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SELF-ORGANIZING URBAN TRAFFIC CONTROL ARCHITECTURE WITH SWARM-SELF ORGANIZING MAP IN JAKARTA: SIGNAL CONTROL SYSTEM AND SIMULATOR

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Abstract- Urban traffic control is the main factor that contributes to traffic jam. Approach in distributed Urban traffic control has been developed in several research, but the coordinating controller factor is basically a quite complicated task to tackle, because between intersection have dependency, so required a method of distributed control system capable for synchronizing between intersections. In this paper we present architecture of decentralized self-organizing traffic control with swarm-self organizing map in real situation even on non-structure intersections like in Jakarta (Indonesia). Based on the proposed architecture we have been implemented Traffic Signal Control System for controlling traffic lights in which the coordination between the intersections is implemented using distributed swarm self-organizing map. Traffic Signal Control System were tested in a simulated real-road scenario of Jakarta. By means of the computer simulation, the application of distributed swarm signal self-organizing control is proved effective in urban traffic.

Index terms*: Traffic Control , Swarm-self Organizing Map, Distributed Traffic Control.*

I. INTRODUCTION

Ineffective traffic management in urban areas is the main factor causing heavy congestion. This unfavorable condition involves problems such as increasing traffic accidents, environmental pollution and economic loss in terms of money and time. In line with this hectic situation some researchers have been attempting to model a new algorithm in order to come up with the optimization of the traffic controller. Traffic control systems try to minimize the traveling delay of vehicles through a network of intersections. Arterial control, such as green wave [1], is an efficient strategy only to some arterials by sacrificing branches benefits.

Many methods have been introduced to manage traffic signal controller. Pate1[2] presents a real-time intelligent decision making system for urban traffic control applications. The system integrates a backpropagation-based artificial neural network (ANN) that can learn and adapt to the dynamically changing environment and a fuzzy expert system for decision making. Hong [3] used fuzzy control to manage the urban traffic signal. And Binghamde [4] built the model of urban traffic control using the fuzzy-neuro method. Most works on this management focus on single or stand alone controller algorithm, in fact it is a distributive controller problems, where every traffic signal is assumed like “a node”.

Distributed urban traffic control has been developed in several research. Edward[5] introduces Decentralized Control of Traffic Networks. Srinivasan[6] adopts the multiagent system approach to develop distributed unsupervised traffic responsive signal control models, where each agent in the system is a local traffic signal controller for one intersection in the traffic network using Neural Network. Coordinating controller is a quite complicated task to tackle. Because between intersection have dependency, so required a method of distributed control system capable for synchronizing between intersections.

The objective of this paper is to design a decentralized and self-organizing control strategy for a traffic signal network adapting to dynamical environmental changes based on only local traffic information. Previously, a decentralized control method is arbitrary interconnected one-way traffic network by adjusting the split setting [5]. The studies in [9, 10, 11] pose the traffic signal control as an optimization problem such as a combination of reinforcement learning to maximize local traffic at each intersection and global optimization by Evolutionary Computational Method [9,12] , minimization of the total delay experienced by all network traffic at each section in a given network using a dynamic programming technique [10] and adjustment of green period by reinforcement learning [11]. However, we have found no studies concerned with adjusting all the three parameters (cycle time, spilt and offset) based on the completely decentralized approach.

In this paper, first we describe the architecture of the Self-Organizing Control of Urban Traffic Control. Second, we describe a traffic signal network using a system of nonlinear coupled oscillators. The self-organization observed in nonlinear coupled oscillators is referred to as “synchronization” or “the phenomenon of entrainment” [13], where oscillators having different natural frequencies are phase locked with some phase delays as a result of their mutual or one-sided interaction. In this signal network control problem, we found it useful to apply a nonlinear coupled oscillator system to achieve desired signal pattern of the network using such a self-organizing phenomenon of collective oscillation. Third, we develop traffic signal control system by adopting decentralized control strategy of the cycle time and the split setting of the signals. So the desired offset patterns are self-organized through mutual entrainment based on local traffic demand to achieve efficient traffic flow reducing the cost of the “stop-and-go” at signals [7]. Finally, visualization of simulation demonstrates the effectiveness proposed method under unstructured condition like in Indonesia.

II. THE ARCHITECTURE OF SELF-ORGANIZING CONTROL OF URBAN TRAFFIC CONTROL

The swarm-self organizing map traffic control model consists of one signal controller at each intersection in the traffic network and the communication is essential between the adjacent intersections. The architecture of the Self-Organizing Control of Urban Traffic Control is illustrated by Figure 1. The proposed architecture has fifth components.

The first component is the Traffic Signal Control System (TSCS). TSCS was developed to enable rapid creation of real-time systems with limited involvement of programmers and control experts. This component will discuss into two sections, the algorithms and implementation system.

Second component is the simulator. The simulator used in verification and testing TSCS. In the process of verification and testing, simulator is set to be can modeled in a synthetic traffic conditions in Indonesia. Verification and testing is intended to ensure that TSCS is able to handle the situation in real world.

Third component is the map converter (MP). MP is an application to obtain a road information and intersection from traffic networks on Jakarta. The information is obtained by extract and identify of road network from map image. Then information will be used as data input for Traffic Signal Control System in calculation process. In addition, this information is sent to simulator for verification and testing process.

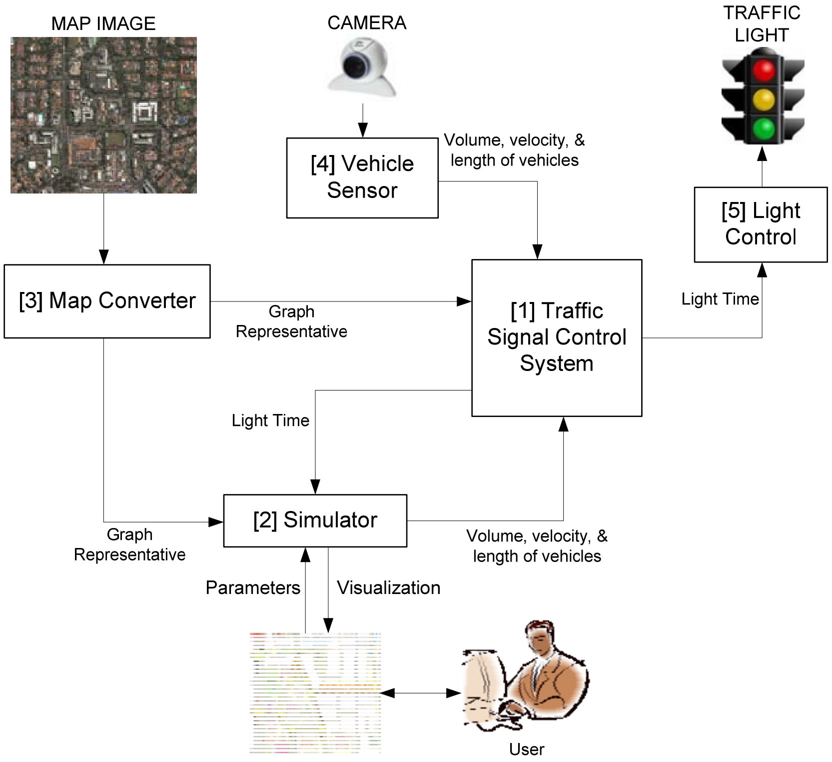


Figure 1. Self-Organizing Control Of Urban Traffic Control Architecture

Fourth component is vehicle sensor (VS). This application has function to detect and calculate the number of vehicles passing through an intersection. The application developed using the camera sensor which currently installed at intersection of many urban area like Jakarta. Furthermore, VS provides much information such as number of vehicles, the vehicle length, velocity of vehicle, and vehicle queue length measurement.

