Improved Discrete Event Simulation Model of Traffic Light Control on A Single Intersection

Sony Sumaryo[1], A. Halim[2], K. Ramli[3]
Department of Electrical Engineering, Faculty of Engineering
Universitas Indonesia
16424 Depok, Indonesia
[1]sony.sumaryo@ui.ac.id, [2]ahalim@ee.ui.ac.id, [3]k.ramli@eng.ui.ac.id

Abstract—**Transportation systems are complex dynamic systems that hard to be modeled exactly. The correct model need model verification and validation. This paper presents an improved discrete event simulation model of traffic light control on a single intersection. Model is developed using SIMULINK / SimEvent toolbox provided by MATLAB. We proposed the improved model using controller with two input switches and two output switches combined with traffic signal logic block. In this research, the fixed time controller algorithm is located within traffic signal logic block. The intersection model uses four approaches, and each approach consists of one trough stream and one right turn stream. Each stream is modeled as an M/M/1 queue. FIFO discipline is applied to the vehicles queue in each stream. Inter arrival time between vehicles is modeled using exponential distribution. Model validation is done in two different scenarios of inter-arrival time between vehicles 15 s (for low traffic volume), and 5 s (for high traffic volume) respectively. Experiment results show that the number of vehicles in queue and average waiting time of low traffic volume is lower than high traffic volume. That means the model has functioned correctly.**

Keywords—discrete event model; traffic light control; single intersection; validation; distribution

I. INTRODUCTION

Transportation systems are complex dynamic systems that hard to be modeled exactly [1]. For this reason, many current methods do not have good theoretical bases. However, without modeling the system appropriately, the characteristic of transportation system cannot be identified correctly. Furthermore, it is hard to evaluate existing algorithms and to recognize potential problems and improve them. The model needs to be verified and validated. A model should be developed for specific purpose and its validity determined with respect to that purpose [2]. So far as we know most existing research works [3,4,5,6,7,8,9,10,11] have developed the single intersection model for implementation of the specific algorithm. Moreover those research works did not describe how to develop the model and how to perform validation.

Consider the simplified version of the model development process in Fig. 1 [2]. The problem entity is the system (real or proposed), idea, situation, policy, or phenomena to be modeled; the conceptual model is the mathematical / logical / verbal representation of the problem entity developed for a particular study; and the computerized model is the conceptual model implemented on a computer. The conceptual model is developed through analysis and modeling phase, the computerized model is developed through a computer programming and implementation phase, and inferences about the problem entity are obtained by conducting computer experiments on the computerized model in the experimentation phase.

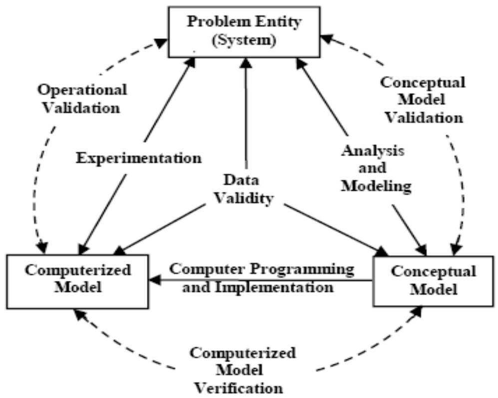

Fig. 1. Simplified version of the modeling process [2].

This research has two goals:

- Propose the improved traffic light discrete event simulation model using controller with two input switches and two output switches combined with traffic signal logic block. In this research, the fixed time controller algorithm is located within traffic signal logic block. The advantage of this model is that it can be used to test any traffic light algorithm without major modification and also can be modified to fit for real system.

- Validate model through evaluation the number of vehicles in queue and average waiting time.

II. DESCRIPTION AND MODEL OF SINGLE INTERSECTION

A. System

The real common intersection consists of four approaches (east, west, north and south) [3,4,5,6,7,8,9,10,11] with two or three streams in each approach. The approach that consists of three streams [3,6,8,9] are one through stream, one right turn stream and one left stream while the approach that consists of two streams [4,5,7,11] are one through stream and one right turn stream. The signalized intersection is equipped with a fixed time traffic control system.

