A Discrete-Event Traffic Simulation Model for Multilane-Multiple Intersection

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***Abstract*— In this paper, the model is simplified by proposing a decomposed queuing theory to multilane-multiple intersection. The concept of queuing theory looks promising due to its simplicity and its combination with standard approach techniques. This can expand the model to be more reliable in dealing with problem associated to multilane-multiple intersections. The proposed model is simple, flexible and fit to any real case study with different structure of topology. The traffic model is developed using discrete-event simulation (DES) framework for computation and analysis the model. Simulation results have shown good correlation between the proposed traffic model and data taken from real traffic situations, and have confirmed that the proposed modeling technique based on queuing theory and standard decomposition method can be realized. In addition, simulation results give a confirmation of the model capability to correctly predict traffic performance measures.**

Keywords—queue theory; decomposition method; discrete-event; multilane-multipe intersection

I. INTRODUCTION

Traffic model is very important to model a traffic intersection in the urban area before control is applied to the intersection. In urban area, most traffic network links intersect frequently and closed with each others. Multiple intersections have a different characteristic, different structure of topology, different length between neighbor and different number of the lanes. This leading to conflicts between flows and faced with the problem of controlling flow at intersections. According to [1], the physical or analytical traffic models in some cases cannot match completely the depicted actual phenomena even though certain correcting factors are introduced. Strong relationships between the properties of traffic flow and the corresponding local environment, such as geographical features and human behaviors limit the model. The proposed traffic model developed in urban area must consider the properties of traffic intersection as mention above. The concepts of traffic model derived must be general and fit for any case study with different structure of topology.

Many multiple intersection studies [2]-[4] also investigate the single intersection problem as a basic problem and offer satisfying results. For multiple intersections, individual intersection is not an isolated problem, but is dependent on other intersections especially their close neighbors. In urban areas, intersections tend to be close to each other and the relationship between adjacent intersections becomes significant. Multiple intersection problems tend to be more difficult than the single intersection problems.

The proposed traditional traffic models are too complex and the use of mathematical equations are often hard to solve the pertinent problem since the evaluations of traffic performance only fit for one characteristic of traffic systems[5-7]. Typically, many of the AI techniques function as supported element to backup the algorithm for developing urban traffic model and freeway traffic flow. All types of traditional traffic model are not generalized and also not suitable to enhance with the different type of controllers. The complicated traditional method and limited parameters involved will require changes to the traffic model for simpler and easier implementation in real case studies.

Since most of these studies are based on the traditional method, the models are too complex to be implemented in real situation. The complicated traditional method and limited parameters involved will require changes to the traffic model for simpler and easier implementation in real case studies. To solve this problem, a new model for multilane-multiple traffic intersection in urban area is desirable. In line with the pertinent information gathered from thorough literature search in this study, the queue theory based on macroscopic model which seemed to be suitable and flexible for complex traffic model used.

In this research, a macroscopic of M/M/1 single server network with arbitrarily-linked topology structure is used as the model framework. In queue theory, the vehicles in the queue or lane are attended based on service discipline. Generally, the priority discipline technique is one of the service methods currently being used in the case of multilane. However, for M/M/1, only one vehicle will be served at one time. In multilane-multiple intersections, all vehicles in each lane move simultaneously according to its respective signal phase, thus priority discipline based technique is not suitable. To resolve this problem, a virtual server is introduced to traffic light systems to operate its own lane and simultaneously activate all the lanes which have the same signal phase. A discrete-event simulation has been built for the purpose of general model of multilane-multiple intersection analysis. Ideally, the proposed traffic model is flexible and ideal to be applied to any real case study.

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II. TRAFFIC MODELLING

This section describes the model framework of a real case study and some crucial model characteristics which need to be specified for the steady-state analysis. In this research, the model is simplified by proposing a decomposed queuing theory to multilane-multiple intersection. The model framework will be defined at two levels; the framework of the overall system and that of each station in the system. A real case study has been conducted in one of the busiest streets in Kuala Lumpur and it can be decomposed into four sub-systems where the layout of the case study is depicted in Figure 1.

