION

Junction 1 (Lanes A and B) is being controlled by TLC 1 while junction 2 (Lane C) is being controlled by TLC 2 and similar with the rest of the junctions with their respective numbered TLC. As shown in the Figures 2, only junction 1 is having more than one lanes which are lane A and lane B. These two lanes are used to depict the different exit points for junction 1 which having different TLC operation timing but still getting the signal from the same TLC. To make it easier, TLC 1 is a twin signal TLC. Lanes A and B will both receive the green light signal at the same time. After several seconds, vehicles from lane B need to stop and give turn for vehicles from lane C to depart while vehicles from lane A are still permitted to go. Vehicles from lane C have two exit points which are either take exit to junction 4 (Lane E) or straight to north. There is no need for vehicles that intend to exit junction 4 to wait for TLC signal as there is a bypass path for that event.

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication

After lanes A and C get the red-light signal, it is the turn for lane D to receive green light signal. All vehicle from the rest of junctions at first intersection are not allowed to depart as the TLC shows red light signal. As for lane D, there are three exit points which are either take exit to junction 4 or take exit to north, or enter lane I. During RTC period, vehicles that intend to enter lane I often unable to proceed even when the TLC shows green light signal due to bottleneck at junction 5. This problem does not happen to vehicles which taking either junction 4 or north as their exit point. As for that reason, the vehicles from lane D are separated into two paths which are lane D for entering lane I and lane D-sub for otherwise.

The last TLC cycle at first intersection is performed by lane E. When lane E gets the green light signal, the rest of junctions at first intersection shows red light. There are only two exit points for lane E which either take exit to north or enter lane I. Vehicles wish to exit north are often not involve in the queue as there are several alternative paths to do so. When the TLC shows red light, it indicates that one complete cycle of TLC for first intersection is completed.

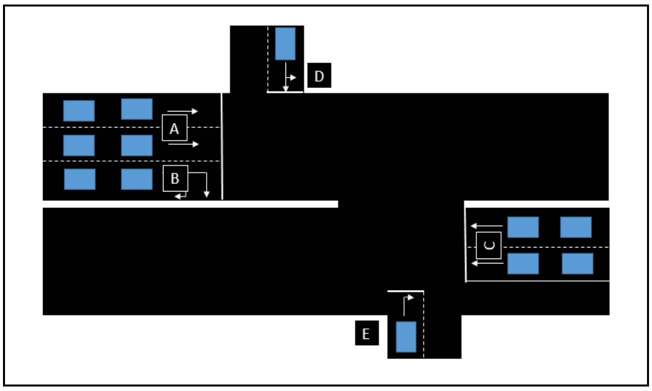

Fig. 2 Layout for junctions at Changloon first intersection.

As for second intersection, as shown in Figure 3, the traffic cycle is not complex as first intersection. There is no specific synchronization for TLC cycle between first intersection and second intersection, which means for instance, when first intersection is having green light for lane A, green light cycle at the second intersection can be at any lane either at lanes I, J, K or L.

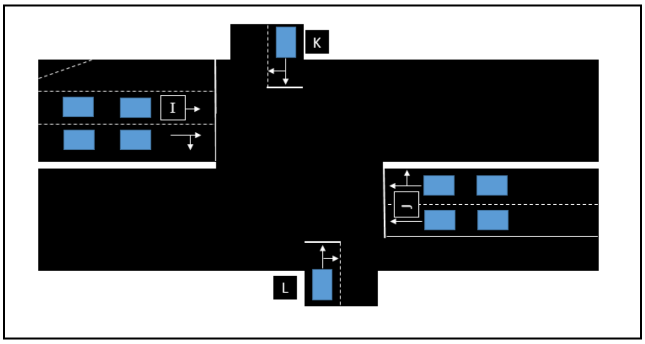

Fig. 3: Layout for junctions at Changloon second intersection.

IV. RESULTS AND ANALYSIS

The Changloon traffic light system for the junctions was modelled and simulated using ARENA software to represent the real activities with the purpose of further improvement analysis. The description of the model development was detailed out in Jalal et al. [19]. In the model, the moving vehicles were presented as the entity that moves throughout the system.

Existing system performance

The duration for simulation run was set to two hours, which is the period of peak hours of 5.00 to 7.00 p.m. at Changloon main road. The statistics and the system was initialized between replications. Tables 2 and 3 show the output for all junctions under study.

