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SCENARIO MODEL TO REDUCE TRAFFIC CONGESTION USING INTELLIGENT TRANSPORTATION SYSTEMS

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Abstract

This study aims to develop scenario model to reduce traffic congestion using intelligent transportation systems (ITS). ITS is an application of advanced technology in the fields of electronics, computers and telecommunications to make transportation infrastructure and facilities more informative, smooth, safe and comfortable. It encompasses the latest wireless, electronic, simulation, and automatic technology. As a method to develop the scenario model, system dynamics (SD) is utilized considering that it can accommodate a system with complex non-linearity, faster and easier sensitivity analyses through the tests on the structure of the models. SD has been used at *the macroscopic and microscopic levels of the traffic flow to explore the interaction of transportation and urban planning as well as to evaluate the effect of different transport policies. ITS can reduce traffic congestion through the placement of several surveillance cameras in some corners of the city and is equipped with sensors to detect the number of vehicles. This detection results can be used as an input in setting the time for traffic signal control to reduce the volume of vehicles by prioritizing solid lines to get the green light so that the flow of heavy traffic can run first. With this scenario, traffic congestion is projected to decrease to be in the range 0.71 – 0.79 (below the maximum saturation level of 0.85) due to the decrease in vehicle volume as the impact of the implementation of ITS.*

Keywords

Model, Simulation, Intelligent Transportation Systems, System Dynamics, Traffic Congestion

1. Introduction

Transportation is a major component in everyday life and the social system. In urban areas, there is a trend of a high increase in population due to birth rates and urbanization. Traffic congestion occurs when traffic conditions on a highway are unstable and the speed of operation decreases rapidly (Sumadi, 2006). Intelligent Transportation System (ITS) is the application of advanced technology in the fields of electronics, computers, and telecommunications to make transportation infrastructure and facilities more informative, smooth, safe, and comfortable as well as environmentally friendly. ITS can retrieve traffic data through sensors and video cameras installed on roads and bridges (Cheng, Pang, & Pavlou, 2019). ITS can be a solution in dealing with traffic congestion, reducing traffic accidents, and mitigating environmental externalities caused by road transportation (United Nation, 2017).

Intelligent Transportation Systems use accurate knowledge of traffic conditions and the level of road safety to improve user safety and overcome traffic congestion (Souza, Pedrosa, Botega, & Villas, 2018). Intelligent Transportation Systems have been developed for more sophisticated traffic demand management and the selection of effective and reliable congestion mitigation strategies (Sun et al., 2019). Therefore, this research developed a scenario model to reduce traffic congestion using intelligent transportation systems (ITS). ITS can overcome congestion by placing surveillance cameras and is equipped with sensors to detect the number of vehicles. These detection results can be used as input in regulating and manipulating the time of the traffic lights so that the flow of heavy traffic can run first.

1.1 Intelligent Transportation System (ITS)

ITS is an integrated technology that includes electronics, information processing, wireless communication, and control which aims to improve safety, efficiency, and comfort (Shaheen & Finson, 2017). ITS can detect the flow of traffic collected from sensors and video cameras installed on roads. ITS can facilitate the road traffic control system and carry out traffic monitoring (Jarasuniene & Batarliene, 2013). ITS also facilitates the management of transportation flows by reducing congestion and ensuring the safety and comfort of the driver (Chowdhury & Sadek, 2003). ITS aims to solve road traffic problems such as traffic congestion by connecting people, roads, and vehicles in information and communication networks as seen in Figure 1 (Japan Society of Civil Engineers, 2016).

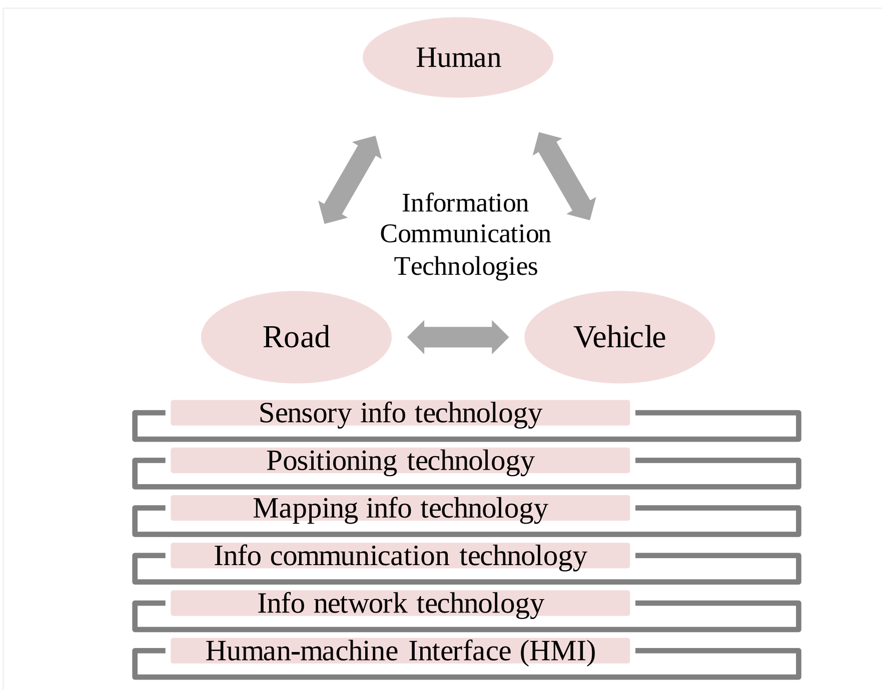

Figure 1: *ITS Components*

2. Literature Review

This section presents a literature review consisting of intelligent transportation systems and the role of system dynamics in reducing traffic congestion using ITS.

2.1 The role of system dynamics in reducing traffic congestion

System dynamics is a discipline based on the theory of nonlinear dynamics and feedback control. The system dynamics simulation model of traffic congestion is required due to the dynamic complexity of the real system. The application of the system dynamics simulation model in the field of transportation systems has been explored in some literature (Barlas, 2002; Springael, Kunsch, & Brans, 2002; Wegener, 2004). System dynamics is a method to learn about system behavior in complex systems (J. D. Sterman, 2000).

Swanson (2000) has developed a dynamic urban model to simulate interactions between transportation, land use, population, and economic activity in urban areas. Yao & Chen (2015) have developed a dynamics model system for urban sustainable transportation planning. (Frances Agyapong & Ojo, 2018) have developed a system dynamics model for managing traffic congestion. To develop a system dynamics model, several steps are required (John D. Sterman, 2002), namely: 1) problem formulation; 2) dynamic hypothesis; 3) simulation model development; 4) model validation; and 5) scenario development

3. Base Model Development

This section presents base model development consisting of problem formulation, causal loop diagram development, as well as stock and flow diagram development.

3.1 Problem Formulation

This step includes the determination of the model boundaries and variables to ensure that the model variables are aligned with the modelling goal. We determined the endogenous and exogenous variables based on previous researches as seen in Table 1.

Table 1: *Mapping between the Model Objective with the Endogenous and Exogenous Variables*

Modelling Objective	Endogenous variable	Exogenous variable
Reducing traffic congestion	Population (Ismiyanti, D., & D., 2012)	Road Capacity (Ismiyanti et al., 2012)
	Daily Traffic Volume (Harahap, Suryadi, Ridwan, Darmawan, & Ceha, 2017) (Ismiyanti et al., 2012)	
	Intelligent Transportation Systems (Desertot, Lecomte, Gransart, & Delot, 2013)	

3.2 Causal Loop Diagram (CLD) Development

A CLD is a qualitative method for demonstrating the interrelationships of variables in a system. Traffic congestion depends on the average daily traffic, road capacity, traffic monitoring using an intelligent transportation system (ITS) (Desertot et al., 2013; Harahap et al., 2017; Ismiyanti et al., 2012) as seen in Figure 2.