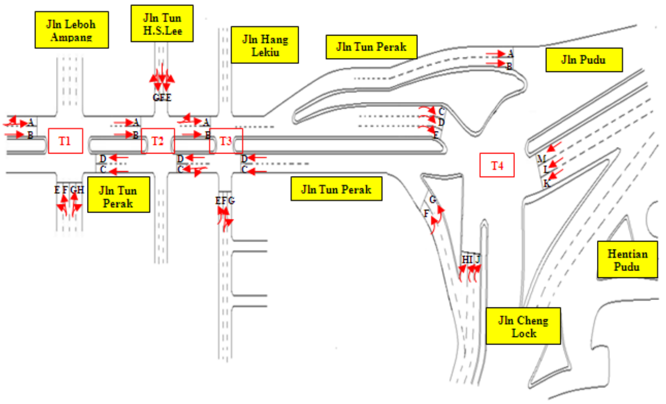


Figure 1. Case Study

A queuing network is composed of a set of linked queues, hereafter, referred to as stations. In the intersection, these stations are referred to as intersections. Of interest is the study of the flow of vehicles throughout the network. We consider open queuing networks where vehicles are allowed to leave the network and where the external arrivals arise from an infinite of population vehicles. Vehicles arriving to an intersection are either served immediately or queue until a traffic light (server) gives a green indicator (availability). Once a vehicle is served it is routed to its next intersection according to the respective signal phase.

A virtual server for each lane in a multiple intersection is introduced, in order to control the outgoing vehicles in each lane by their own server. When the traffic light system is activated (shown green), the entire virtual server in the same signal phase will be activated simultaneously and vehicles can then leave to a downstream intersection. The virtual server in this model depends on the number of the lane in each intersection which is denoted as:

$$V_{In} = (V_{InA}, V_{InB}, \ldots, V_{InLd}) \tag{1}$$

where *In* *(In=1,2,…)* is the location of intersection *Ld* *(Ld=A,B,C,…)* which is referred to as the lane detector.

Vehicles arrive at a single-server facility according to a Poisson process with mean arrival rate λ (vehicles per unit time). Equivalently, the inter-arrival times between vehicles are independent and identically distributed with mean *1/λ*. Vehicles, therefore, enter the system according to a Poisson process with arrival rate, λ. The number of arriving vehicles in the system per time period obeys the Poisson distribution, which has a probability density function (PDF) as follows:

$$p\{y_{in}(t) = k\} = \frac{(\lambda_{In}\Delta t)^k e^{-\lambda_{In}\Delta t}}{k!} \tag{2}$$

where (λ_{In}< 0) is the arrival rate which is the mean number of arriving vehicles per time period and *k=0,1,2,…* .

Since most analytical methods require that a queuing station has exactly one arrival and one departure, traffic merging and splitting steps are required. The traffic merging step is a process that combines the arrival vehicles from many intersections to a single arrival is given by (3)

$$\lambda = \lambda_{1A} + \ldots + \lambda_{1Ld} + \lambda_{2A} + \ldots + \lambda_{2Ld} + \ldots + \lambda_{InLd} \tag{3}$$

where *In(In=1,2,…)* is the location of the intersection and *Ld(Ld=A,B,C,…)* *is* referred to as the lane detector.

The traffic splitting step is a process that splits the overall departure into the required number of departure. The process of splitting has described below and is given by (4), respectively:

$\lambda_{\text{arrival rate of vehicle departure}}$ =
probability number of vehicle to joint intersection 1+probability number of vehicle to joint intersection 2 +…+ probability number of vehicle to joint intersection *n*.

$$\begin{aligned}\lambda_{InLd} &= P^1_{InLd}\ \lambda_{InLd} + P^2_{InLd}\lambda_{InLd} + \ldots + P^p_{InLd}\lambda_{InLd} \\ &= \lambda_{InLd}(P^1_{InLd} + P^2_{InLd} + \ldots + P^p_{InLd})\end{aligned} \tag{4}$$

where *In(In=1,2,…)* is the location of the intersection, *Ld(Ld=A,B,C,…)* *is* referred to as the lane detector, *p(p=1,2,…)* is the probability split that depends on the traffic splitting between lanes and $P^1_{InLd} + P^2_{InLd} + \ldots + P^p_{InLd} = 1$.

The service time is defined as the time used to discharge the individual vehicles from the intersection during the time where the traffic light stays green. In the departure process, the number of vehicles leaving the intersection is dependent on the total of service time, T_s for the green phase length of *j-th* movement. So the departure time for vehicles leaving the intersection can be defined as

$$T_s = t^j_{out_1} + t^j_{out_2} + \ldots + t^j_{out_{f-1}} + t^j_{out_f} \tag{5}$$

where superscript *j(j=1,2,…,8)*denotes the *j-th* movement and t^j_{outf} is the departure time for the last vehicles leaving the intersection.

