Urban Mobility Modeling to Reduce Traffic Congestion in Surabaya: A System Dynamics Framework

by Lily Dewi

Urban Mobility Modeling to Reduce Traffic Congestion in Surabaya: A System Dynamics Framework

Abstract

Purpose

This paper addresses the urban mobility and traffic congestion problem under environmental dynamics to improve mobility and reduce traffic congestion using system dynamics simulation and scenarios.

Design/methodology/approach

System dynamics simulation was used to analyze urban mobility and traffic congestion. Data were collected from the Transportation Department of Surabaya City. Several scenarios to improve urban mobility and reduce traffic congestion were developed by modifying the structures and parameters of the model.

Findings

Several factors influence urban mobility, including modal split, trip frequency, delay performance, and the ratio of public transport supply and demand. Urban mobility, daily traffic, and road capacity are some factors that affect traffic congestion. Scenarios can be designed based on the assumptions of the proposed strategy.

Research limitations/implications

The study was conducted at Surabaya City, East Java, Indonesia, which is the fourth most congested city in the world.

Practical implications

By implementing several strategies (MRT and BRT development and public transport delay reduction), mobility performance is projected to be improved by 70.34-92.96%. With this increased mobility, traffic congestion is projected to decline by 52.5-65.8%.

Originality/value

The novel contributions of this research are: formulating relationships between several variables, modeling dynamic behavior of urban mobility and traffic congestion, and building scenario models to improve mobility and reduce traffic congestion in Surabaya. With the increase in urban mobility and the decrease in average daily traffic, traffic congestion could be reduced by a minimum of 57.6% and a maximum of 69%.

Keywords: simulation; model; system dynamics; urban mobility; traffic congestion

1. Introduction

Mobility is the ease of movement from one location to another by using transportation services and networks (Beimborn *et al*., 1999). The rapid increase in the urban population will increase travel demand and mobility. Traffic congestion occurs when the travel demand exceeds the limited supply of transportation services (Alam and Ahmed, 2013). The number of vehicles continues to increase with an average of over 3% annually, while the construction of roads is less than 1% annually (de Rozari and Wibowo, 2015). Furthermore, causes of traffic congestion include the decreasing public inclination to use public transport, road capacity below normal requirements (20% of city area), inadequate public transportation, too many bottlenecks, and poor spatial planning (Sa'diyah, 2013).

Based on the above problems, it is necessary to improve urban mobility and mitigate traffic congestion. Improving mobility can support efforts to achieve sustainability and reduce traffic congestion in urban areas (Herrero, 2011). Mobility represents the ability of a transportation system to provide access to public facilities and mainly refers to travel time (Kaparias and Bell, 2011). Strategies to reduce traffic congestion include the development of Mass Rapid Transit (MRT) and Bus Rapid Transit (BRT), the improvement of public transport facilities, and the use of information technology (Sari, 2016).

Torres, Kunc and O'Brien (2017) state that system dynamics modeling can influence an organization's performance and suggest potential strategic actions to be taken in the future. Gary *et al*. (2008) utilized system dynamics in the field of strategy to build and test theories to explain longitudinal patterns of performance differences between organizations. Based on previous studies, this research was designed to make a novel contribution to system dynamics modeling to improve urban mobility and reduce traffic congestion. **The novel contributions of this research encompass model formulation in the field of urban mobility and congestion, model development of transport system behavior, and scenarios planning to improve mobility and reduce traffic congestion**. Some references related to urban mobility and traffic congestion were used as basic knowledge in developing the model. Validation was carried out to check the basic model's validity. With the validated model, several potential strategies to increase urban mobility and reduce traffic congestion were tested and evaluated through structural scenarios. An overview of the contributions of this research can be seen in Table 1.