B. Conceptual Model

The traffic light control on a single intersection model shown in Fig. 2 is designed based on the real traffic light system. In this model, there are four approaches (east, west, north and south) with total 8 streams. Each approach consists of two streams are one through stream and one right turn stream. At this time pedestrian crossing and the left turn stream are not considered. The input flow rates in each stream are assumed to be provided by sensors accurately.

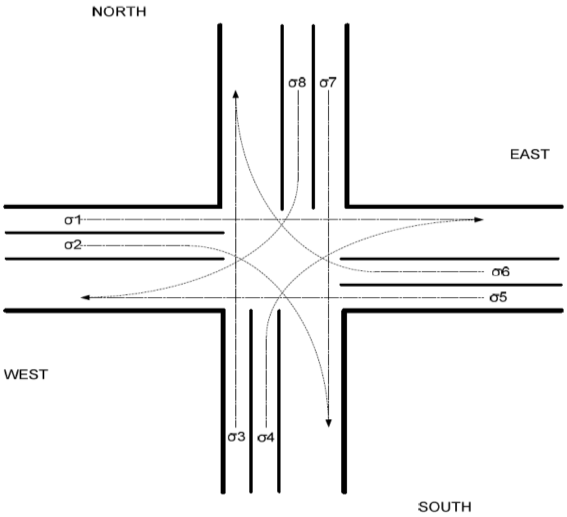

Fig. 2. Single intersection traffic stream model.

Each stream is modeled as an M/M/1 queue (based on Kendall notation) and it is built based on the three main concepts in queuing theory which are customers, queues, and servers. The first and the second M in M/M/1 stand for "memoryless" distribution of interarival time and service time, respectively. The "1" indicates that the single intersection has single server with specific service time.

First-In-First-Out (FIFO) discipline is applied to the vehicle queue in each stream. From queuing theory, the vehicles in this model are known as customers while service time is the time for the vehicles to depart from queue and to cross the intersection in their own stream.

Based on research works [4,6,8,12], the characteristic of arrival traffic according to Poisson process. Many other models have been used for describing the arrival process of vehicles on the approach. However, most of them are more complex, but the Poisson model is still used for most practical purposes [12]. With Poisson flow, the probability of arrival of m_i vehicles of traffic stream σ_i to an intersection, during interval τ, is expressed by the equation [12]:

$$P_{mi}(\tau) = \text{p[mi vehicles arrive in interval } \tau] = \frac{(q_i\,\tau)^{m_i}}{m_i!}\; e^{-q_i \tau} \tag{1}$$

q_i: constant, arrival rate

The interarrival times for a Poisson process with rate q_i are IID (Independent and Identically Distributed) exponential random variabels with mean $1/q_i$. The Poisson model is good for describing the real arrival process on an intersection approach in the case when the ratio between volume and approach capacity is not high [12].

Modelling each stream as an M/M/1 queue is still suitable for real traffic system that observed, since the intersections or network that we are observed is a single intersection with not too high traffic volume. If the network is large with huge traffic volume then the suitable model is Stochastic Fluid Model-SFM [13]. Based on research [1,3,4,5,6,8] and much more, the number of vehicles and the average waiting time in each stream are popular performance indices for traffic light signal control.

Traffic light control is divided into four signal groups (D1, D2, D3, D4), that are D1: for approach west (stream 1 and stream 2), D2: for approach south (stream 3 and stream 4), D3: for approach east (stream 5 and stream 6) and D4: for approach north (stream 7 and stream 9). A signal group is the set of traffic streams that are controlled by identical traffic light indication. If a signal group is active it means green light indication. Green light indication for vehicles means allowed passage the intersection, while red light indication means forbidden passage. In this research, sequence and duration for signal groups is determined using fixed time algorithm.

Fig. 3 shows the sequence and duration of signal groups. Label "1" indicates the signal group is active while label "0" is not active. The durations of signal group are labeled t1, t2, t3, and t4 for signal group D1, D2, D3, and D4 respectively. In this simulation the durations of each signal group are 100 s.