The headway *(h)* is a measure of the time interval between the fronts of one vehicle to the front of a following vehicle. It is also known as the inter-arrival or inter-departure times in a queue model. The headway can be measured from the service times of the departure process, i.e.

$$h = t^j_{out_f} - t^j_{out_{f-1}} \tag{6}$$

Assume a continuous traffic flow process that is sampled at every Δt time interval with discrete time index, k. The output of the intersection (i.e., number of vehicles leaving this intersection/departure process) $y_{out}(k)$ can be defined as the following vector:

$$y_{out}(k) = [y_{out1}^{1}(k), \ldots, y_{out1}^{8}(k), \ldots, y_{outi}^{1}(k), \ldots, y_{outi}^{8}(k)]^{T_s} \tag{7}$$

where the element of this vector $y_{outi}^{j}(k)$ denotes the output queue of the j-th movement $(j=1,2,\ldots,8)$ of the i-th intersection $(i=1,2,\ldots)$ and T_s is the total service time.

The current queue $q(k)$ can be also be written as:

$$q(k) = q(k-1) + y_{in}(k) - y_{out}(k) \tag{8}$$

where $q(k-1)$ is the queue at the previous time instant $(k-1)$ and $y_{in}(k)$ is the input (number of vehicles) during time interval $(k-1,k)$.

The maximum number of vehicles that is able to store between the intersections (link) is called capacity. The formula to calculate the capacity is denoted as below:-

$$C = n\left(\frac{L}{L_{avg\_veh} + D}\right) \tag{9}$$

where L is the length of the link, n is the number of the lane in the link, L_{avg_veh} is the average length of the passenger car ($\approx$ 4.5 m) D *is* distance between cars in queue ($\approx$ 2 m).

Offset is adjusted to coordinate adjacent signals such that stops in the direction of main traffic flow are minimized. Consider two successive intersections J_1 and J_2 and the networks link z that connects both intersections, leads from J_1 to J_2, and receives right of way during the main stage of intersection J_2 with L_z the link length and v_z the free-flow mean speed on link z. As long as the number of vehicles within the link is zero, the offset between intersections is equal to the free flowing travel time on the link is denoted as below:

$$T_{\text{offset}} = \frac{L_z}{v_z} \tag{10}$$

The cycle in the downstream intersection should start accordingly later than the cycle of the upstream intersection. Actually, this case is referring to the first setting operation adjacent signals in multiple intersections.

The offset time proposed by Integrated Transport Information System (ITIS) [8] in the case study have discussed below is calculated by using (10). The design speed or free-flow mean speed for urban area is suggested by ITIS is about 50km/hr. By using the fixed value of free-flow mean speed, the offset time is only depends on the length of the link. When the length of the link is far between adjacent signals, the offset time is long and vice-versa.

The decomposition method used in this study is the stochastic analysis of the queuing model. The relevant performance measures in the network queuing model, using the assumptions of Poisson arrivals (with λ_i=arrival rate) and exponential service times, (with μ_i=service rate) can be applied for the model as follows: (a) average time a vehicle spends for waiting in queue, (11) and (b) average time a vehicle spends in the system, (12).

$$W_{qi} = \lambda_i / \{\mu_i (\mu_i - \lambda_i)\} = \rho_i \{\mu_i (1-\rho_i)\} \tag{11}$$

$$W_i = 1/(\mu_i - \lambda_i) \tag{12}$$

The parameter $\rho_i=\lambda_i/\mu_i$ is known as the utilization or traffic intensity at Intersection i. The case $\rho_i > 1$ represents a situation where the mean arrival rate, λ_i, is larger than the maximum service rate, μ_i at intersection i. Under this circumstance, the queue increases without bounds over time, and a steady-state cannot be achieved. Thus, $\rho_i < 1$, is essentially the stability condition for (11)-(12) to hold [9].