Fifth component is the light control as the main output of TSCS. A variety of Ligh using in intersection is need to arrangement by TSCS.

The Traffic Signal Control System and simulator will discuss on the next section.

III. TRAFFIC SIGNAL CONTROL SYSTEM

1. Traffic Light Control Model

Figure 2 is a generic model of traffic lights in real world which is commonly found in Indonesia.

There are 3 important parameters in controlling traffic lights:

1. Cycle time : the time required for one full cycle of signal phase including red, yellow and clearance (green) lights.
2. Green split: the percentage of green time allocated for each direction in one cycle of the signal.
3. Offset : the relatively difference time between starting times of green phases on consecutive signals.

These three parameters are important in controlling the flow of traffic. The controller must be coordinated in a distributed manner. There should be a corelation between adjacent intersection with the others, as shown in figure 3.

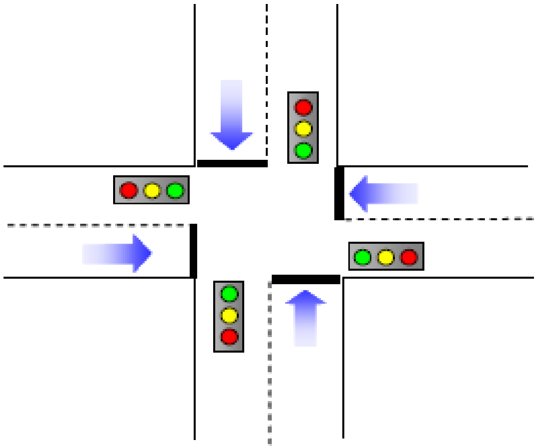


Figure 2. Generic traffic light model

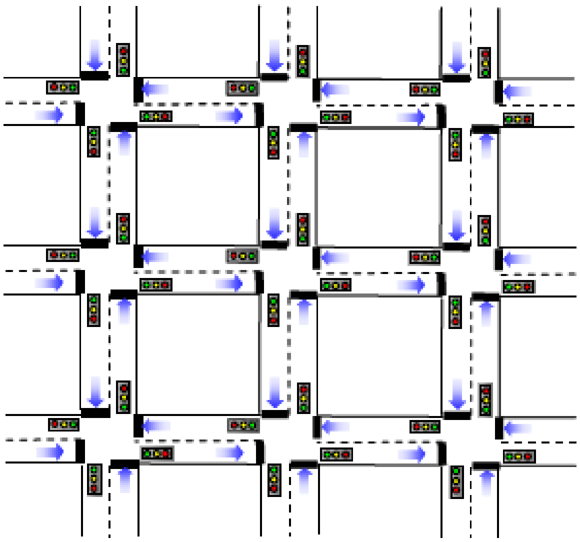
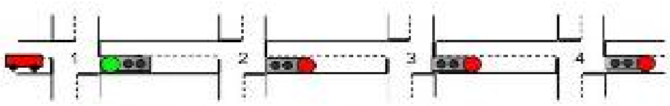
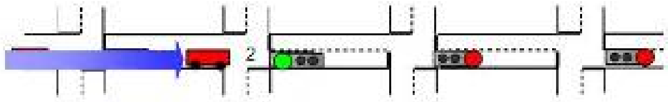


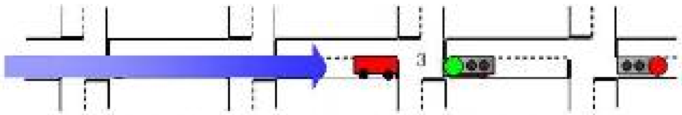
Figure 3. Traffic light model with relation between intersections.



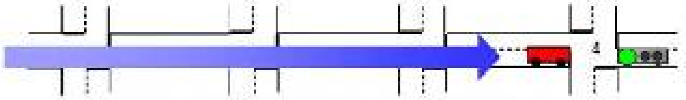
(a) Traffic light intersection 1 color green for vehicle that flow from left to right.



(b) Coordination between intersection 1 and intersection 2



(c) Coordination between intersection 2 and intersection 3



(d) Coordination between intersection 3 and intersection 4

Figure 4. Coordination between nearest intersections for achieving the optimal flow of traffic.

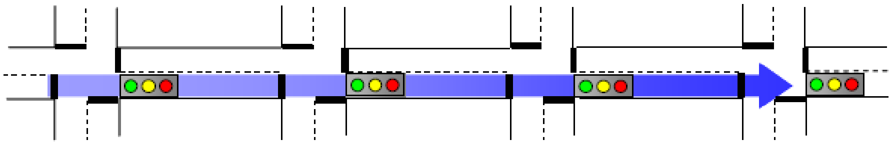


Figure 5. Traffic light control optimization result between nearest intersections.

In figure 4(a), a vehicle will move from left to right (from intersection 1 to intersection 4). If the traffic light at intersection 1 is green, then intersection 1 will coordinate with intersection 2 to control the offset value. The coordination will make vehicles can pass through without stopping at intersection 2, as seen in figure 4(b). Likewise in figure 4(c) and figure 4(d), the vehicle can go without stopping at intersection 5 and 6, making an optimal velocity of the vehicles between intersection 1 to intersection 4. The result of traffic light control optimization can be seen in figure 5.

2. Swarm-Self Organizing Map Method

To the best knowledge of the author, in the last condition of distributed urban traffic control implementation, coordination between intersections is not established well. For resolving this, author implements a swarm-self organizing map method.