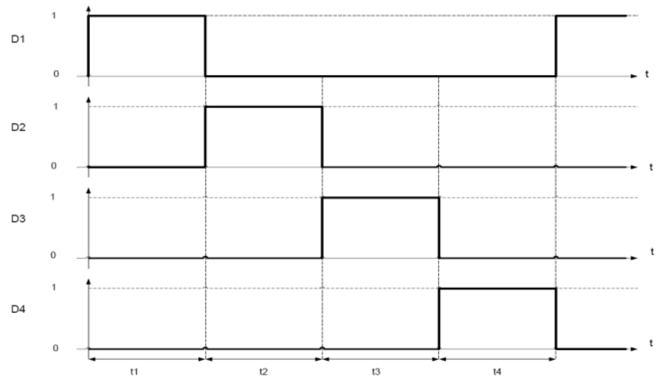

Fig. 3. Signal group

C. Computerized Model

The single traffic intersection model developed in MATLAB using SIMULINK and SimEvent toolbox is shown in Fig. 4. SimEvents software incorporates discrete-event system modeling into the Simulink time-based framework, which is suited for modeling continuous-time and periodic discrete-time systems [14]. In time-based systems, state updates occur synchronously with time. By contrast, in discrete-event systems, state transitions depend on asynchronous discrete incidents called events. Since we are interested in the number of vehicles and the average waiting time in each stream and we are not interested in the details of how an vehicle move and cross the intersection-for example-then we can use discrete-event simulation.

The discrete event simulation model of traffic light control on a single intersection in this research is an improvement model from discrete event model that developed by Devdatt Lat [15]. The improvement that we are proposed is using two input switches and two output switches that controlled by Traffic Signal Logic block as implementation of traffic light control algorithm, and modeling each traffic stream in each approach (see also Fig. 2) with using a time based entity generator (for generation of customers) , a queue and a server. As describe at paragraph above, each stream is modeled as an M/M/1 queue and traffic arrival is modeled by inter arrival between vehicles using exponential distribution. First-In-First-Out discipline is applied to the vehicles queue.

Fig. 4 shows the signal group D1, D2, D3 and D4 are implemented using input port IN1, IN2, IN3 and IN4 at input switch 1 and input switch 2 respectively. The sequence of input port of input switch 1 and 2 is controlled by the output signal of traffic signal logic block that connected to the input port "p" of input switch. Output switch 1 and 2 have function so that the customer (vehicle) can arrive at the approach destination.

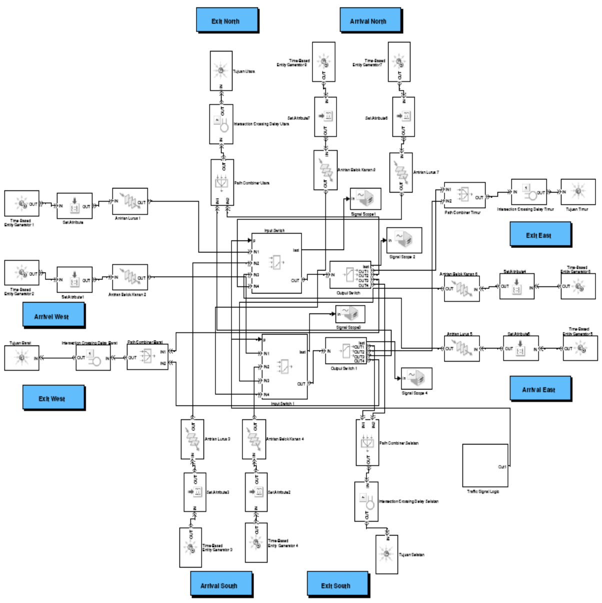

Fig. 4. Simulink / SimEvent block diagram of single intersection traffic model.

Inside Traffic Signal Logic Block (in Fig. 5), the duration of green time is determined by Event Based Sequence block and then executed by server block. The sequences of Signal Group activation are determined by another Event Based Sequence 1 block. The output signal of traffic signal logic block (from output port of the signal latch block) will control the sequence of input port activation of input switch 1 and input switch 2. Since the model implemented using Simulink / SimEvents, model verification through with ensuring that an error free simulation language has been used.

The advantage of this model can be used to test any traffic light algorithm without major modification of the model since traffic light algorithm located within a traffic signal logic block.