III. Simulation Model Framework

Theoretically, the three main concepts in queuing theory are customers, queues, and servers (service mechanisms). In general, customers for the queuing system are generated by an input source in accordance to a statistical distribution which describes their inter-arrival times. This refers to the times between each arrival of the customers. At times, customers are selected for services by the server (service mechanism) and the basis in which the customers are selected is called the queue discipline. In describing the model for traffic intersection based on queuing theory, the research arrived with the following definitions:-

- Customer is the vehicle that arrives at a specific place and requires services.
- Server is the traffic light system that is capable of servicing the vehicles. A virtual server introduced in this study is referred to a dedicated unit for operating each lane.
- Queue is referred to as the number of vehicles staying in the lane waiting to be served by the virtual server. The length of the lane (link) is called the buffer and the capacity of vehicles that stored or stayed in the lane depends on its size.
- Queue Discipline is the calling order method of vehicles in the queue (lane) which is serviced by the traffic light system. The first-in first-out (FIFO) queue discipline type is used in the model.
- Station is referred to as the intersection which has multi-lanes (queues).

The simulation software MATLAB was used for the analysis. The traffic model is developed using SimEvents® and Simulink® software with a discrete-event simulation (DES) model of computation. A discrete-event simulation or event-based simulation permits the state transitions of the system to depend on asynchronous discrete incidents called events. SimEvents template has various blocks, each of which performs a specific function. The main blocks used in our framework consist of Server blocks, Queue blocks, Generator blocks, Sink blocks and Routing blocks. The combination of these main blocks can develop the sub-systems which are designed based on the function of the system or model operation. In the traffic model framework, the Arrival/Departure, Multilane and Performance Measure sub-systems have been developed to reduce the computation and complexity of the traffic model.

The Arrive/Departure sub-system represents a point in the model where vehicles arrive from outside of a function as an input in this model. In Arrive/Departure sub-system, the Event-Based Entity Generator block is chosen to generate vehicles in response to signal-based events that occur during the simulation. To generate vehicles based on Poisson distribution, the normal random number with the math's function block is used. The Multilane sub-system is designed to model a multilane-single intersection based on decomposition techniques. In this research, the traffic model developed based on M/M/1 queue approach. Therefore in this sub-system, the FIFO queue block and Single Server block is used. Each lane in this sub-system is controlled by the single server which is also known as virtual server. Model framework for multilane-multiple intersection is developed based on the combination of multilane-single intersection using Routing blocks. Finally, the outputs are designed in the Performance Measure subsystem. Commonly specified outputs include the travelling time performance such as the average waiting time, and the average delay time. The additional performance for multiple intersections is the utilization for test stability of the system.

IV. SIMULATION ANALISIS OF TRAFFIC MODEL

This section discusses the simulation work that has been carried out in the traffic modelling which is applied to the real case study in the middle of Kuala Lumpur. The simulations are done in the three situations based on traffic volume data, which are in the high condition (S1), medium condition (S2) and low condition (S3). The general characteristic of traffic model for this case study is evaluated based on M/M/1 queue theory and standard approach technique. From the theory, the key elements of a queuing system are the customer and server [9]. The customer is referring to vehicles and server is referring to traffic light system. The vehicles in terms of an arrival rate, λ (number of arrivals per hour) enter the intersection as the input parameter and generated based on Poisson distribution. The traffic light system provides the service to vehicles before leaving the intersection to downstream intersection. From the real data observed, the average time of vehicles leaving the intersection is about 2 seconds. Therefore, the service rate (µ) for each vehicle setting in this simulation is fixed to 2 seconds. This value 2 seconds is considered and used in this simulation because the volume data is provided by ITIS in terms of passenger car unit (pcu). The total service rate however depends on green time.

The characteristics of traffic model are performance measures evaluated in terms of average waiting time and average delay time. Due to the variability of service times and the variability of the arrival process, is what causes waiting lines to build up and congestion to occur. For most systems, if the arrival rate increases, or if the service rate decreases, then the system will become more congested. The equation (11)-(12) of these terms is depending on the arrival rate (λ) and the service rate (µ). In this case, service rate of the model is fixed, so the characteristics of traffic model based on the performance measurement is only affected by varying the input parameters, λ.

Case Study (Figure 1) describes three traffic scenarios, where three simulations were performed for a total run-time of T=3600 seconds. The service time for each vehicle is fixed to 2 seconds. In this simulation, three kinds of time intervals in a day with different arrival rate have been considered as shown in Table I. The simulation is done in three different scenarios, which are high traffic volume (S1: 9.00am -10.00am), medium traffic volume (S2: 6.00am - 7.00 pm) and low traffic volume (S3: 7.00am - 8.00 am). At Intersection 4, the West Bound direction shows that the arrival rate for Scenario 3(S3) is higher than Scenario 2(S2).