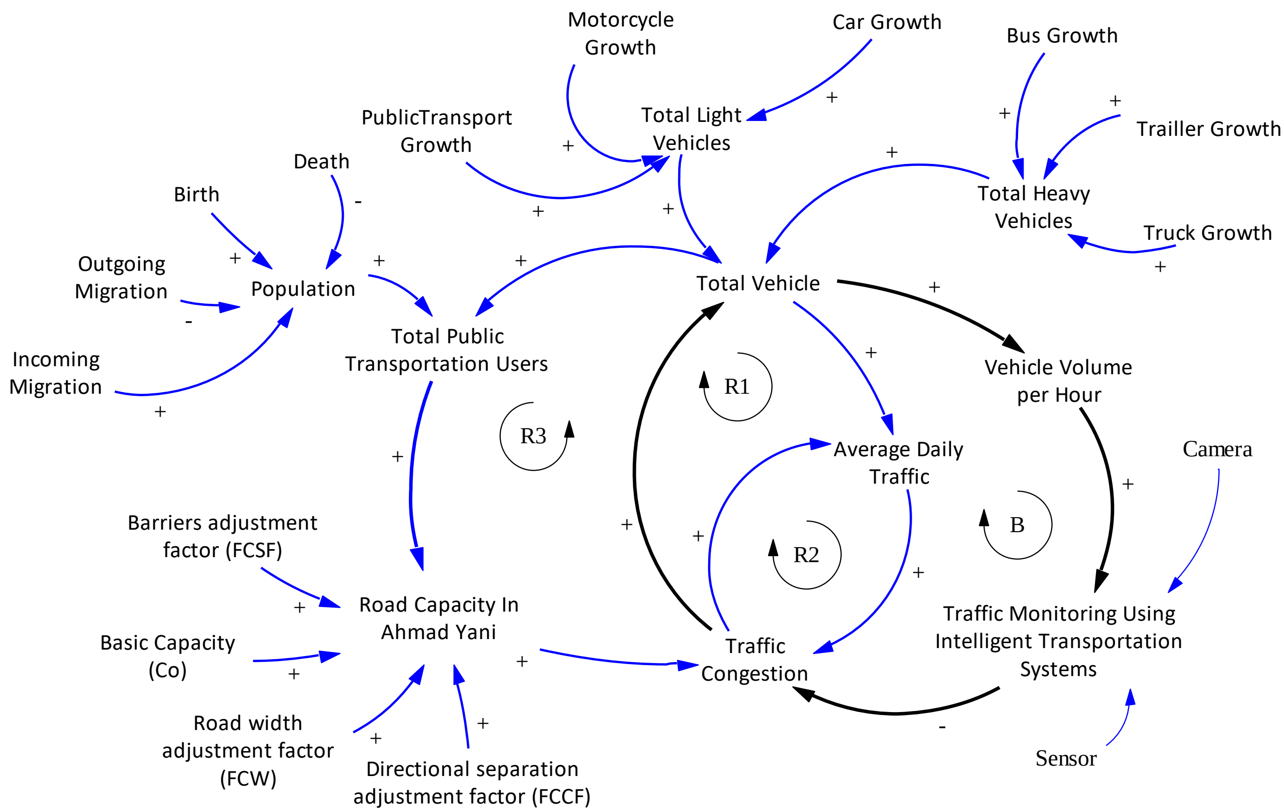

Figure 2: *CLD of Traffic Congestion*

CLD describes the behavior of a system by presenting feedback loops such as reinforcing and balancing loops. Reinforcing feedback loops (R) indicate that changes in a node are in the same direction, whereas the balancing feedback loop (B) represents a change in the opposite direction. Road capacity depends on the basic capacity, barriers adjustment, road width adjustment, and directional separation adjustment factors. The total vehicle affects vehicle volume per hour. The implementation of ITS is expected to reduce traffic congestion by regulating and manipulating the time of the traffic to reduce congestion.

3.2 Stock and Flow Diagram (SFD) Development

SFD consists of symbols and specific components that represent the structure of the system.

3.2.1 SFD of Population

The population depends on the birth and death rates as seen in Figure 3. Incoming migration and the number of births can increase the population. Meanwhile, the outcoming migration and the number of deaths decrease the number of population.

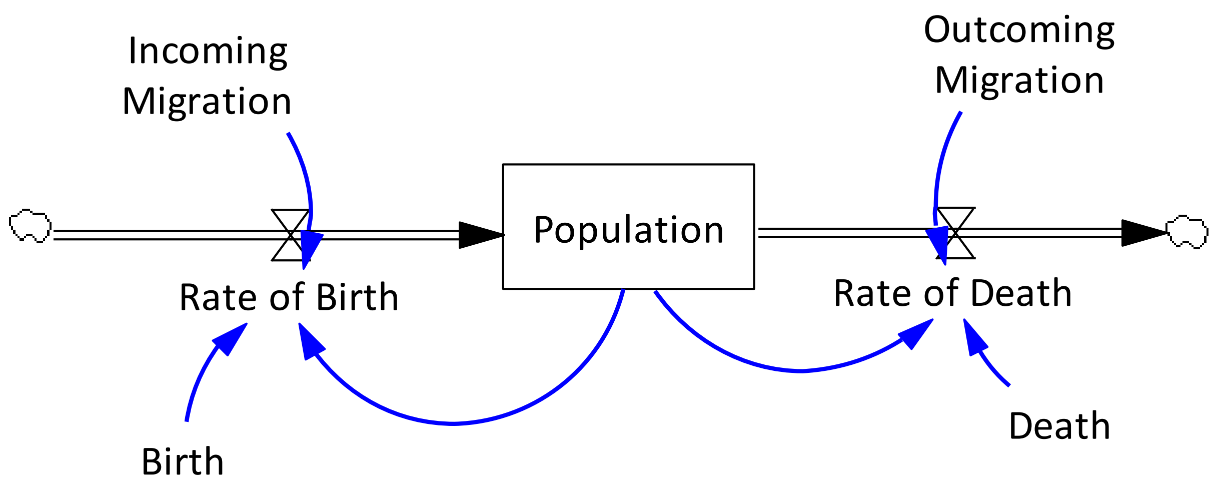

Figure 3: *SFD of Population*

The model formulation of the population can be seen in Eq. (1):

$$P\ (t{+}1) = P\ (t_0) + \int B\ (t) - D(t) \qquad (1)$$

where:

P = Population

B = Birth Rate

D = Death Rate

3.2.2 SFD of Total Vehicle

The total vehicle is the summation of total light vehicle and total heavy vehicle as seen in Figure 4. As we can see from Figure 4, total light vehicle is influenced by the number of motorcycles, cars, and public transportation (Lyn). Meanwhile, the total of heavy vehicle depends on the number of trailers, buses, and trucks.