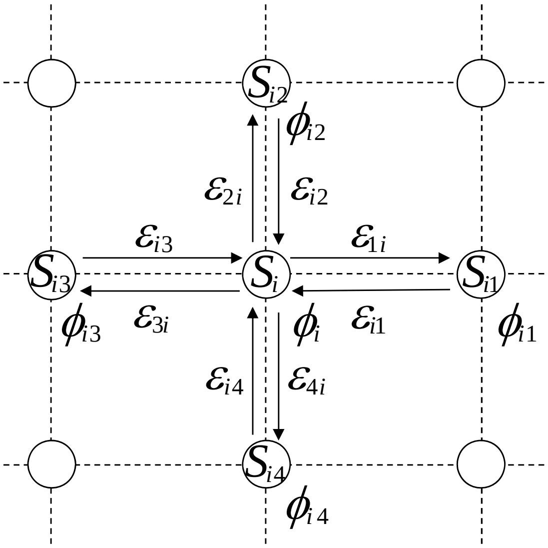


Figure 6. Model signal network

Urban traffic signal network is modeled with bi-directed graph as seen in figure 6. Every intersection is denoted by a node, $S_i (1 \le i \le N),$ and the neighbor of S_i is S_{ij}. ϕ_i defines phase of one cycle signal S_i, and $\phi_{ij} (j \in \{1,2,..., n_i\})$ is phase for S_{ij} signal, where n_i is the number of signal paired with S_i. ε_{ij} is normalized flow of vehicles which is defined as:

$$\varepsilon_{ij} = \frac{1}{\rho_{im} Ti} \int_t^{t+T_i} \rho_{ij}(t) dt \tag{1}$$

$$\rho_{im} = const.$$

Where ρ_{im} is capacity and $\rho_{ij}(t)$ is density of the lane between S_i and S_{ij} in interval $[t, t+T_i]$. In figure 5 the phase of S_i , i.e ϕ_i , is affected by the neighboring signal, which is S_{ij} dan ϕ_{ij}. This signal phase S_{ij} is affected by the size of the traffic coming from. Author implements phase model description of coupled oscillator proposed by Kuramoto [9], which is a model generalized and denoted with:

$$\dot{\phi}_i(t) = \omega_i + \frac{K}{n_i} \sum_{j=1}^{n_i} \Gamma_i(\phi_i, \phi_{ij}) \tag{2}$$

With coupling constants ε_{ij} (which will be defined in the next section), where:

$$\Gamma_i(\phi_i + 2\pi, \phi_{ij}) = \Gamma_i(\phi_i, \phi_{ij} + 2\pi) = \Gamma_i(\phi_i, \phi_{ij}) \tag{3}$$

Equation above holds for every value of i and j.

For the remainder of the paper, author will use following model for oscillator:

$$\dot{\phi}_i(t) = \omega_i + \frac{K}{n_i} \sum_{j=1}^{n_i} \varepsilon_{ij} \sin(\phi_{ij} - \phi_i) \tag{4}$$

Euler formula defines that,

$$\sin x = \frac{e^{ix} - e^{-ix}}{2i}$$

If $x = (\phi_{ij} - \phi_i)$, then by Euler's formula, equation (4) can be desired as ,

$$\dot{\phi}_i(t) = \omega_i + \frac{K}{2i} \left(e^{-i\phi_i} \sum_{j=1}^{n_i} \frac{\varepsilon_{ij}}{n_i} e^{i\phi_{ij}} - e^{i\phi_i} \sum_{j=1}^{n_i} \frac{\varepsilon_{ij}}{n_i} e^{-i\phi_{ij}} \right) \tag{5}$$

Then by defining Ai and Bi as :

$$A_i = \sum_{j=1}^{n_i} \frac{\varepsilon_{ij}}{n_i} e^{i\phi_{ij}} \tag{6}$$

$$B_i = \sum_{j=1}^{n_i} \frac{\varepsilon_{ij}}{n_i} e^{-i\phi_{ij}} \tag{7}$$

Equation (5) can be written as ,

$$\dot{\phi}_i(t) = \omega_i + \frac{K}{2i}\left(e^{-i\phi_i} A_i - e^{i\phi_i} B_i\right) \tag{8}$$

Euler formula defines that,

$$e^{ix} = \cos x + i \sin x \tag{9}$$

$$e^{-ix} = \cos x - i \sin x \tag{10}$$

With utilizing euler formula, equation (8) can be rearranged as:

$$\dot{\phi}_i(t) = \omega_i + \frac{K}{2i}\left((\cos\phi_i (A_i - B_i) - i \sin\phi_i (A_i + B_i)\right) \tag{11}$$

Thus,

$$A_i - B_i = 2\sum_{j=1}^{n_i} \frac{\varepsilon_{ij}}{n_i} i \sin\phi_{ij} \tag{12}$$

$$A_i + B_i = 2\sum_{j=1}^{n_i} \frac{\varepsilon_{ij}}{n_i} \cos\phi_{ij} \tag{13}$$

If ai and bi are defined as:

$$a_i = \sum_{j=1}^{n_i} \frac{\varepsilon_{ij}}{n_i} \cos \phi_{ij} \tag{14}$$

$$b_i = \sum_{j=1}^{n_i} \frac{\varepsilon_{ij}}{n_i} \sin \phi_{ij} \tag{15}$$

Then (equation 11) can be rearranged as

$$\dot{\phi}_i (t) = \omega_i + K\left(b_i \cos \phi_i - a_i \sin \phi_i\right) \tag{16}$$

After that, equation (16) will expand through be model entrainment, i.e.:

$$\dot{\phi}_i (t) = \omega_i + \sigma_i K \sin (\overline{\phi_i} - \phi_i) \tag{17}$$

if equation 16 is equalized with equation 17 then this relationship will be:

$$\sigma_i \sin(\overline{\phi_i} - \phi_i) = b_i \cos\phi_i - a_i \sin\phi_i \tag{18}$$

With trigonometri manipulation, it can be proven that bellow relationship will hold between σ_i, ai and bi:

$$\sigma_i = \sqrt{{a_i}^2 + {b_i}^2} \tag{19}$$

$$\overline{\phi_i} = \arctan\left(\frac{b_i}{a_i}\right) \tag{20}$$

The followong wil describe, the adjustment of split setting of traffic light. First, cycle time of signal S_i will be defined as follow:

$$T_i(\tau_i) = T_{i1}(\tau_i) + T_{i2}(\tau_i) + 2T_{cl} \tag{21}$$

The above equation includes T_{cl} which is clearence constant, where $T_{i1}(\tau_i)$ and $T_{i2}(\tau_i)$ are split time from S_i on the vertical and horizontal direction consecutively.

Clearence time is included to adapt the periods between red and green lights on the model traffic light system. This period is yellow traffic light which is used for transition between red and green traffic light and vice versa. In the area that doesn`t use clearence, $T_{cl} = 0$.