Table. 2 Average waiting time for basic model

Lane	Average time (seconds)
A	47.43725
B	79.60225
C	24.23263
D	171.6938
D sub	178.5763
E	359.5825
I	23.38263
J	71.671
K	83.68813
L	75.673

Table. 3 Average number in queue for basic model

Lane	Average number in queue
A	10
B	2
C	3
D	5
D sub	5
E	25
I	7
J	16
K	8
L	4

Model experimentation

Once the model has been verified and validated, experimentation phase take place to search for better solution with the aim of reducing average waiting time and number in queue.

*Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication*

Three experiments have been conducted, and each of these experiments is called a scenario. All these scenarios were designed based on suggestion from local people, informal interview with staff from Public Works Department, and common sense, which lead to several hypotheses. Those hypotheses were then becoming the foundation for each scenario design. Based on the observation, at certain time, the vehicles from junction 1 are often stuck due to road traffic bottleneck. The experimentations were conducted based on the preference to improve this problem. In the following sub-section, several scenarios will be discussed.

Scenario 1

The first scenario was designed by eliminate the barrier from junction 1. Removing the barrier means vehicle from lane B and lane D sub can proceed to respective exit points without having to travel for the extra distance. The movement for vehicle from lane D sub was also expected to be smoothed without getting interfered by occupied space.

Scenario 2

The second scenario was designed based on scenario 1. Since there was a significant improvement in total average waiting time, the model from the first scenario became the current model to be further experimented. By making the duration of green light signal at lane I longer, it can improve the road traffic condition. Initially, the green light timing configuration for lane I was set to 57 seconds. For this scenario, the green light duration was extended to 80 seconds.

Scenario 3

For the third scenario, it was designed also based on the first scenario. The difference from the second experiment was instead of just only altering the timing configuration for lane I, the timing configuration for lane A and lane E were also being manipulated.

Output analysis

The results obtained from the simulation run for all scenarios were compared. Table 4 presents the comparison of average waiting time, whereas Table 5 show the comparison of average number in queue for all three scenarios, respectively.

Table. 4 Comparison of average waiting times for all scenarios

Lane	Average time (seconds)			
	Basic model	Scenario 1	Scenario 2	Scenario 3
A	47.43725	52.39263	29.425	45.661
B	79.60225	79.83263	77.94438	80.62575
C	24.23263	23.30438	25.89475	37.65263
D	171.6938	157.12	102.9466	117.0969
D sub	178.5763	72.09475	70.26863	72.61488
E	359.5825	350.6663	136.512	86.19763
I	23.38263	22.2505	17.88913	17.54313
J	71.671	70.25838	86.07388	87.34363
K	83.68813	83.13575	117.5034	106.3558
L	75.673	75.23013	89.91063	90.763

In comparison between basic model and all scenarios, there are not much improvement for average waiting time except for lanes D and D sub. As an example, for lane D, average of 8 replications for average waiting time reduces from 171.69 s to 157.12 s for scenario 1, 102.95 s for scenario 2, and 117.10 s for scenario 3. On the other hand, for lane D sub which gives more significant reductions, average waiting time reduces from 178.58 s to 72.09 s for scenario 1, 70.27 s for scenario 2, and 72.61 s for scenario 3. The other significant improvement can be seen in scenario 2 with lane A average waiting time reduces from 47.44 s to 29.43 s and lane E average waiting time reduces from 359.58 s to 136.51 s. However, this improvement comes with trade-off of increased average times at lanes J, K, and L.

Table. 5 Comparison of average number in queue for all scenarios

Lane	Average number in queue			
	Basic model	Scenario 1	Scenario 2	Scenario 3
A	10	10.625	5.75	9
B	2	2.375	1.875	2
C	3	3.25	3.875	5.375
D	5	4	2.625	2.875
D sub	5	2	2	2
E	25	25.375	9.875	6.375
I	7	6.75	5.375	5.375
J	16	14.75	18.5	18.625
K	8	7.75	11.375	10.125
L	4	4.125	5.25	5.125

Similar pattern of improvement also happens for average number in queue comparison between basic model and all scenarios. From Table 5, for example, average number of queue for lane D sub reduces from 5 to 2 for all scenarios. In addition, significant reduction of number in queue for scenarios 2 and 3 can been seen for lane E, with 25 decreases to 9.88 and 6.38 respectively.