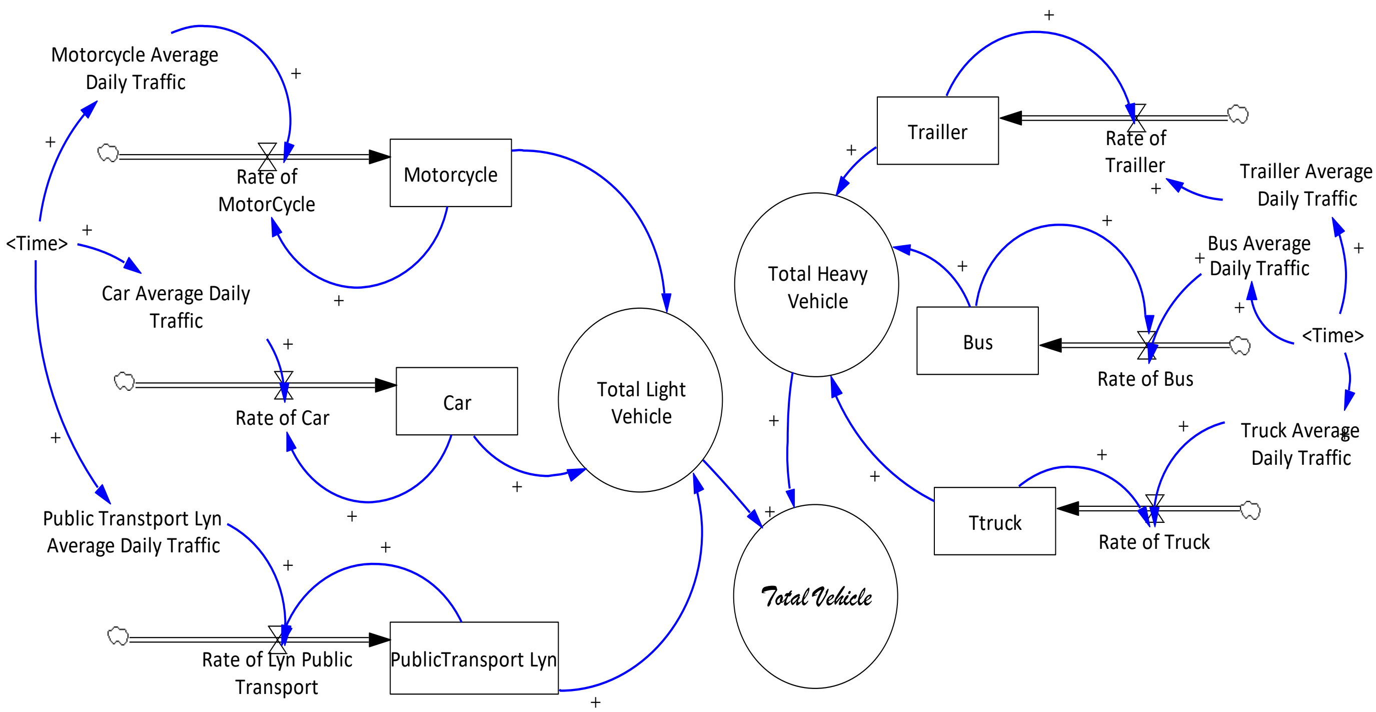

Figure 4: *SFD of Total Vehicle*

3.2.3 SFD of the Percentage of Public Transport (PT) Users

The percentage of PT users depends on the number of population and the number of people who use PT as seen in Figure 5.

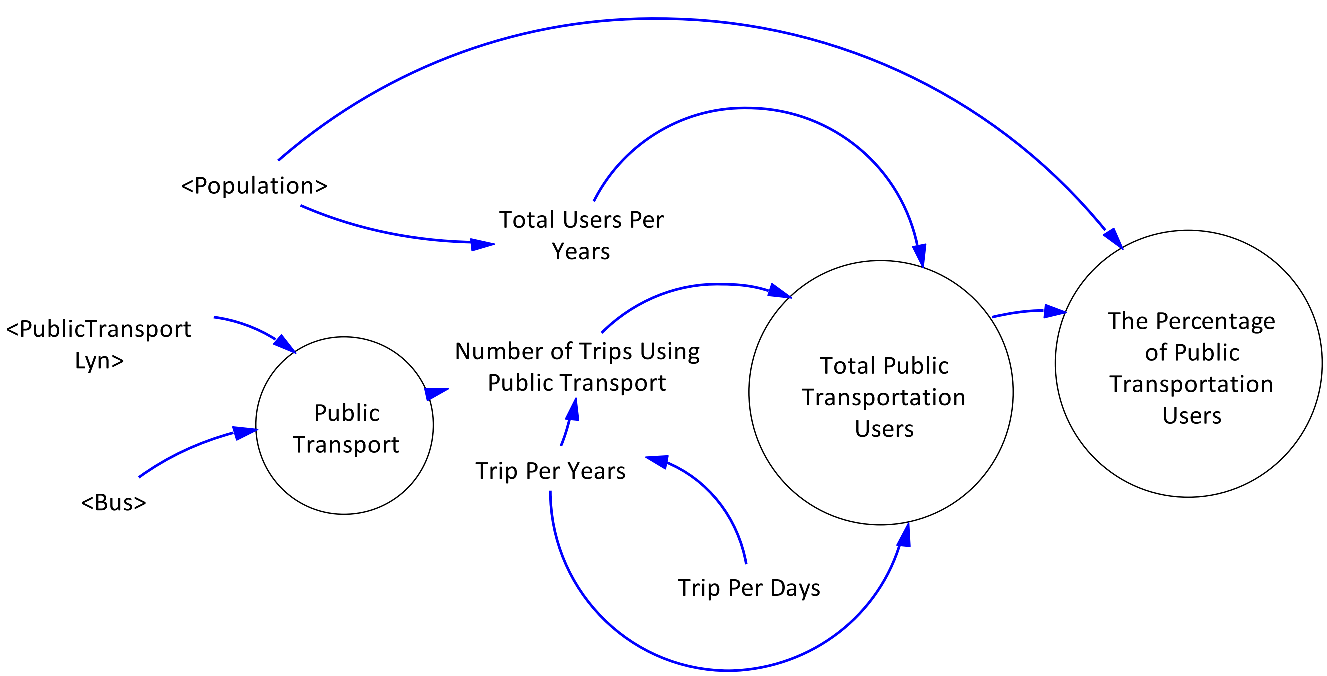

Figure 5: *SFD of the Percentage of Public Transport Users*

Model formulation of the percentage of PT users can be seen in Eq. 2.

$$PPT = (TPTU / P) * 100 \quad (2)$$

where:

PPT = The Percentage of PT Users

TPTU = Total PT Users

P = Population

3.2.4 SFD of Traffic Monitoring Using ITS

SFD of traffic monitoring using ITS can be seen in Figure 6.