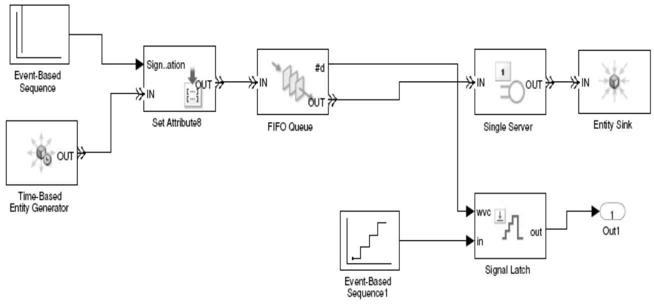

Fig. 5. Traffic signal logic block diagram

III. RESULTS AND DISCUSSION

The objective of this simulation is to validate the model that has been built if the output simulation of the model has the same characteristic with the real traffic light control system. The outputs of the simulation that we evaluated as performance indices are the number of vehicles in queue and average waiting time in each stream. The simulation time is 1000 s. Duration each signal group D is 100 s and two different scenarios of inter arrival time between vehicles are 15 s (for low traffic volume), and 5 s (for high traffic volume) for all stream respectively.

Fig. 6 shows the numbers of vehicles in each queue using inter arrival time 15 s in stream 1 (red curve) and 5 (blue curve). From the figure it looks if the signal group of stream is active, the number of vehicles in the queue will be reduced compared to the inactive group signal. For clarity we take an example, stream 1 gets an active group signal (D1) for a duration of 100 s first, then the number of vehicles in the queue a bit. For time 100 s to 400 s where the signal group of stream 1 is not active (see also Fig. 3), the number of vehicles continues to grow. At the time of 400 s to 500 s, when the signal group is active, the number of vehicles is reduced. The number of vehicles increased again when the time 500 s to 800 s are currently no active signal group again and so on. The same characteristics were obtained for the other streams.

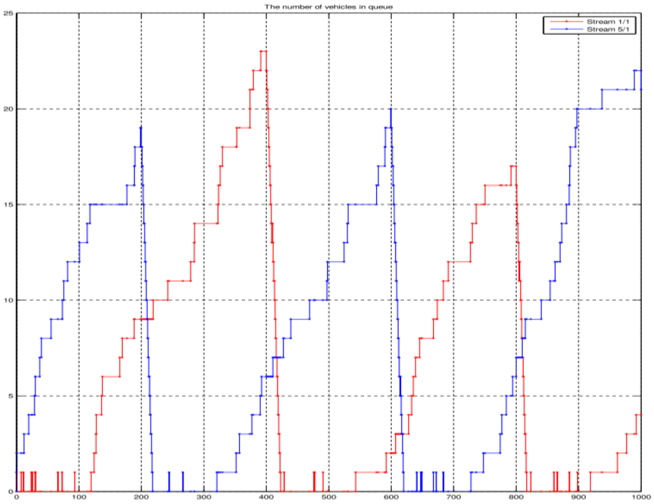

Fig. 6. The numbers of vehicles in each queue using inter arrival time 15 s.

If the inter arival time between vehicles converted to 5 s, then the number of vehicles coming into the queue increasingly or high traffic volume. It resulted in the number of vehicles in queue greater than if inter arival time between vehicles 15 s or low traffic volume. These characteristics are shown in Fig. 7. For example again, few the number vehicles in the queue of stream 1(red curve in Fig.7) at time 0 s to 100 s. For time 100 s to 400 s when the signal group of stream 1 is not active the number of vehicles continues to grow. At the time of 400 s to 500 s, when the signaling group is active, the number of vehicles is reduced. The number of vehicles increased again when the time 500 s to 800 s are currently no active signal group again and so on. The same characteristics were obtained for the other streams. In Fig. 7 shows that the decrease of the number of vehicles in the queue (at the time of signal group is active) is lower than in the scenario inter arival 15 s (see Fig. 6). It is caused to the addition of vehicles to the queue is greater than the speed of vehicles crossing the intersection that simulated by setting service time 5 s.