TABLE I. EXTERNAL INPUT & ROUTING PROBABILITY(RP)

Inter section	Lane	Arrival rate, λ S1	Arrival rate, λ S2	Arrival rate, λ S3	RP
1	T_{1A} T_{1B}	λ_{EB11}= 0.4567	λ_{EB12}= 0.3017	λ_{EB13}= 0.1947	P_{1x} = 0.50 (x=A,B)
	T_{1E} T_{1F} T_{1G} T_{1H}	λ_{NB11} = 0.2108	λ_{NB12} = 0.1819	λ_{NB13} = 0.1078	P_{1y}= 0.25 (y=$E,\ldots,H$)
2	T_{2E} T_{2F} T_{2G}	λ_{SB21} = 0.1444	λ_{SB22} = 0.1042	λ_{SB23} = 0.0781	P_{2z}= 1/3 (z=$E,\ldots,G$)
3	T_{3E} T_{3F} T_{3G}	λ_{NB31} = 0.2500	λ_{NB31} = 0.1389	λ_{NB31} = 0.1111	P_{3i}= 1/3 (i=$E,\ldots,G$)
4	T_{4F} T_{4G} T_{4H} T_{4I} T_{4J}	λ_{NB41} = 0.3783	λ_{NB42} = 0.1894	λ_{NB43} = 0.1272	P_{4j}= 0.20 (j=$F,\ldots,J$)
	T_{4K} T_{4L} T_{4M}	λ_{WB41}= 0.1264	λ_{WB42}= 0.0733	λ_{WB43}= 0.0806	P_{4u}= 1/3 (u=$K,\ldots,M$)

The lanes are facing external intersection have the equal routing probabilities depends on the number of lanes at intersection. In this case, the data provided by ITIS is the total vehicles per hour entering the intersection based on the phase. Throughout the simulation, the internal arrival flow was generated to the other lanes in intermediate intersection. The routing probabilities (vehicle flow) for intermediate intersection depend on the number of merge or split in each lane. From the observation, the number of vehicles entering the lanes depends on the lanes facing the upstream intersection. The highest arrival rate is the one entering the upstream intersection. Therefore, a larger number of vehicles can enter the lanes.

A. Utilization

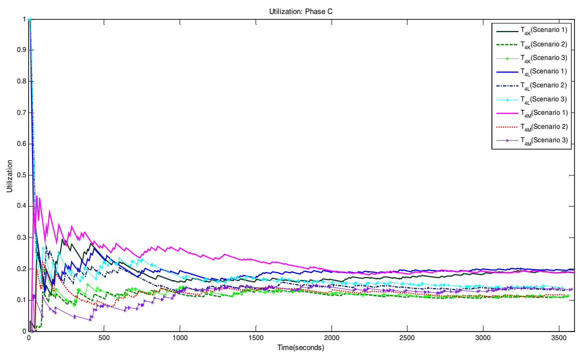
The traffic intensity of the system or known as to utilization factor (ρ) is related to the two parameters which are arrival rate (λ) and service rate (µ). From the theory, the utilization factor ρ can be reduced by reducing the arrival rate, or by increasing the service rate, because, in general, $\rho=\lambda/\mu$.

Again, because the service rate μ is fixed at 2 seconds, therefore the utilization is proportional to the arrival rate.

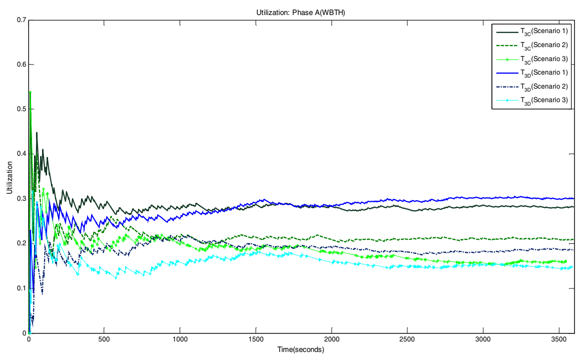
In theory, if the routing probabilities are equal for each lane, thus the number of vehicles entering the lanes is equal in the same phase. But, it is impossible for each lane to get exactly the same number of vehicles at the same time because the vehicles enter the lanes is randomly distributed from upstream intersection. However, the simulation results of utilization are according to the theory. From the Table II, the simulation results show that the S1 with the highest arrival rate has the highest utilization for all the lanes compared to other scenarios. These phenomena are also shown in the plotting curves in Figure 2. The figures show that the vehicles enter Intersection 4 (phase C) from West Bound direction, and travelling through the Intersection 3 (phase B), Intersection 2 (phase B) and leaving network through Intersection 1(phase B). As expected, the curves are slightly broader in the utilization for the highest arrival rate.