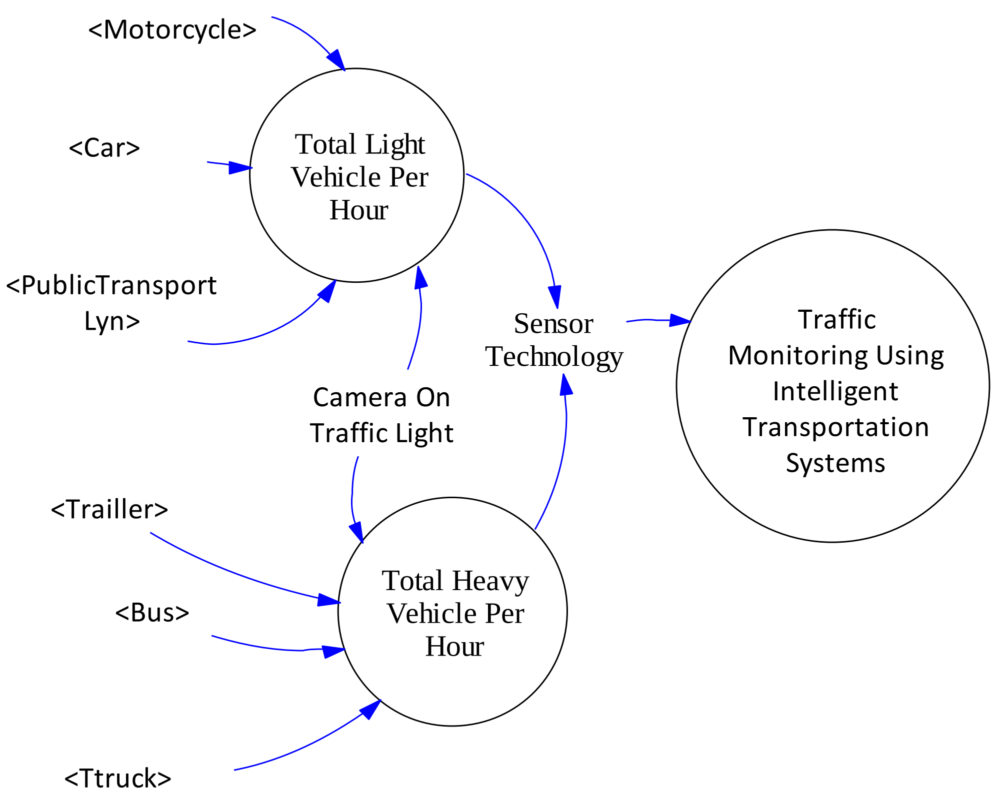

Figure 6: *SFD of Traffic Monitoring Using Intelligent Transportation Systems*

Traffic cameras will detect the incoming vehicles; while, sensor technology is used to collect data on the number of vehicles.

3.2.5 SFD of Traffic Congestion

Traffic congestion is influenced by hourly traffic volume and road capacity as seen in Figure 7. Some factors such as basic capacity, barrier adjustment, road width adjustment, and directional separation adjustment are important factors that influence the road capacity. The model formulation for traffic congestion can be seen in Eq. (3).

$$TC = \frac{HTV}{RC} \quad (3)$$

where:

TC = Traffic Congestion
HTV = Hourly Traffic Volume
RC = Road Capacity

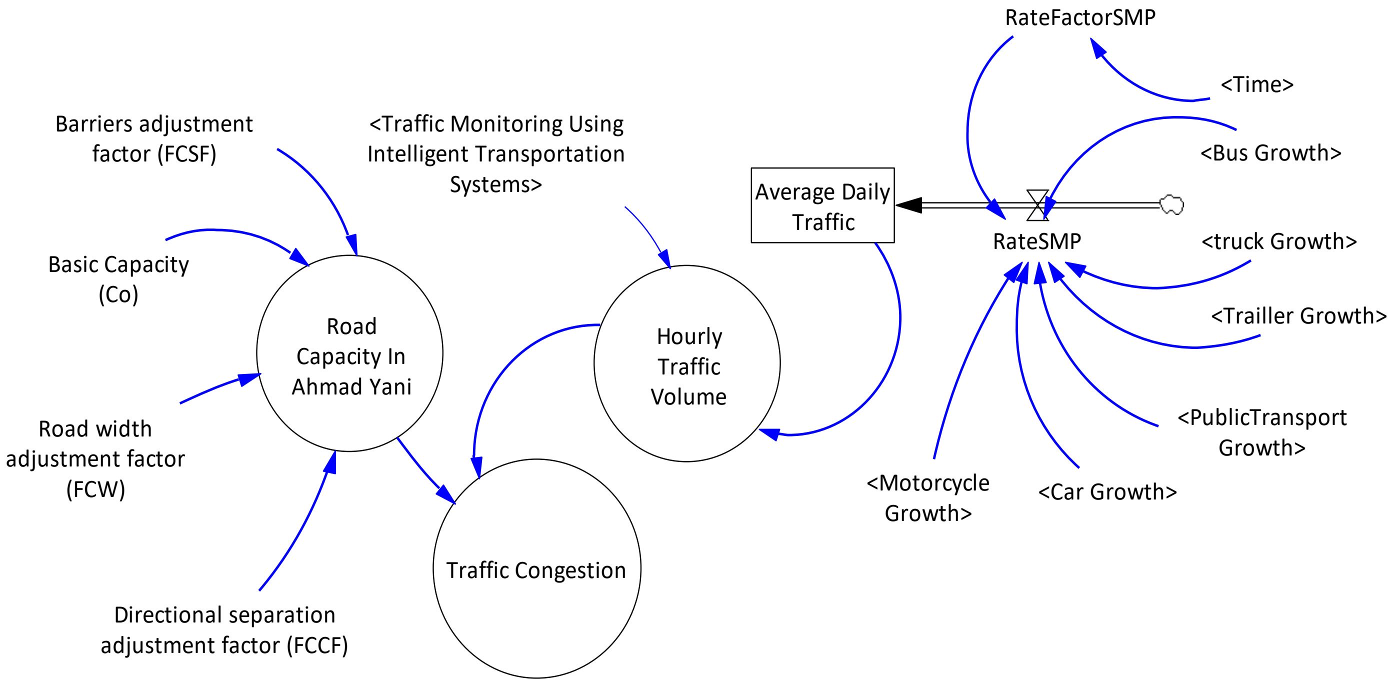

Figure 7: *SFD of Traffic Congestion*

4. Model Validation

Model validation is required to check the model validity. This time frame is considered based on the availability of data and the behavior of the system. The model is valid if the error rate is $\leq 5\%$ and the error variance is $\leq 30\%$ (Barlas, 2002). The model is validated by checking the error rate and error variance as shown in Equation (4) - (5).

$$A = \frac{[\bar{S} - \bar{A}]}{\bar{A}} \quad (4)$$

$$S = \frac{[Ss - Sa]}{Sa} \quad (5)$$

where:

$\bar{S}$ = average rate of simulation

$\bar{A}$ = average rate of data

A = data at time t

S = simulation result at time t

S_s = standard deviation of simulation

S_a = standard deviation of data

The error rates of average daily traffic (ADT) of Lyn PT, private car, and bus were:

Error rate of ‘ADT of Lyn PT’ = $\frac{[4414-4241]}{4241} = 0.041$

Error rate of ‘ADT of private car’ = $\frac{[64343-62134]}{62134} = 0.036$

Error rate of ‘ADT of’ bus’ $= \frac{[830-802]}{802} = 0.035$

The error variances of ADT of Lyn public transport, private car, and bus were:

Error variance of ‘ADT of Lyn public transport’ = $\frac{[2681-2677]}{2677} = 0.145$

Error variance of ‘ADT of private car’ = $\frac{[19490-16406]}{16406} = 0.154$

Error variance of ‘ADT of bus’ $= \frac{[322-340]}{340} = 0.054$

A comparison between the simulation results and the historical data of ADT of Lyn PT, private car, and bus in Ahmad Yani street can be seen in Figs. 8-10.