Split time T_{ik}, will be updated on each the begnning of signal cycle proportion to the sum of incoming from vertical and horizontal direction. The total traffic of incoming vehicle to an intersection, is formulated as:

$$r_{i1} = \varepsilon_{i,1} + \varepsilon_{i,3}, r_{i2} = \varepsilon_{i,2} + \varepsilon_{i,4} \tag{22}$$

From the equation (22), the desired split time for the flow of vehicles coming from horizontal and vertical can be obtained using equation:

$$T_{ik}^* = \frac{r_{ik}(\tau_i)}{r_{i1}(\tau_i) + r_{i2}(\tau_i)}(T_i(\tau_i) - 2T_{cl}), (k = 1,2) \tag{23}$$

Hance, update function can be defined with following equation:

$$T_{ik}(\tau_i + 1) = T_{ik}(\tau_i) + \gamma(T_{ik}^* - T_{ik}(\tau_i)), (k = 1,2) \tag{24}$$

Where γ is change constants which will affects the change rate from current split time to desired split time.

In the followings, the strategy to adjust offset pattern of traffic lights using mutual entrainment is described. Let ψ_i denotes the relative phase between $\bar{\phi}_i$ and ϕ_i which is defined as:

$$\psi_i = \bar{\phi}_i - \phi_i \tag{25}$$

Then the dynamics of the relative phase can be denoted with the following equation:

$$\dot{\psi}_i = \Omega_i - \omega_i - \sigma_i K \sin(\psi_i) \tag{26}$$

where Ω_i is natural frequency from weight phase average, $\bar{\phi}_i$. By examining the fixed point from dynamics and in regard from sinus function that take value in the range of -1 to 1, fixed point on (equation 26) only occur if:

$$\left| \frac{\Omega_i - \omega_i}{\sigma_i K} \right| \leq 1 \tag{27}$$

Thus, under the condition of (Equation 27), phase locking will occur with phase difference of:

$$\psi_i = \arcsin\left(\frac{\Omega_i - \omega_i}{\sigma_i K} \right) \tag{28}$$

When oscillator S_i is phase-locked with neighboring oscillator.

3. The Traffic Signal Control System

The traffic systems control systems (TSCS) are implemented using C Language and multithreading technology. During the running of the simulation in simulator, the multiple threads/processes in C Language representing the control system are running concurrently. For this paper, TSCS systems are tuned to sample the traffic network for the traffic parameters once every the beginning of each signal cycle.

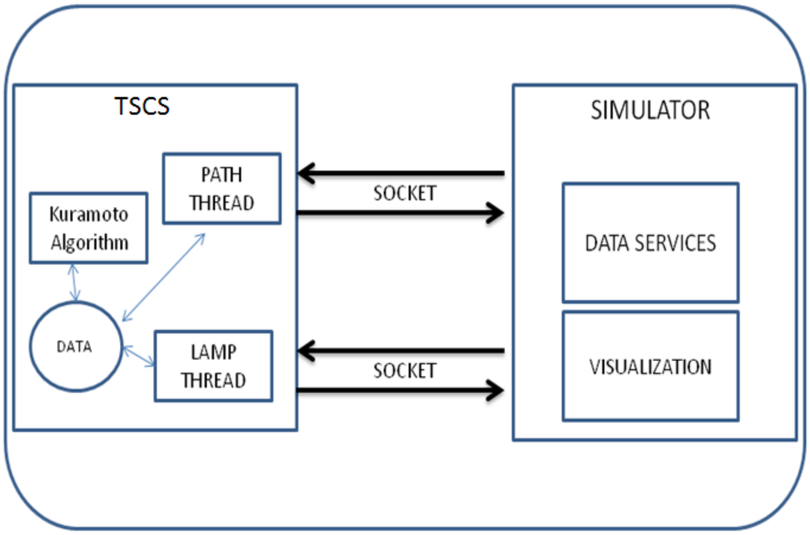


Figure 7. Relationship TSCS and Simulator

There are two kind of threads for communication betwen TSCS and simulator. First is path thread. This thread is using TSCS to get information of several variables in every intersection on simulator. The variables are car volume, avarage of car velocity, and the length of car queue on all intersection. Second thread is lamp thread. This thread is using TSCS to send the traffic light signal data for some intersection on simulator. The traffic light signal control that sends to simulator is time control of Green Light in intersection. In the path tread, Simulator provides the information required by the TSCS. When TSCS request data to the simulator, the simulator will transmit information appropriate with the request for some intersection. Furthermore in lamp tread, when TSCS send the traffic light signal then simulator will update the cycle time of trafffic light phase.

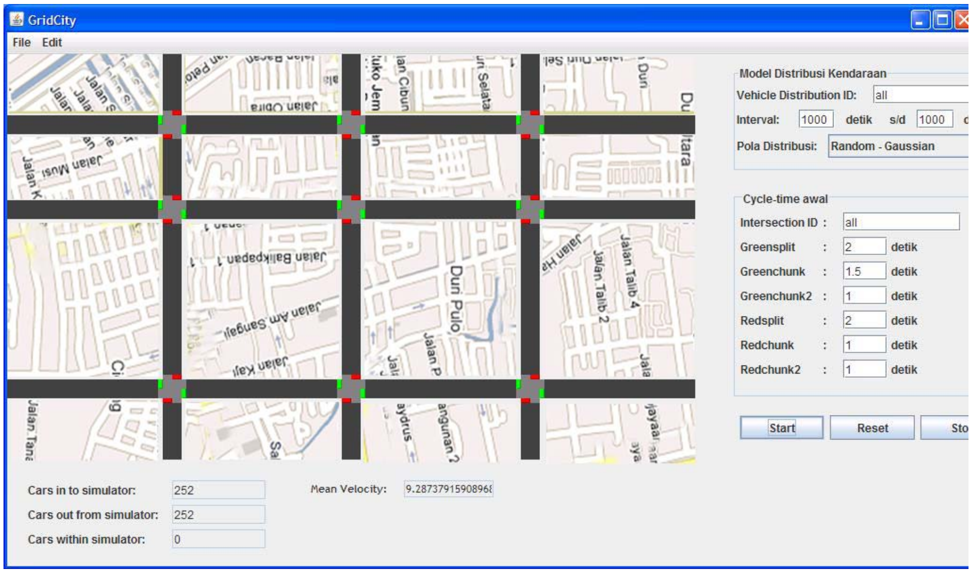
IV. TRAFFIC SIMULATOR

The Traffic simulator is built using Java Language with component based development method. This simulation step is also intended so that the system design and modeling that has been done can be implemented in real world.

There are various scenario to compare the effectiveness between the conventional method and the proposed method. There are two kinds of traffic environment which represent the condition of the traffic network system in Jakarta. First is a simple map (Figure.8) as representative of farranging intersection the traffic network region on Jakarta. Second is the complex map (Figure.9) as representative of compact intersection of the traffic network on Jakarta.