TABLE II. UTILIZATION

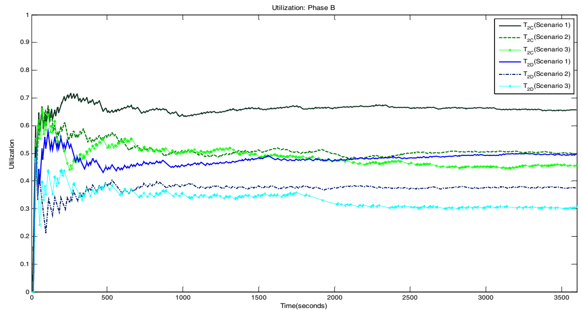
Inter section	Lane	Type	Arrival rate, λ		
			S1	***S2***	***S3***
1	T_{1C}	Internal	0.060	0.289	0.036
	T_{1D}	Internal	0.323	0.242	0.210
2	T_{2C}	Internal	0.658	0.500	0.456
	T_{2D}	Internal	0.496	0.373	0.305
3	T_{3C}	Internal	0.282	0.208	0.160
	T_{3D}	Internal	0.300	0.186	0.148
4	T_{4K}	External	0.187	0.112	0.114
	T_{4L}	External	0.196	0.134	0.140
	T_{4M}	External	0.190	0.110	0.136



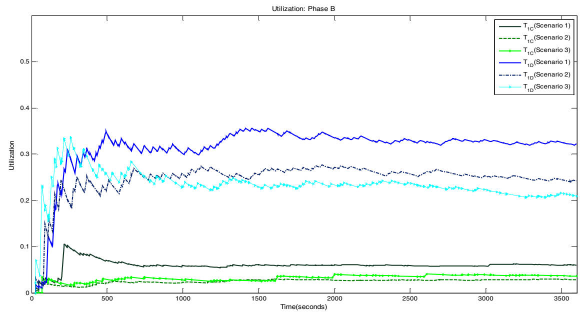
(a) Intersection 4(Phase C)



(b)Intersection 3(Phase A)



(c)Intersection 2(Phase B)

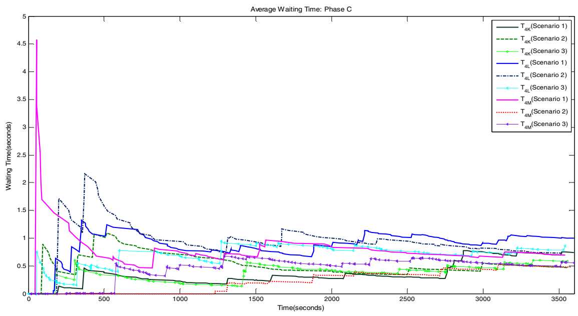


(d)Intersection 1(Phase B)