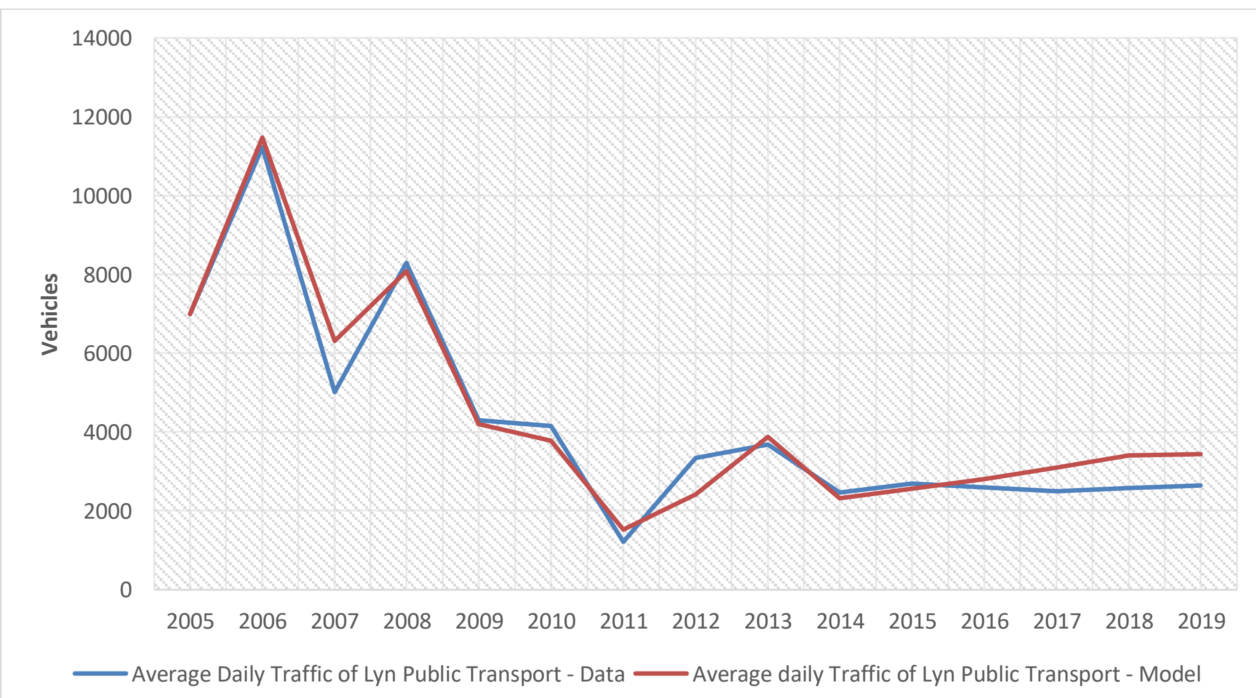

Figure 8: *A Comparison Between Model and Data of the ADT of Lyn PT*

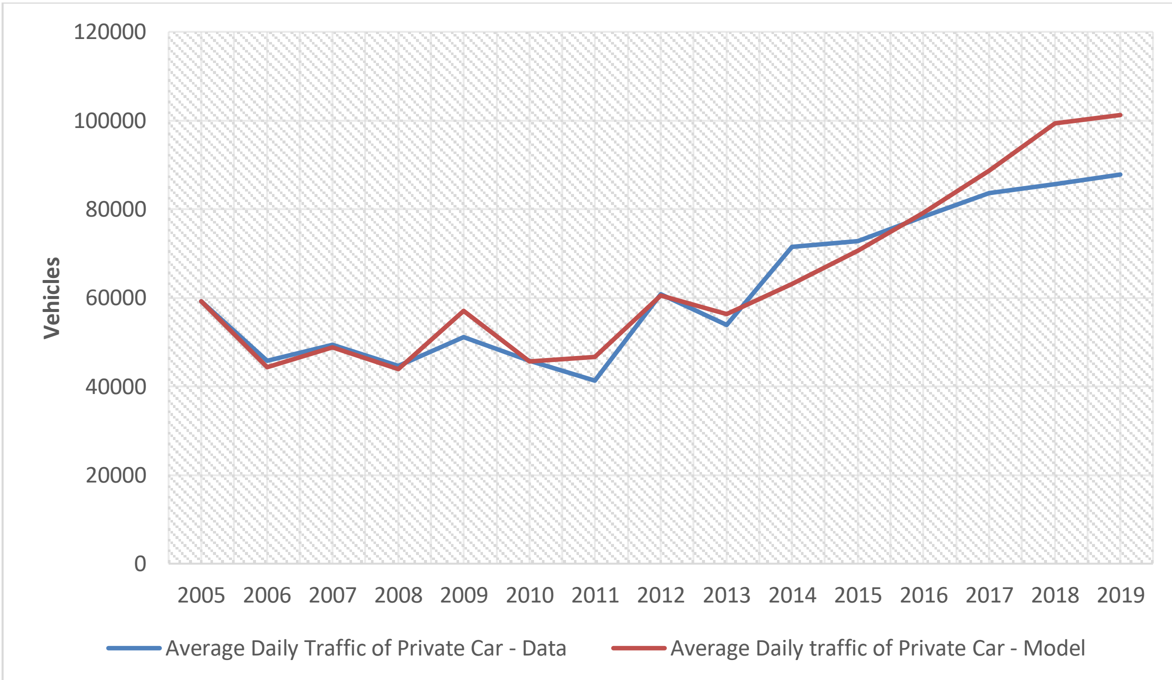

Figure 9: *A Comparison Between Model and Data of the ADT of Private Car*

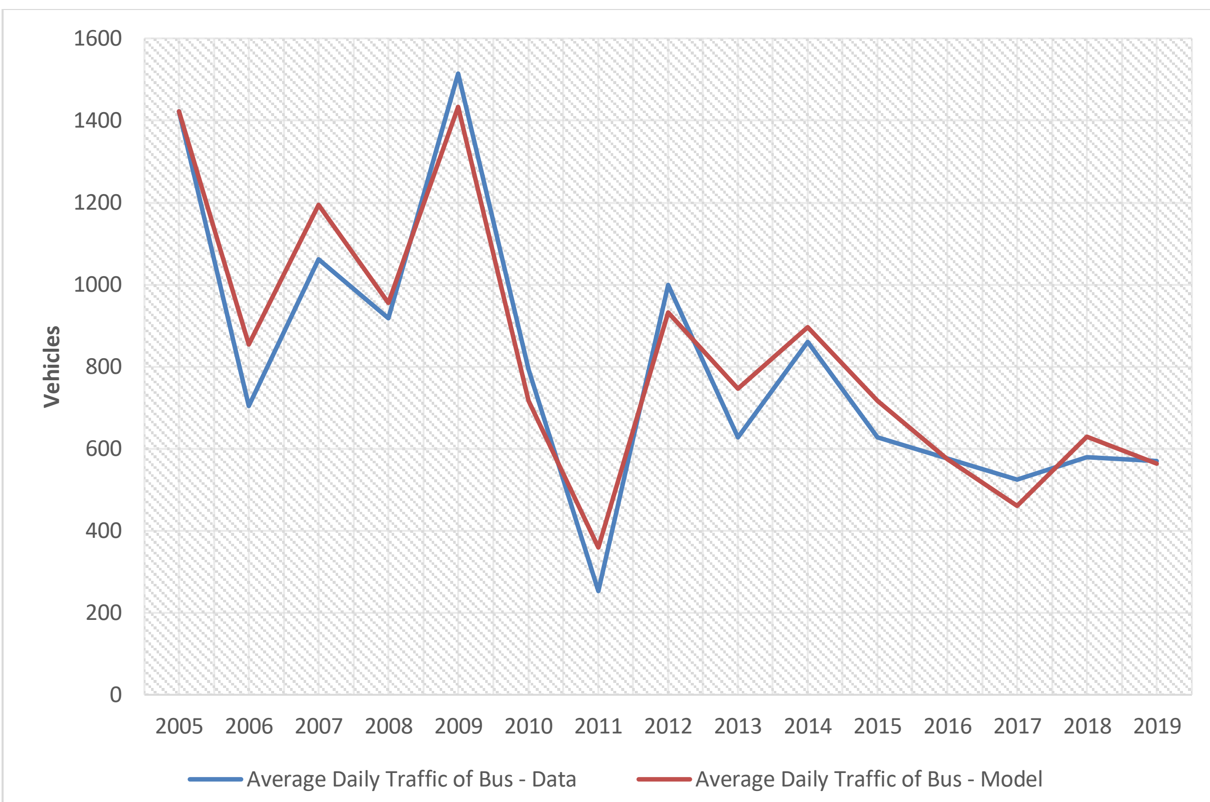

Figure 10: *A Comparison Between Model and Data of the ADT of Bus*

5. Results and Discussion

This section demonstrates the simulation results of several submodels such as population, total vehicle, the percentage of public transport users, traffic monitoring using ITS, and traffic congestion. All data and information in this study were obtained from the city of Surabaya, East Java, Indonesia. We have developed the model as generic as possible so that it can be implemented for other regions by changing the parameter values of the model in accordance with the case study".