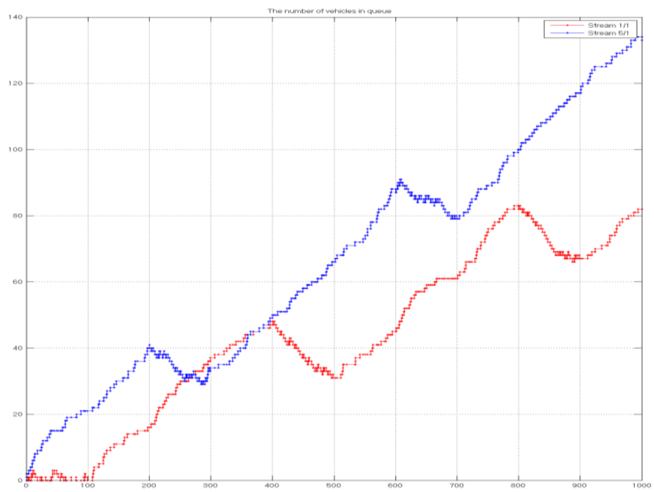

Fig. 7. The numbers of vehicles in each queue using inter arrival time 5 s.

Fig. 8 shows the average waiting time in each queue using inter arrival time 15 s in stream 1 (red curve) and 5 (blue curve). The MATLAB will update the average waiting time in queue for all entities (customers) that have departed from the queue. The customers will depart the queue if the signal group of the stream is active. For an example, stream 1 gets an active signal group (D1) for a duration of 100 s first, then the waiting time in that queue is very short. For time 100 s to 400 s where the signal group of stream 1 is not active, MATLAB does not update the average waiting time. At the time of 400 s to 500 s, when the signal group is active, it appears waiting time increases as the number of vehicles from the 100s to 400 s to grow. That increasing of the waiting time is till to a certain limit and then decreases again. Same characteristics occur at time 800 s to 900 s. The same characteristics were obtained for the other streams.

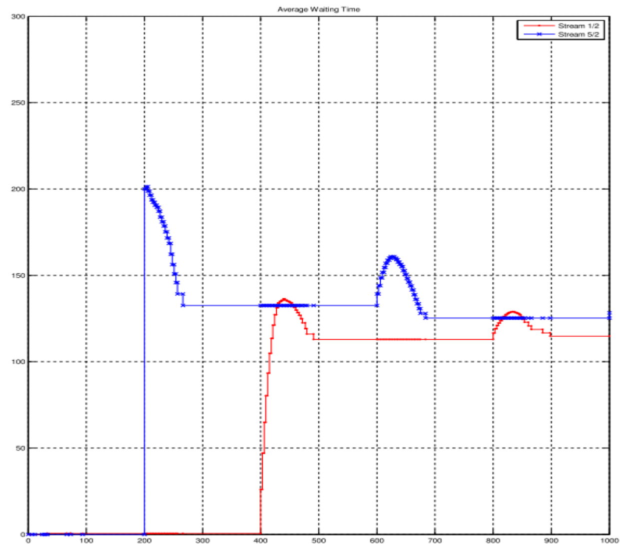

Fig. 8. The average waiting time in each queue using inter arrival time 15 s.

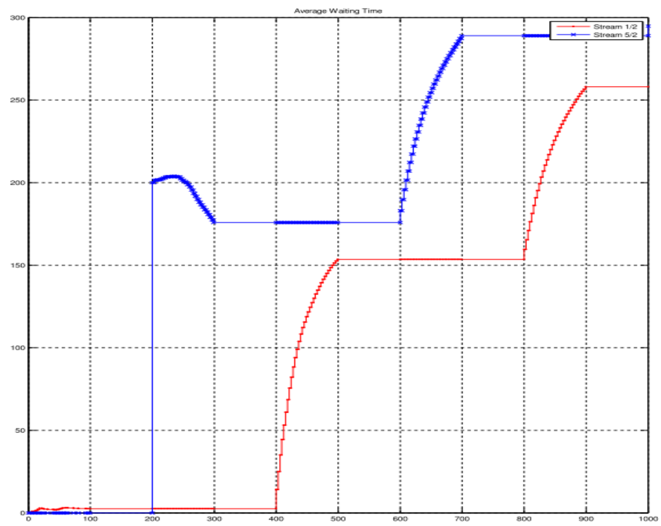

Fig. 9. The average waiting time in each queue using inter arrival time 5 s.