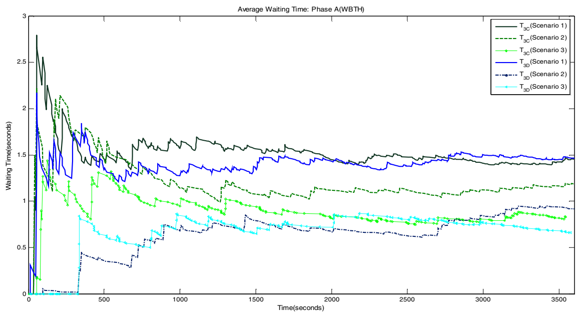
Figure 2. Utilization

B. *Average Waiting Time*

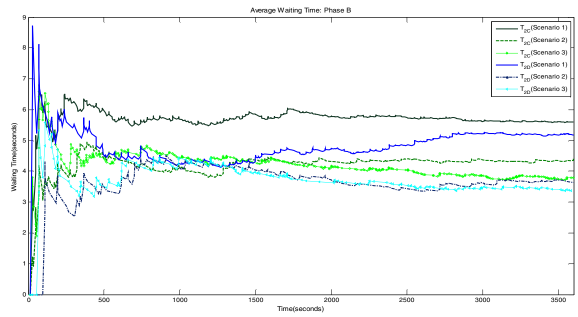
The average waiting time for case study according to the path chosen are presented in Figure 3. From the simulation results of utilization factor (ρ), all the lanes have ρ < 1 and the system is stable. These conditions show that the lanes are not blocking and not congested. The average waiting time for the lanes facing external intersection has a slightly broader curve with a smaller tail when the utilization is slightly higher as shown in Figure 3(a). For the lanes in intermediate intersection, the vehicles entering the lanes depend on the fraction of vehicles from the upstream intersection. From the Figure 3(b), (c) and (d), it can be observed that the average waiting time distribution plotted for the model is dependent on the arrival rate from the upstream intersection which is facing the external intersection. As shown in the figures, the curve of the average waiting time for each lane is in accordance with the theory. The highest average waiting time shows slightly broader curve with a smaller tail for all lanes in the Scenario 1. For the lowest average waiting time, the graphs show much narrower curve and a longer tail for S2 and S 3. The external lanes have equal routing probabilities and the possibilities of the number of vehicles entering the external lanes are the same amount. In this case, supposed that the average waiting time for each lane is equal in the same phase, the average waiting time and average queue length for each lane does not show the same result as expected in Table III.



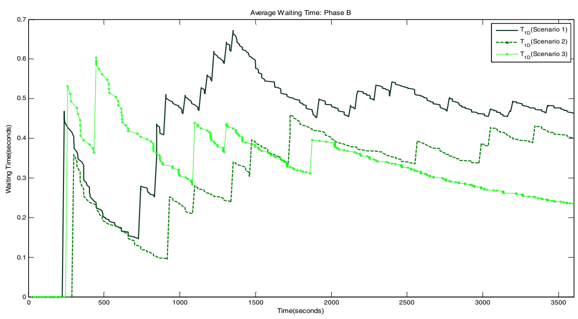
(a) Intersection 4(Phase C)



(b) Intersection 3(Phase A)



(c) Intersection 2(Phase B)



(d)Intersection 1(Phase B)

Figure 3. Average waiting time

TABLE III. AVERAGE WAITING TIME

Inter section	Lane	Type	Arrival rate, λ		
			S1	***S2***	***S3***
1	T_{1C}	Internal	0	0	0
	T_{1D}	Internal	0.463	0.402	0.235
2	T_{2C}	Internal	5.594	4.373	3.790
	T_{2D}	Internal	5.168	3.624	3.378
3	T_{3C}	Internal	1.455	1.177	0.830
	T_{3D}	Internal	1.459	0.913	0.660
4	T_{4K}	External	0.743	0.466	0.579
	T_{4L}	External	0.997	0.728	0.856
	T_{4M}	External	0.690	0.491	0.557

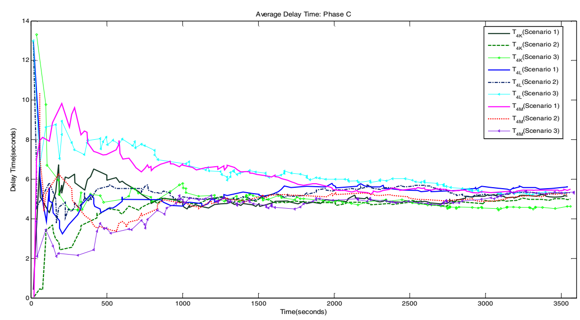
C. *Average Delay Time*

Table IV presents the simulation results of average delay time for Case Study. The characteristics of average delay time only depend on the arrival rate of incoming vehicles. So, the highest arrival rates, the longer delay time per vehicles. As expected, the average delay time for S1 show the highest values compared to other scenario. The arrival rates set up for these three scenarios are not so far each others as seen in Table I. As a result, the different value for the average delay time between these scenarios is very small and the curves plotted closer as expected as shown in Figure 4.