5.1 Population Submodel

The results of the population simulation can be seen in Figure 11. The population in Surabaya city has increased every year with an average growth of 1.3% per year. Therefore, in 2019, it will reach around 3.34 million people.

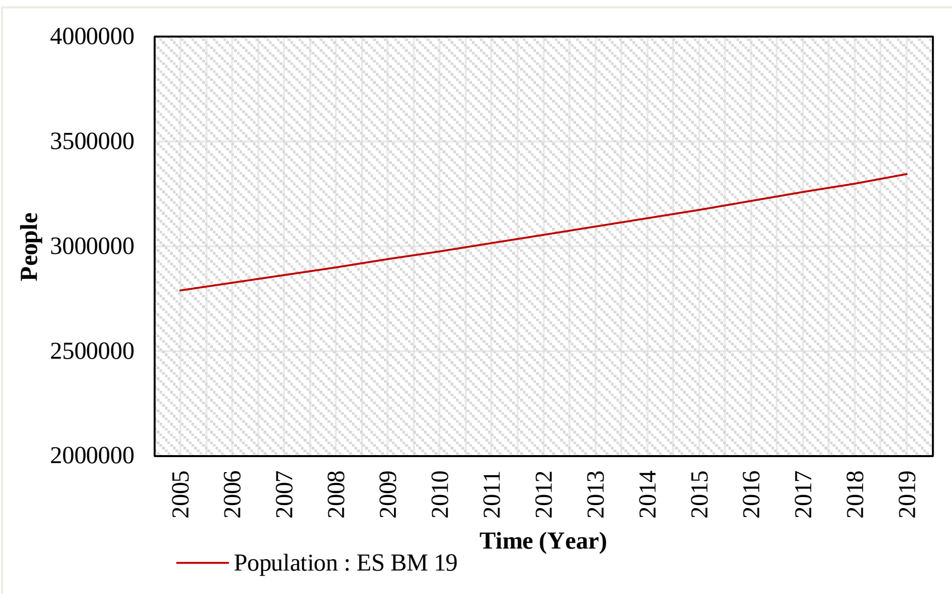

Figure 11: *Population in Surabaya City*

5.2 Total Vehicle Submodel

The simulation result of the total vehicle in Surabaya city can be seen in Figure 12. Total vehicles in Surabaya from 2005-2018 continued to increase with an average growth of 7% per year. In 2019, total vehicles have decreased by 18.4% due to the decreasing number of motorcycles.

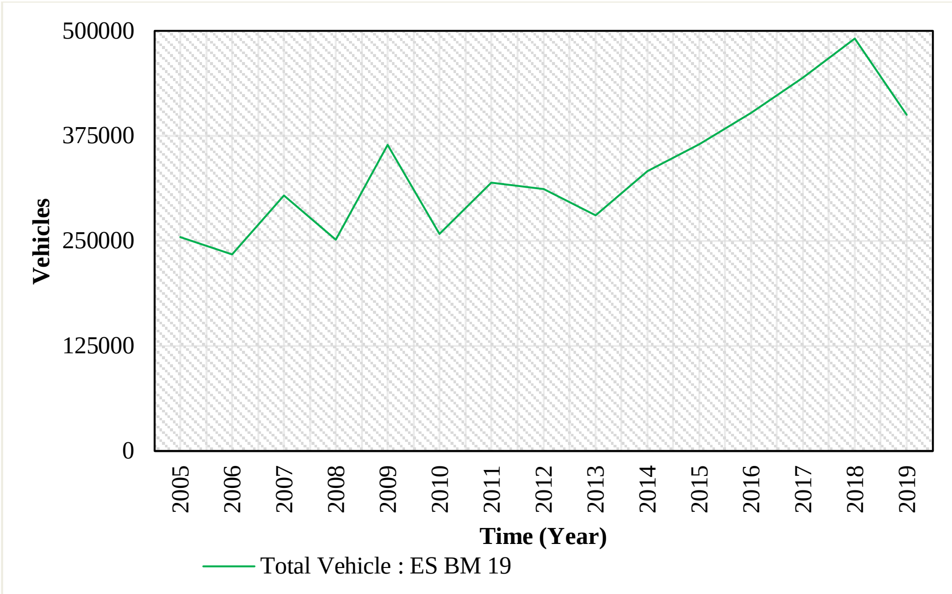

Figure 12: *Total Vehicle in Surabaya City*

5.3 The Percentage of Public Transport (PT) Users Submodel

The simulation result of the total vehicle in Surabaya city can be seen in Figure 13. The results of simulation show that the percentage of PT users in the period of 2006 to 2011 tended to decrease, remaining 1.5% in 2011. The highest percentage occurred in 2006 at around 9.9%. In 2019, the percentage of public transport users was around 3.2%, due to the increasing number of population which was not in line with the increasing use of public transport.

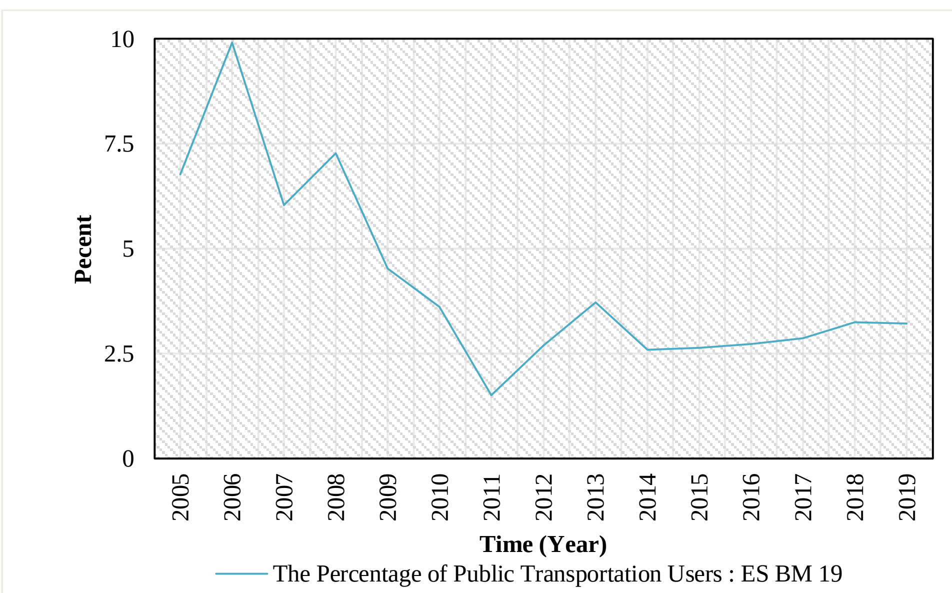

Figure 13: *The Percentage of Public Transport Users*

5.4 Traffic Monitoring Using ITS Submodel

The results of the simulation on the number of vehicles detected by traffic monitoring can be seen in Figure 14. Here, the average number of vehicles per hour increased with a growth of 7% per year, so that it reached 20.452 vehicles per hour in 2018. However, this number decreased in 2019, i.e. to 16.686 vehicles per hour, due to the decreasing number of motorcycles.