We use two parameter for testing TSCS. There are (i) mean of arriving of vehicle per second for every road, and (ii) the average of velocity in meter per second. The mean of arriving of vehicle per second for every road have tree typical scenario vehicle condition for represent of real-time traffic condition in Jakarta, i.e. high traffic density, medium traffic density, and low traffic density. First, high traffic density scenario is represents the peak periods. A peak periods or rush hour is a part of day where traffic congestion on roads and crowding on public transport is at its highest. Normally, this happens twice a day, once in the morning, and once in the evening, the times during when most people commute. Second, Medium traffic density scenario is represents periods of public transport at normal condition. Normal condition happens in between peak times. Third, low traffic density scenario represents traffic condition that happens in the night. Furthermore, the avarage of velocity is get from avarage of distance per total time all vehicle in simulation.

In simulator, every intersection has information such as the path length between the street intersection, the vehicle velocity, cycle time signal phase, the number of vehicles passing through the intersection, road capacity and, other intersection signal phase that have connected with this intersection. These loop detectors are coded in the simulated network at stop lines of the intersection approaches, as in the real-world installations. The value of variables as shown in table 1.

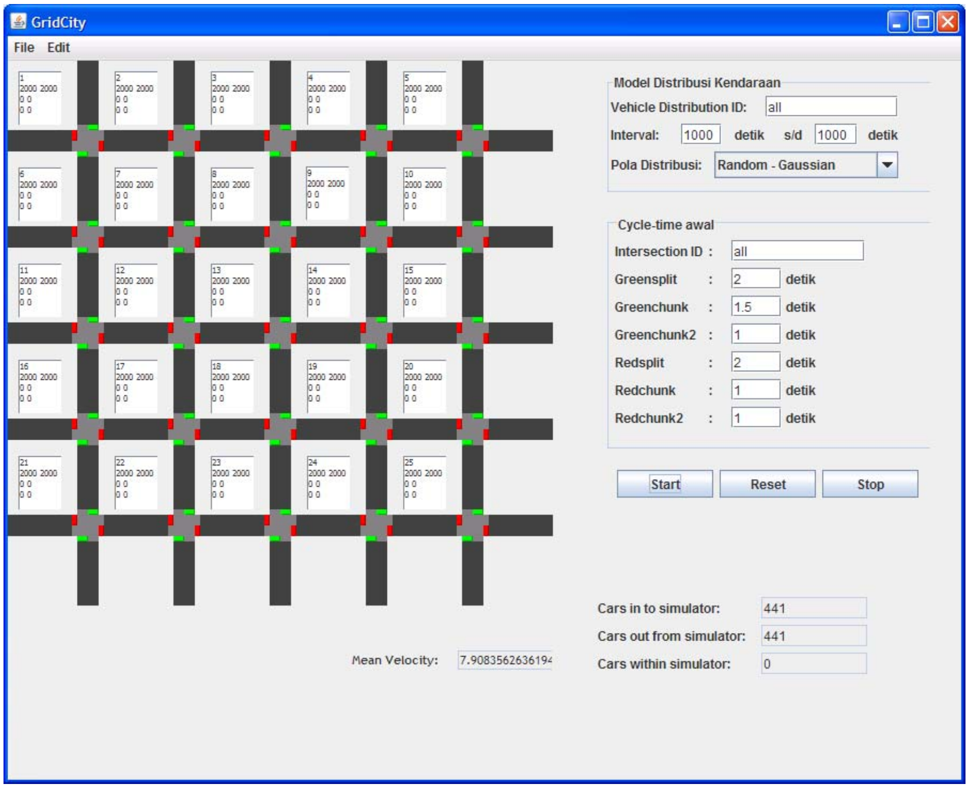


Model Distribusi Kendaraan
Vehicle Distribution ID: all
Interval: 1000 detik s/d 1000
Pola Distribusi: Random - Gaussian

Cycle-time awal
Intersection ID : all
Greensplit : 2 detik
Greenchunk : 1.5 detik
Greenchunk2 : 1 detik
Redsplit : 2 detik
Redchunk : 1 detik
Redchunk2 : 1 detik

Cars in to simulator: 252
Cars out from simulator: 252
Cars within simulator: 0
Mean Velocity: 9.28737915908968

Figure 8. Visualization of simulator using simple map

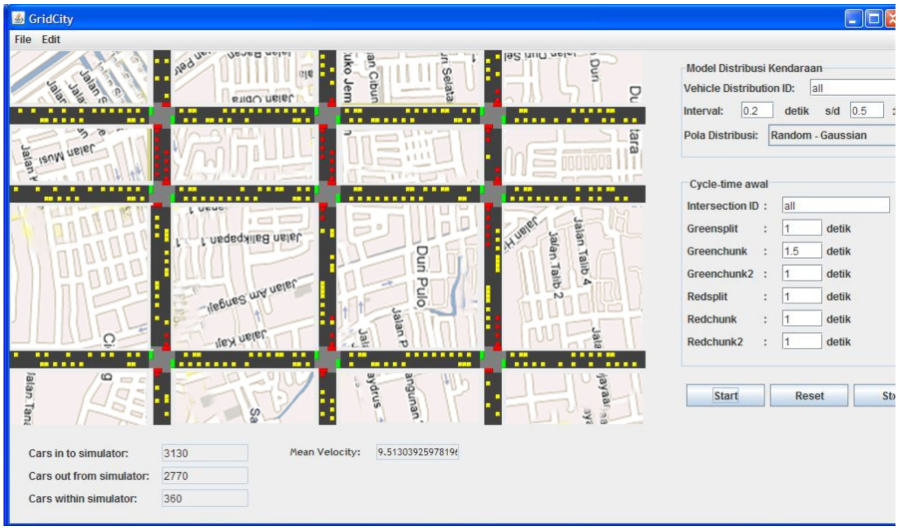


Model Distribusi Kendaraan
Vehicle Distribution ID: all
Interval: 1000 detik s/d 1000 detik
Pola Distribusi: Random - Gaussian

Cycle-time awal
Intersection ID : all
Greensplit : 2 detik
Greenchunk : 1.5 detik
Greenchunk2 : 1 detik
Redsplit : 2 detik
Redchunk : 1 detik
Redchunk2 : 1 detik

Mean Velocity: 7.9083562636194
Cars in to simulator: 441
Cars out from simulator: 441
Cars within simulator: 0

Figure 9. Visualization of simulator using more complex map



Model Distribusi Kendaraan
Vehicle Distribution ID: all
Interval: 0.2 detik s/d 0.5
Pola Distribusi: Random - Gaussian

Cycle-time awal
Intersection ID : all
Greensplit : 1 detik
Greenchunk : 1.5 detik
Greenchunk2 : 1 detik
Redsplit : 1 detik
Redchunk : 1 detik
Redchunk2 : 1 detik