Table 1 Overview of research contributions

Model and experimental scenario	Research contributions
Urban mobility and traffic congestion model	• Identify factors that influence urban mobility and traffic congestion • Formulate and investigate the dynamic behavior of urban mobility and traffic congestion

MRT and BRT development	• Analyze the impact of MRT and BRT development on private transport and daily traffic
Public transport delay reduction	• Investigate the reduction of travel time and the impact on delay performance
Urban mobility improvement and traffic congestion mitigation	• Predict the future of urban mobility and traffic congestion after the implementation of potential strategies

The scenarios were developed based on proposed strategies for managing traffic congestion (Sari, 2016) , such as MRT and BRT development and public transport delay reduction. The questions that guided this research were:

1. What factors influence urban mobility?
2. What factors influence traffic congestion?
3. How can urban mobility be increased through MRT and BRT development public transport delay reduction?
4. What is the impact of increasing urban mobility on traffic congestion?

To answer the research questions and accomplish the research objectives, an SD model was utilized because it is a useful tool to support policy analysis and decision-making (Shepherd, 2014). We developed a set of models of urban mobility and traffic congestion based on existing conditions to learn about the behavior of the system. We also developed a number of scenarios (i.e. MRT development; BRT development; public transport delay reduction) to improve mobility and reduce traffic congestion.

This paper is organized as follows. Section 2 provides a literature review related to urban mobility and traffic congestion. Section 3 describes the system dynamics as the modeling framework. Section 4 demonstrates the development of the basic model, and Section 5 provides the results and discussions. Section 6 describes the model validation to check the basic model's accuracy. Section 7 demonstrates the scenario development. Finally, in Section 8 the conclusion and further research required are presented.

2. Literature Review

In this section, we provide a literature review related to system dynamics simulation modeling to solve urban mobility problems and the scenario planning approach to reduce traffic congestion.

2.1 System Dynamics Simulation to Solve Urban Mobility Problem

In line with population growth and high urbanization to urban areas, this has resulted in an increase in the number of motorized vehicles which can increase congestion and reduce mobility (Arifiyananta and Fanida, 2015). This indicates that the road network system cannot keep up with volume growth vehicle. Congestion occurs in every major city such as Jakarta, Surabaya, Medan, Bandung, and Makassar.

Mobility is the ease of movement from origin to destination using transportation services and transportation networks (Beimborn *et al*., 1999). Urban mobility is influenced by travel time and affordability (Litman, 2003). Factors that affect mobility are travel time, public transport supply, accessibility to public transport, and modal split (Kaparias and Bell, 2011). Modal split refers to different modes of transport and pedestrian trips in the total transport need (Jovic, 2000). Delay is the time lost while traveling because of traffic and road network conditions (Macababbbad and Regidor, 2011) . Daily traffic is the total volume of vehicle traffic in one year divided by 365 days. Accessibility to public transport represents the ease with which inhabitants can reach public transport. Modal split represents the percentage of travelers using a particular mode of transportation. Armah, Yawson and Pappoe (2010) utilized system dynamics to solve traffic problems. Shigeru and Acharya (2013) analyzed urban transport in Asian megacities. They found that the system should be developed to serve large travel demand. To overcome urban mobility problems, systems thinking provides a way to understand the interactions between subsystems that drive the behavior of urban mobility. **System dynamics (SD) is a holistic method to study and manage complex systems. It has been used for the analysis of transportation systems to explore the feasibility of SD for transportation-related energy consumption, CO_2 emissions, health impacts, and economics (Batur and Muammer Koç, 2017). Wang, Lu and Peng (2008) have developed a high level interaction model between population, vehicle ownership, environment, GDP, travel demand and infrastructure supply in Dalian. They suggest that Dalian should restrict the total number of vehicles to improve the sustainability of transportation system. From the above studies and some problems in transport systems in Surabaya - Indonesia, there is a need and the knowledge gap of system dynamics approach to increase urban mobility and reduce congestion. In this research, the SD contributions include model formulation of several variables that influence the mobility and congestion, modeling the dynamic behavior of system being modeled, and building scenario models to improve urban mobility and reduce congestion in Surabaya**.