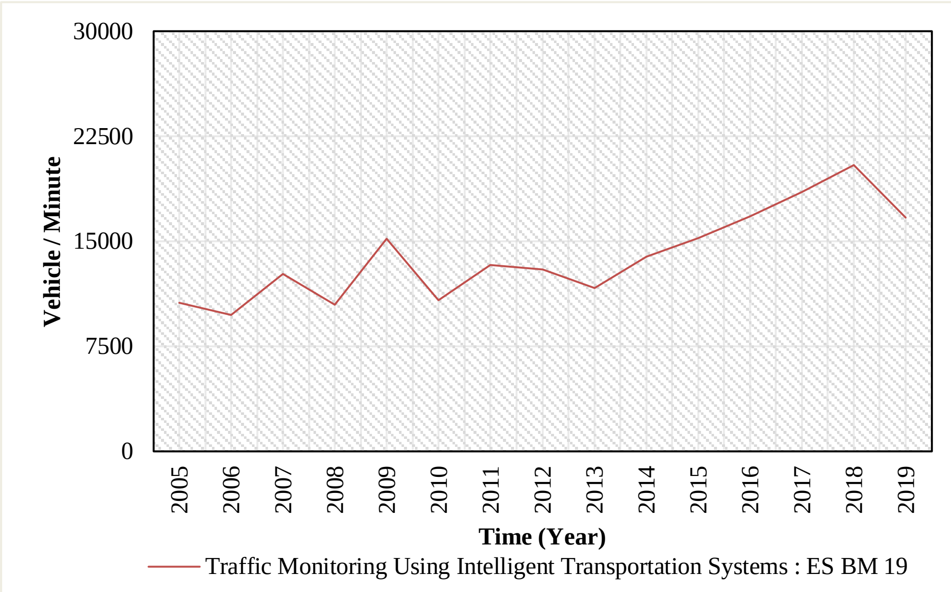

Figure 14: *The Number of Vehicles Detected by Traffic Monitoring*

5.5 Traffic Congestion Submodel

The results of the simulation on traffic congestion can be seen in Figure 15. Traffic congestion exceeded 0.85 (Dmnl = Dimension Less) in 2005, 2009, 2012, 2014-2019. Hale & Courage (2002) stated that the maximum saturation level of traffic congestion was 85%, therefore, it needed a strategy to reduce traffic congestion.

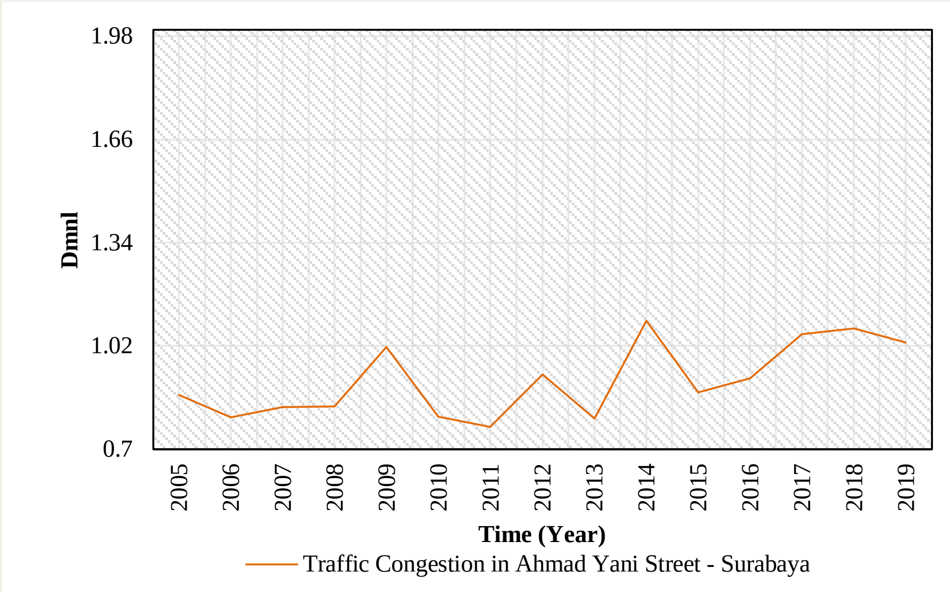

Figure 15: *Traffic Congestion in Ahmad Yani Street – Surabaya*

6. Scenario Model Development

This section presents a scenario model development to reduce traffic congestion. Scenario development is a method of strategic planning that can analyze projections for the interpretation of future conditions (Brose, Fügenschuh, Gausemeier, Vierhaus, & Seliger, 2013). Scenario development can be conducted by modifying the model's structure and parameters (Suryani, 2011). The scenario model of reducing traffic congestion using traffic monitoring and control system can be seen in Figures 16-17. By using traffic monitoring and control, the number of vehicles passing the highway can be detected by sensors. Vehicle data are then delivered to the server of ITS and can be used as input for traffic signal control. The control method used is a dynamic control method that will prioritize dense lanes to get the green light.

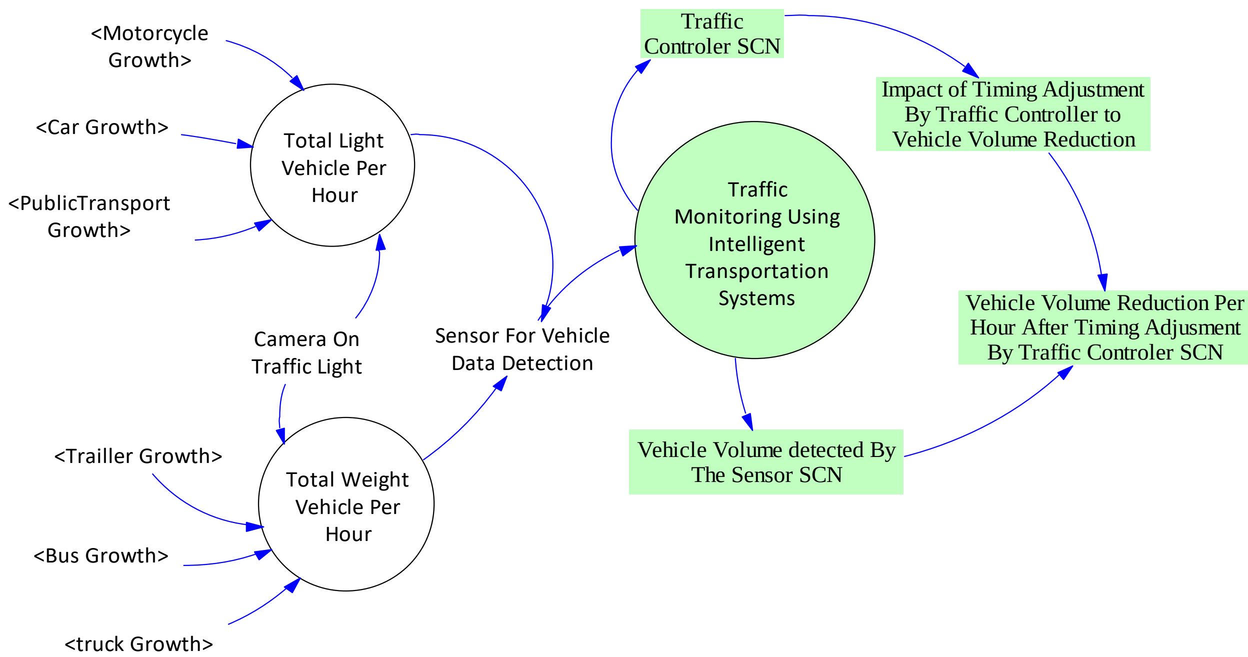

Figure 16: *Scenario Model of Vehicle Volume After Timing Setting by Traffic Controller of ITS*

This vehicle volume reduction per hour then becomes a feedback variable on the hourly traffic volume as seen in Figure 17.