Cars in to simulator: 3130
Cars out from simulator: 2770
Cars within simulator: 360
Mean Velocity: 9.5130392597819

Figure 10. Visualization of running simulator

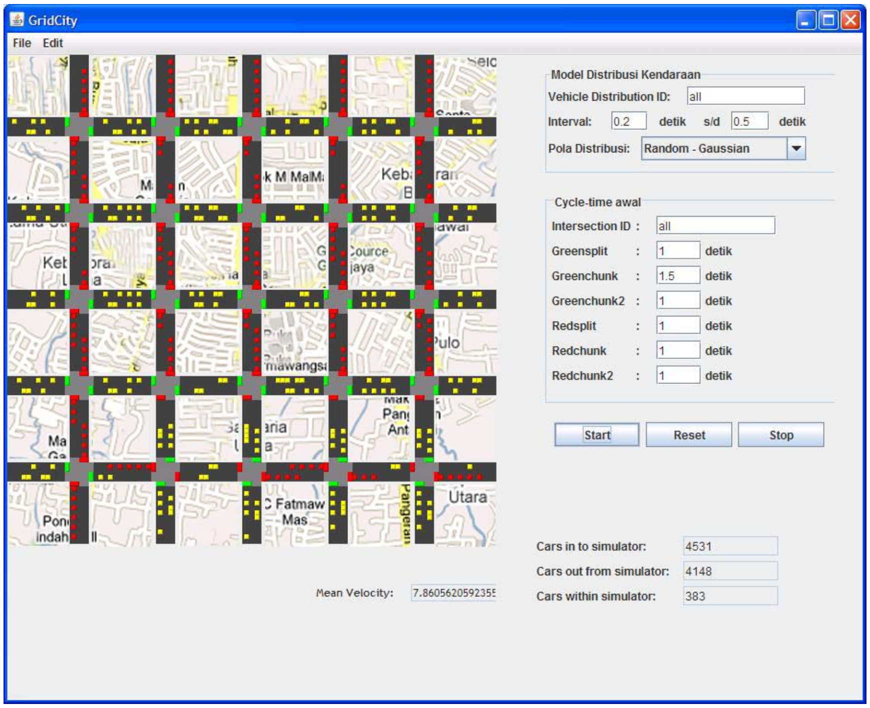
Table 1. TSCS and Simulator parameter

The simple map	9 intersection
The complex map	25 intersection
High Traffic Density	60 vehicle/minute for every street
Medium Traffic Density	30 vehicle/minute for every street
Low Traffic Density	15 vehicle/minute for each street
Minimum Green Time	15 second
Maximum Green Time	60 second
Minimum distance betwen vehicle	1.5 meter
Maximum Road Capacity	60 vehicle
Maximum velocity	60 kmph
Coupling constant	0.05

V. RESULTS

The algorithm presented in the previous sections was tested in a simulated real road scenario on Jakarta, and compare the performance of the algoritm with other algoritm has been applied on Jakarta Traffic Control System. The system was tested 30 times using random input and running simulation in 3 minute.

The screeshoot comparation of simulation using traffic signal control conventional and traffic signal control modification based on self-organizing methods to handle a complex real traffic light system in Indonesia showed in Fig 11.



Model Distribusi Kendaraan

Vehicle Distribution ID: all

Interval: 0.2 detik s/d 0.5 detik

Pola Distribusi: Random - Gaussian

Cycle-time awal

Intersection ID : all

Greensplit : 1 detik

Greenchunk : 1.5 detik

Greenchunk2 : 1 detik

Redsplit : 1 detik

Redchunk : 1 detik

Redchunk2 : 1 detik

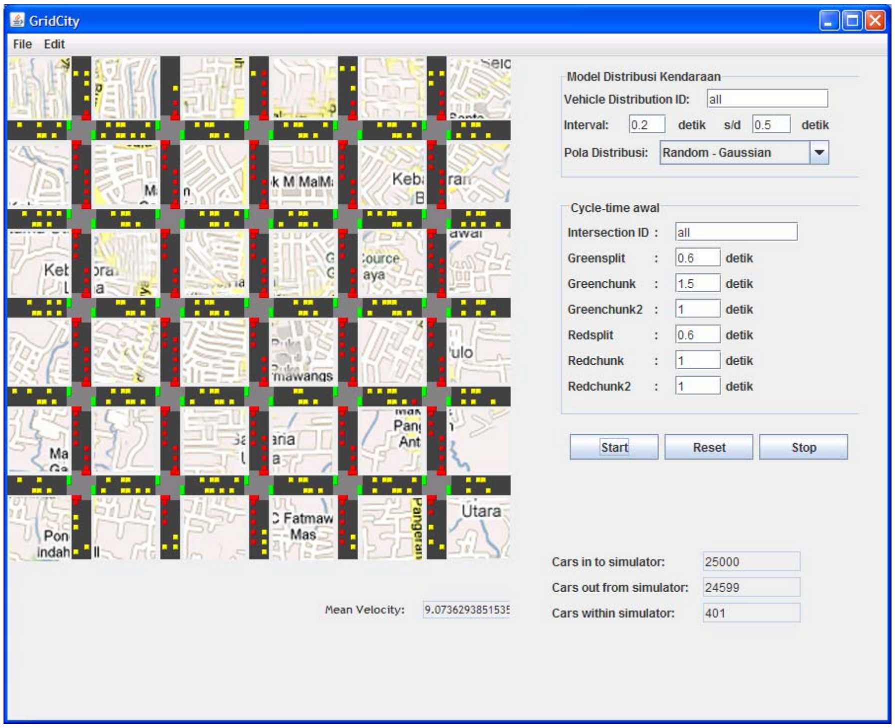
Mean Velocity: 7.8605620592355

Cars in to simulator: 4531

Cars out from simulator: 4148

Cars within simulator: 383

(a)