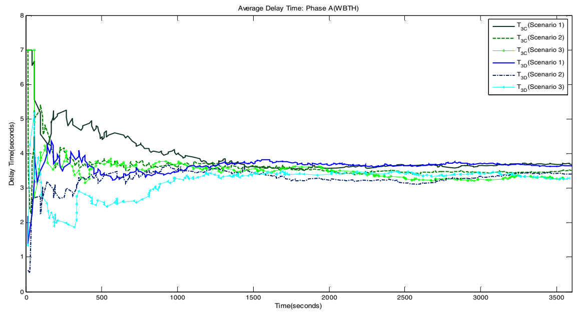
The average delay time can also be predictable from the average waiting time. As discussed above, increasing the average waiting time could increase the average delay time at all intersections. From the simulation results, the average delay time tallies with the average waiting time as expected for all scenarios.

TABLE IV. AVERAGE DELAY TIME

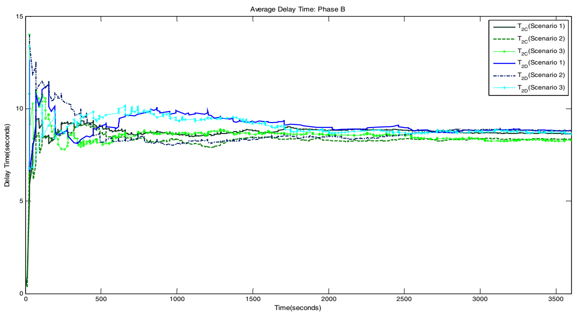
Inter section	Lane	Type	Arrival rate, λ		
			S1	***S2***	***S3***
1	T_{1C}	Internal	0.775	0.564	0.476
	T_{1D}	Internal	3.192	3.004	2.450
2	T_{2C}	Internal	8.638	8.341	8.294
	T_{2D}	Internal	8.836	8.767	8.634
3	T_{3C}	Internal	3.666	3.514	3.273
	T_{3D}	Internal	3.633	3.386	3.289
4	T_{4K}	External	5.143	4.628	4.997
	T_{4L}	External	5.631	5.294	5.324
	T_{4M}	External	5.499	5.214	5.305



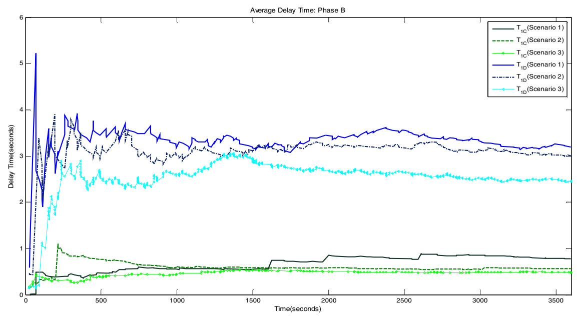
(a) Intersection 4(Phase C)



(b) Intersection 3(Phase A)



(c) Intersection 2(Phase B)



(d) Intersection 1(Phase B)

Figure 4. Average delay time

Overall, the simulation results of the average waiting times and average delay times for different scenarios as expected and accordance with the theory. In this case study, it can be observed that the splitting and merging process do not affect the average waiting time and the average queue length. This is because the routing probabilities of lanes are equal and the number of vehicles entering the lanes is almost the same for each lane. This scenario cause the number of vehicles entering or exiting intersection is quite balance for each lane, thus, the average waiting time and average delay time can be reduced without any delay by the vehicles during this process.

V. CONCLUSIONS

In this paper, the general characteristics of the traffic model based on queue theory and standard approach techniques have been investigated. The model has been analyzed using the decomposition method. The real case study of traffic intersections in Kuala Lumpur have shown how the decomposition method can accurately decompose the network into intersections, where each intersection can then be analyzed independently in order to obtain the overall model.

As observed in the simulation results, the arrival rate is the one important parameter to evaluate the characteristics of the lanes in multilane-multiple intersection. Using the arrival rate, the utilization factor was obtained for all the lanes to check the stability of the traffic model. The utilization for each lane in the model is below unity which indicates that the model proposed is stable. From the formula, the utilization factor also can be used as a parameter to measure the other characteristics such as average waiting time and average delay time. Another characteristic is the average delay time, which is only dependent on the arrival rate based on the formula from the queue theory. Therefore, the average delay time can be estimated directly from the arrival rates. The results show that, all the characteristics measured for each lane give results in accordance with the theory.

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