V. CONCLUSION

This paper discusses the application of discrete-event simulation to solve a road traffic congestion system. First, a basic simulation model was developed to represent the existing system. Then, three scenarios by modifying the layout of the traffic light intersection has been made to experiment with the intention of improvement of average waiting time and number in queue. From the analysis, it is found that all scenarios give better results for the reduction of average waiting time and number in queue for lanes D and D sub. Further improvement can be achieved with implementation of scenario 2 or 3, with significant reduction for lane E. However, further "what-if analysis" could be done to find further improvement. In summary, the simulation model would be useful tool to policy makers of road transport planning in designing a new or changing an existing road traffic system.

Acknowledgement

This research is funded by Universiti Utara Malaysia under Geran Penjanaan with S/O Code 13411.

REFERENCES

1. Ismail R, Hafezi MH, Nor RM & Ambak K (2012), Passengers preference and satisfaction of public transport in Malaysia, Australian Journal of Basic and Applied Sciences 6, 410–416.
2. Road Transport Department Malaysia (2015), Total Vehicle Registration Based on Year, available on line: http://www.jpj.gov.my
3. Ferreira M, Fernandes R, Conceição H, Viriyasitavat W & Tonguz OK (2010), Self-organized traffic control, Proceedings of the seventh ACM international workshop on VehiculAr InterNETworking-VANET'10
4. Kamrani M, Hashemi Esmaeil Abadi SM & Rahimpour Golroudbary S (2014), Traffic simulation of two adjacent unsignalized T-junctions during rush hours using Arena software, Simulation Modelling Practice and Theory, 49, 167–179.
5. Qi L, Zhou M & Luan W (2018), A Two-level Traffic Light Control Strategy for Preventing Incident-Based Urban Traffic Congestion, IEEE Transactions on Intelligent Transportation Systems, 19, 13–24.
6. Sánchez-Medina JJ, Galán-Moreno MJ & Rubio-Royo E (2010), Traffic signal optimization in la Almozara District in Saragossa under congestion conditions, using genetic algorithms, traffic microsimulation, and cluster computing, IEEE Transactions on Intelligent Transportation Systems, 11, 132–141.
7. Yousef KM, Al-Karaki JN & Shatnawi AM (2010), Intelligent Traffic Light Flow Control System Using Wireless Sensors Networks, Information Science and Engineering, 26, 753–768.
8. Barrachina J, Garrido P, Fogue M, Martinez FJ, Cano JC, Calafate CT & Manzoni P (2012), D-RSU: a density-based approach for road side unit deployment in urban scenarios, International workshop on ipv6-based vehicular networks (Vehi6), collocated with the 2012 IEEE intelligent vehicles symposium, 1–6.
9. Kok AL, Hans EW & Schutten JMJ (2012), Vehicle routing under time-dependent travel times: The impact of congestion avoidance, Computers and Operations Research, 39, 910–918.
10. Jain V, Sharma A & Subramanian L (2012), Road traffic congestion in the developing world, Proceedings of the 2nd ACM Symposium on Computing for Development - ACM DEV '12.
11. Downie A (2008), The World's Worst Traffic Jams, Time Magazine, available on line: http://content.time.com/time/world/article/0,8599,1733872,00.html
12. Su B, Huang H & Li Y (2016), Integrated simulation method for waterlogging and traffic congestion under urban rainstorms, Natural Hazards, 81, 23–40.
13. Huang Y, Weng Y & Zhou M (2014), Modular Design of Urban Traffic-Light Control Systems Based on Synchronized Timed Petri Nets, IEEE Transactions on Intelligent Transportation Systems, 15, 530–539.
14. Tan KK, Khalid M & Yusof R (1996), Intelligent traffic lights control by fuzzy logic, Malaysian Journal of Computer Science, 9, 29–35.
15. Adam I, Wahab A, Yaakop M, Salam AA & Zaharudin Z (2014), Adaptive Fuzzy Logic Traffic Light Management System, 4th International Conference on Engineering Technology and Technopreneuship, 340–343.
16. Hewage KN & Ruwanpura JY (2004), Optimization of traffic signal light timing using simulation, Proceedings - Winter Simulation Conference, 2, 1428–1433.
17. Maidstone R (2012), Discrete Event Simulation, System Dynamics and Agent Based Simulation: Discussion and Comparison, System, 1–6.
18. Nawawi MKM, Jamil FC & Hamzah FM (2015), Evaluating performance of container terminal operation using simulation, AIP Conference Proceedings, 1660.
19. Jalal MZHA, Nawawi MKM, Desa WLHM, Khalid R, Abduljabbar WK & Ramli R (2017), Green supply chain: Simulating road traffic congestion, Journal of Physics: Conference Series, 890, 012111.