Fig. 9 shows the average waiting time in each queue using inter arrival time 5 s in stream 1(red curve) and 5 (blue curve). As described for Fig. 7, if the inter arrival time between vehicles converted to 5 s, then the number of vehicles coming into the queue increasingly or high traffic volume. It resulted in the average waiting time in queue is greater than if the inter arival time between vehicles 15 s or low traffic volume. For example, it is clear the waiting time in the queue of stream 1 at time 800 s to 900 s longer than the waiting time in the scenario of inter arival time 15 s (see also Fig. 8). The same characteristics were obtained for the other streams.

IV. CONCLUSION

This paper proposed an improved discrete event simulation model of traffic light control on a single intersection. The improvement of the model is to use the controller with two input switches and two output switches combined with traffic signal logic block. Based on queuing theory, the model is easy to develop using SIMULINK / SimEvent toolbox in MATLAB.

The simulation has shown that the model has functioned correctly. Experiment results also have shown that the number of vehicles in queue and average waiting time of low traffic volume is lower than high traffic volume. But it has to configured carefully for service time at each server. The model can be extended further for multiple intersection and will be extended further in our ongoing research on using adaptive traffic light control algorithm.

REFERENCES

[1] Li Jinyuan, Pan Xin, and Wang Xiqin,"State-space equations and first-phase algorithm for signal control of single intersections'', Tsinghua Science and Technology, vol. 12, no. 2, pp. 231-235, Apr. 2007, ISSN 1007-0214 14/14.

[2] Robert G. Sergent,"Verification and validation of simulation models'', Proceeding of the 2009 Winter Simulation Conference.

[3] Ehsan Azimirad, Nazer Pariz, and M. B.N. Sistani," A novel fuzzy model and control of single intersection at urban traffic network", IEEE System Journal, Vol 4, No. 1, March 2010.

[4] Azura Che Soh/Lai Guan Rhung, and Haslina Md. Sarkan," MATLAB simulation of fuzzy traffic controller for multilane isolated intersection'', International Journal on Computer Science and Engineering, Vol. 02, No. 04, 2010, 924-933.

[5] Zoran Gacovski, Stojce Deskovski, and Kostandina Veljanovska,"Fuzzy traffic controller for urban intersection developed in Simulink/SimEvents", 13th IFAC Synposium on Control in Transportation Systems, The International Federation of Automatic Control, September 12-14, 2012, Sofia, Bulgaria.

[6] B. Madhavan Nair, and J. Cai,"A fuzzy logic controller for isolated signalized intersection with traffic abnormality considered", Proceeding of 2007 IEEE Intelligent Vehicle Symposium Istanbul, Turkey, June 13-15, 2007.

[7] Lai Guan Rhung, Azura Che Soh, Ribhan Zafira Abdul Rahman, and Mohd Khair Hassan,"Fuzzy traffic light control using sugeno method for isolated intersection", Proceeding of 2009 IEEE Student Conference on Research and Development (SCOReD 2009), 16-18 Nov 2009, UPM Serdang, Malaysia.

[8] Leng Junqiang, and Feng Yuqin,"Research on the fuzzy control and simulation for intersection based on the phase sequence optimization", International Conference on Measuring Technology and Mechatronics Automation, 2009.

[9] Michal Kutil,"Modeling and optimization of traffic flow in urban areas", Doctoral Thesis, Czech Technical University in Prague, Faculty of Electrical Engineering Department of Control Engineering, January 2010.

[10] S. Harjono, A. Halim, and K. Ramli,"Simulation of improved hybrid petri nets intersection model considering traffic distribution", International Journal of Soft Computing 7 (4): 217-223, 2012.

[11] Binbin Zhou, Jiannong Cao, Xiaoqin Zeng, and Hejun Wu,"Adaptive traffic light control in wireless sensor network-based intelligent transportation system", IEEE, 2010.

[12] Slobodan Guberinic, Gordana Senborn, and Bratislav Lazic," Optimal traffic control: urban intersections", CRC Press, 008.

[13] Herman Sutarto, Rene Boel,"Perturbation analysis and sample-path optimization: stochastic flow models of urban traffic networks case", Faculty of Engineering, Universiteit Gent, 2011.

[14] ....,''SimEvents-getting started guide", R2012a, Matlab & Simulink, MathWorks.

[15] Devdatt Lad,"Vehicle traffic patterns at intersection (SimEvents)", 13 June 2008 (Updated 06 Aug 2012), The MathWorks.