Model Distribusi Kendaraan

Vehicle Distribution ID: all

Interval: 0.2 detik s/d 0.5 detik

Pola Distribusi: Random - Gaussian

Cycle-time awal

Intersection ID : all

Greensplit : 0.6 detik

Greenchunk : 1.5 detik

Greenchunk2 : 1 detik

Redsplit : 0.6 detik

Redchunk : 1 detik

Redchunk2 : 1 detik

Mean Velocity: 9.0736293851535

Cars in to simulator: 25000

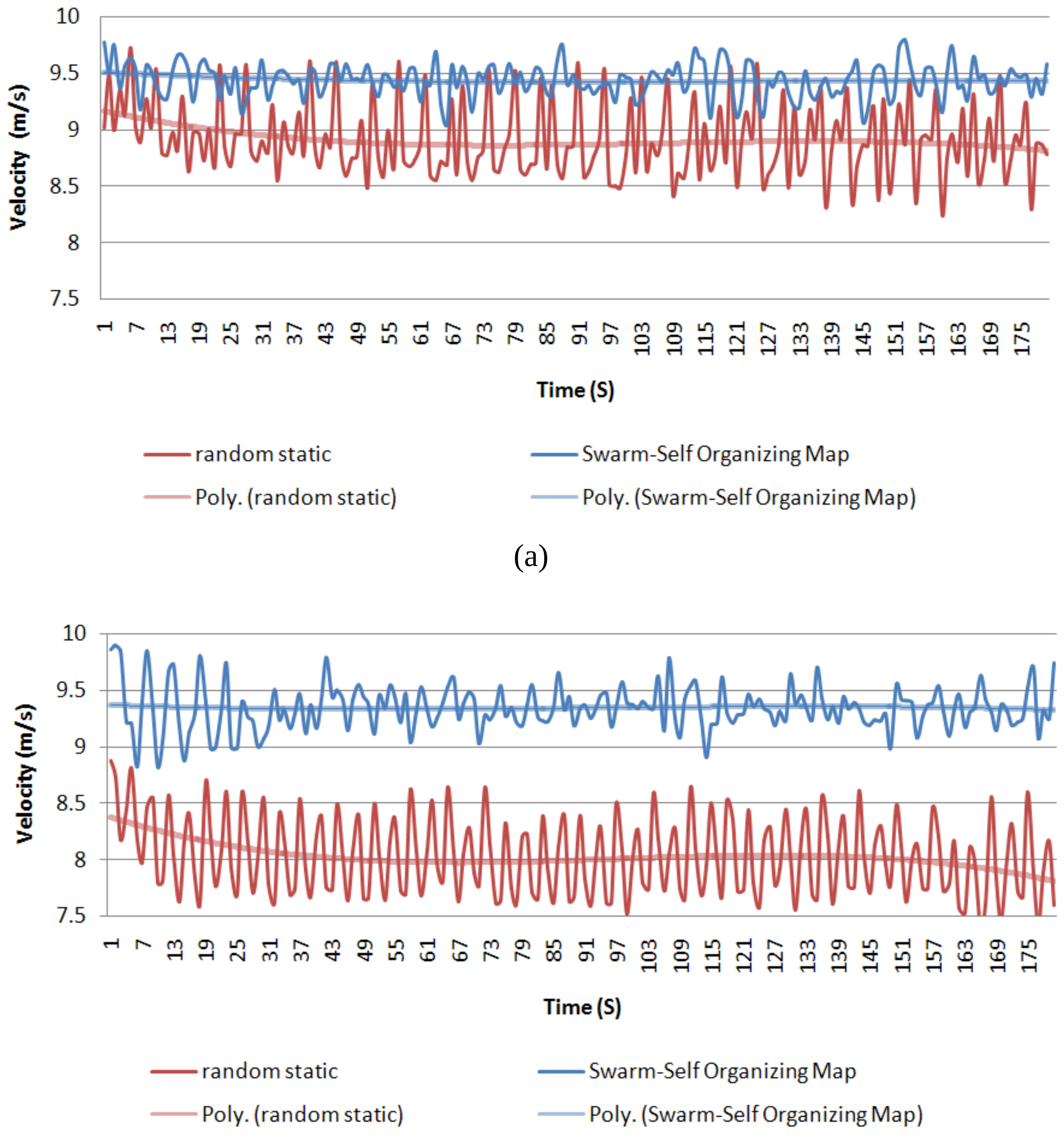
Cars out from simulator: 24599

Cars within simulator: 401

(b)

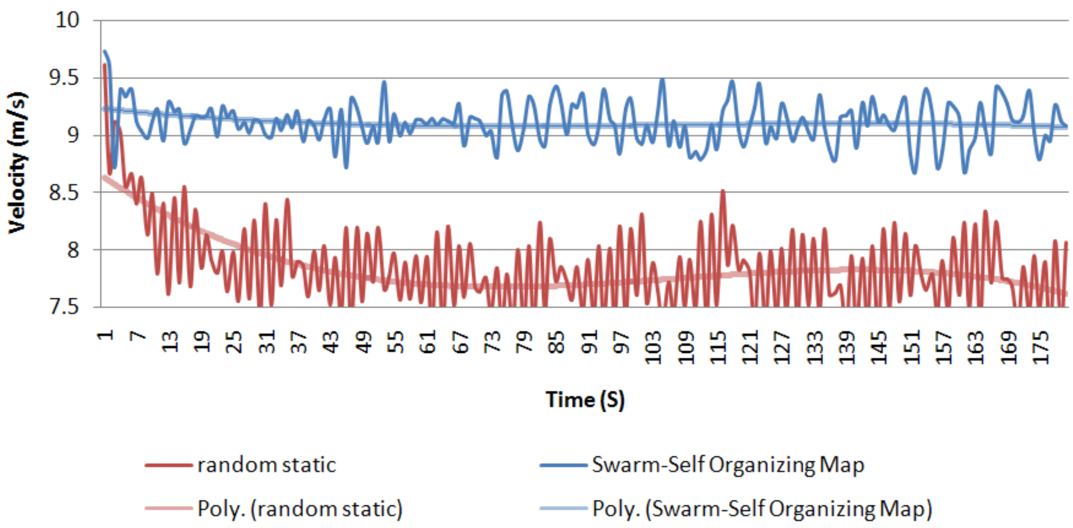
Figure 11. Comparation running simulator between (a) conventional method and (b) proposed method

The result of the experiment that shows of avarge velocity of vehicle is shown in Figure 12 and Figure 13.



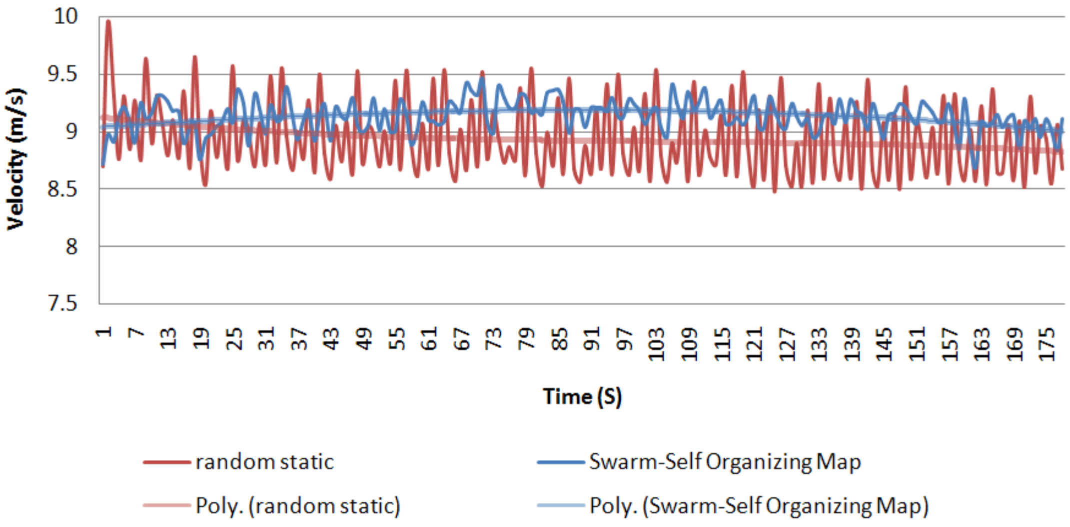
(a)