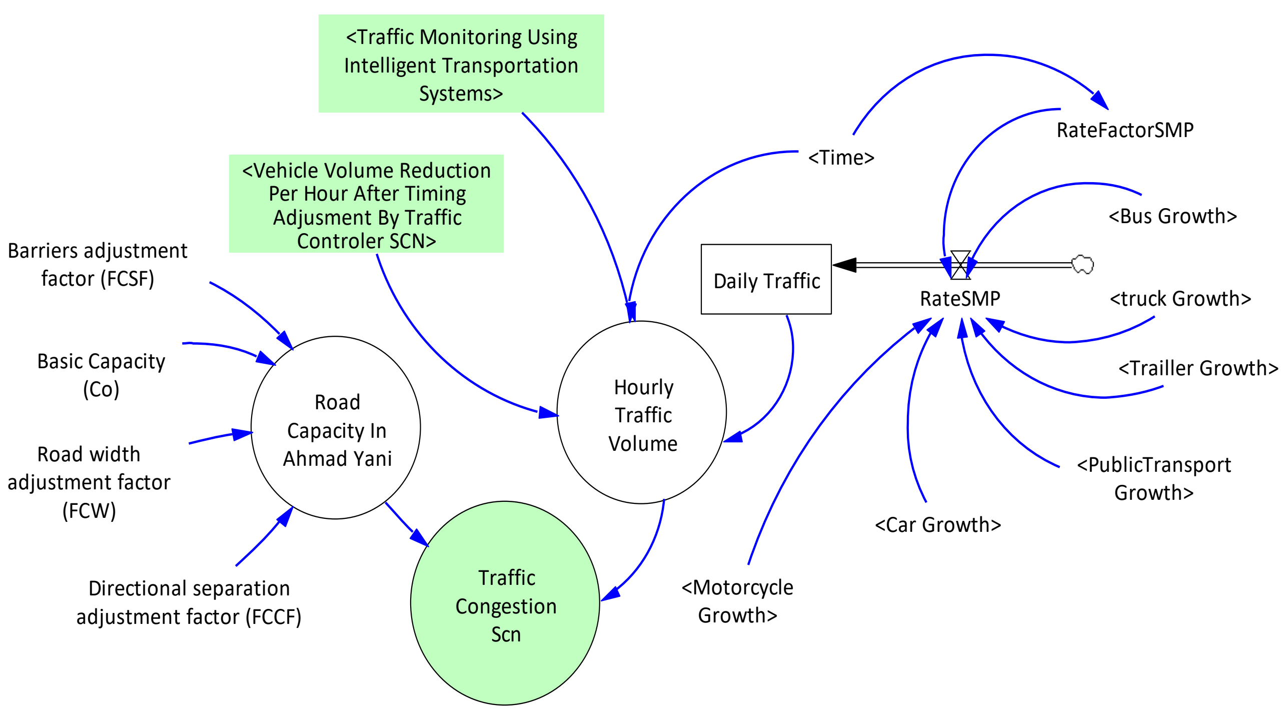

Figure 17: *Scenario Model of Traffic Congestion After Scenario*

The results of simulation show that traffic congestion after using traffic monitoring and control can be below the maximum saturation level (0.85). Traffic congestion was projected to be in the range 0.71 - 0.79 as seen in Figure 18, due to the decrease in vehicle volume as the impact of the implementation of ITS which facilitated the traffic monitoring and control system.

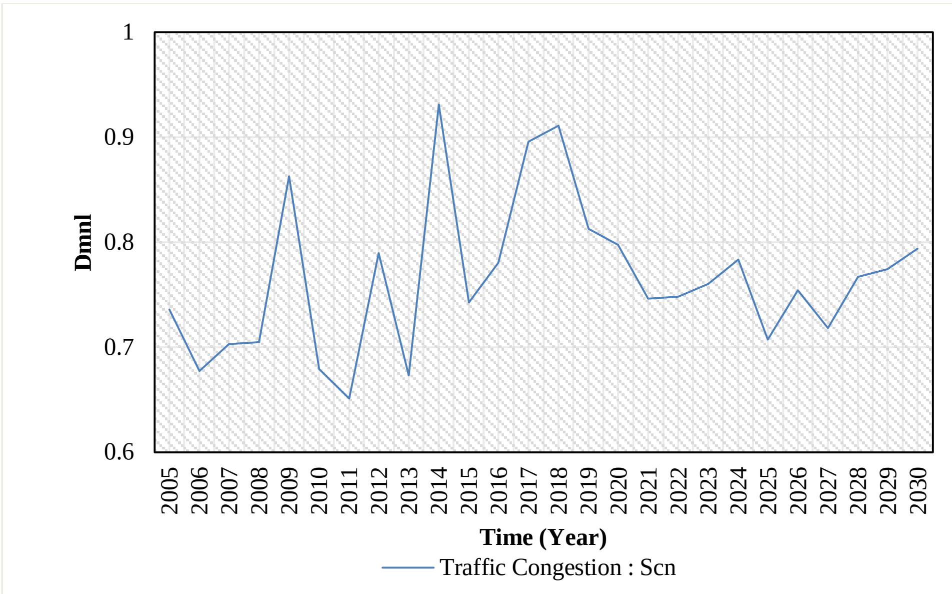

Figure 18: *Traffic Congestion after Using Traffic Monitoring and Control*

6. Conclusion and Further Research

This research was designed to provide a comprehensive and objective assessment of reducing traffic congestion using simulation models and scenarios. To build the simulation models and develop the scenario, system dynamics (SD) was used considering that SD can accommodate the dynamics complexity of traffic congestion. This research was conducted in Surabaya City, Indonesia, which is the fourth most congested city in the world. The novel contributions of this research are, namely: formulating relationships between variables, building the dynamic behavior of traffic congestion as well as developing scenario to reduce traffic congestion using ITS. All data and information in this study were obtained from the city of Surabaya - East Java - Indonesia. Although the data is regional, we have developed the model as generic as possible, so that it can be implemented for other regions by changing the parameter values of the model in accordance with the case study. Some important factors that affect traffic congestion are vehicle volume and road capacity. Road capacity depends on the basic capacity, barriers adjustment, road width adjustment, and directional separation adjustment factors. Total vehicle affects the vehicle volume per hour. The implementation of ITS can reduce traffic congestion by regulating and manipulating the time of the traffic. The total vehicle is the summation of total light vehicles and total heavy vehicles. Total vehicles in Surabaya from 2005-2018 continued to increase with an average growth of 7% per year. The percentage of public transport users in the period of 2006 to 2011 tended to decrease, the remaining 1.5% in 2011. The highest percentage occurred in 2006 at around 9.9%. In 2019, the percentage of public transport users was around 3.2%, due to the increasing number of population which was not in line with the increasing use of public transport. Scenario results show that traffic congestion after using traffic monitoring and control can reduce traffic congestion below the maximum saturation level (0.85). Traffic congestion was projected to be in the range 0.71 - 0.79, due to the decrease in vehicle volume as the impact of the implementation of ITS which facilitates the traffic monitoring and control system. Further research is required to develop a sustainable transportation system by considering the transit-oriented development (TOD) program.

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