(b)

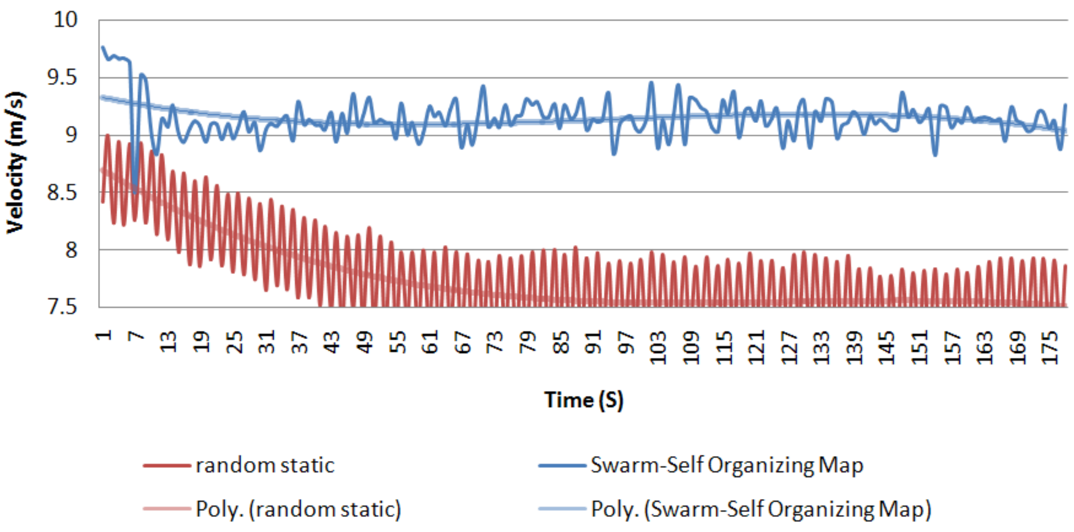


(c)

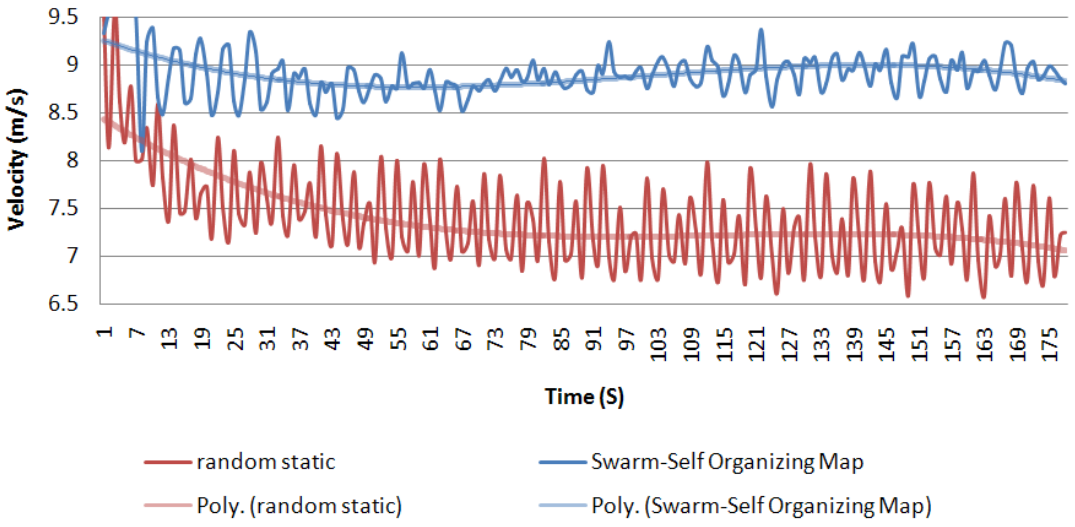
Figure 12. The simulation results on simple map



(a)



(b)



(c)

Figure 13. The simulation results on complex map

The simulation results on simple map in three conditions of traffic density (low, medium, high) are presented in Fig. 12. From the graph 12 (a) we observe at low traffic density condition, the velocity of vehicle values for proposed algorithm is about 5.9% higher than random static algorithm. From the graph 12 (b) we observe that at medium traffic density condition, the velocity of vehicle values for proposed algorithm is about 16% higher than random static algorithm. From the graph 12 (c) we observe that at high traffic density condition after a short period of time the simulation, the velocity of vehicle values for proposed algorithm is 16-20% higher than random static algorithm. Because, random static algorithm is unable to handle the congestion due to the big waiting queues for each street and traffic light phase. We can conclude that for simple map in three condition of traffic density, our proposed algorithms have improvements to the traffic flow, and good results in cases of high traffic density.

The simulation results on complex map in three conditions of traffic density (low, medium, high) are presented in Fig. 13. From the graph 13 (a) we observe at low traffic density condition, the velocity of vehicle values for proposed algorithm is about 2.1% higher than random static algorithm. From the graph 13 (b) we observe that at medium traffic density condition, the velocity of vehicle values for proposed algorithm is about 18% higher than random static algorithm. From the graph 13 (c) we observe that at high traffic density condition after a short period of time the simulation, the velocity of vehicle values for proposed algorithm is 20-25% higher than random static algorithm. In this case, proposed algorithm is able to handle the congestion due to the big waiting queues for each street and traffic light phase. Because every intersection occurs synchronize to set the green wave of traffic flow, so there were no big queues for each street. We can conclude that for complex map in three condition of traffic density, our proposed algorithms have very good improvements to the traffic flow, and very good results in cases complex map and high traffic density.

VI. CONCLUSIONS

In this paper, we describe a new architecture of urban traffic control system. We built a visualization of simulation using traffic signal control conventional and traffic signal control modification based on swarm self-organizing map methods to handle a simple and complex real traffic light system in Indonesia. The simulation result for new architecture of traffic signal control system achieved an overall better performance compare to random static for three simulation scenarios. The results suggest that swarm self-organizing map methods can provide effective control of complex traffic network. In next step we will analysis the performance off the system in different scenario. The long term of our research is to simulate whole parts of traffic network in city of Indonesia.

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