2.2 Scenario Planning Approach to Reduce Traffic Congestion

Traffic congestion is a condition where traffic flow exceeds the road capacity, resulting in lower speeds and vehicular queueing (Cambridge Systematics Inc., 2005). SD enables us to identify and clearly define the traffic congestion problem. Model validation is required to check the model's accuracy. After the model has been validated, scenario development can be conducted based on the proposed strategies (Papageorgiou *et al*., 2009). Scenario planning enables us to test the assumptions of the model from a future perspective (Forrest, 1998). Traffic congestion can be reduced by managing transport demand and traffic (European Comission, 2013). Surabaya suffers severely from traffic congestion, occupying the fourth position in the Castrol Magnatec Stop-Start Index (Zainuddin, 2015).

3. System Dynamics

System dynamics (SD) is a methodology developed by Forrester from MIT in the 1950s-60s based on system theory, information science, organizational theory, control theory, tactical decision-making, cybernetics, and military games (Forrest, 1998). It has been applied to fields such as government policy, medicine, the automotive industry, and urban studies (Sterman, 2002). In this study, SD was utilized to develop a set of models related to transportation systems based on the following considerations:

a. **SD uses causal loop diagram (CLD) as dynamic hypotheses before the development of quantitative stock-flow model. This CLD used to bring out the "mental models" of different stakeholders and therefore help remove any barriers to implementation (Shepherd, 2014).**
b. **SD can accommodate modeling structures and explore several factors that drive future demand and explain how to change user behavior (Shepherd, 2014).**

Suryani, Chou and Chen (2010) have developed a set of models to analyze the impacts of population growth and GDP on both runway and terminal capacity. Suryani, Chou and Chen, (2012) extended their model to investigate air cargo demand. Goh and Love (2012) developed two SD models to investigate policies to improve traffic safety. SD can be utilized to underlay the problem structure and understand the implications of an optimistic scenario and the factors that influence the need for additional capacity of airport infrastructure Suryani, Chou and Chen, (2012). Compared to other methods, such as discrete event simulation (DES), SD can be used qualitatively and can map system variables in a causal relationship (Brailsford and Hilton, 2001). DES has traditionally been used at the operational or tactical level to answer specific questions (Brailsford and Hilton, 2001). It is well suited to strategic issues since it is a useful tool for policy analysis and decision-making (Abbas and Bell, 1994).

SD models are used to learn and anticipate changes over time in complex systems. SD can be used for systems with limited data problems. The information used for system conceptualization and the model formulation is much broader than the numerical database used in operations research and statistical modeling. SD enables us to gain insight and understanding in uncertain situations by sketching a sophisticated CLD (European Foresight Platform, 2010). Besides those advantages, SD has limitations: 1) although SD can accommodate many variables, SD is only able to present a version of the situation at a time, 2) different stakeholders will bring different assumptions, so they can produce different models, 3) SD model might be very complex if the actual system has many significant variables.

Ventana Simulation (Vensim) can support system dynamics with discrete event and agent-based modeling capabilities (Vensim Inc, 2015). Vensim is more flexible than other software and enables us to integrate stock and flow and causal loop components. The steps to implement the system dynamics model are (Sterman, 2002) :

1. Problem formulation: determining the model boundaries, variables, time horizons, and data requirements.
2. Dynamic hypothesis: synthesizing the problems to evaluate the quantitative model, CLD and SFD development.
3. Simulation model development: model formulation, parameter estimation, setting initial conditions, and checking model consistency.
4. Model validation: testing the model's accuracy.
5. Scenario (experimentation) development: applying a 'what if?' analysis of the model based on the proposed strategy.

4. Model Development

The model's boundaries, causal loop diagram, and model development for urban mobility and traffic congestion are provided in this section. The stakeholders are traffic management agencies, regional transport authorities (Department of Transportation in Surabaya, Indonesia), private sector transport operators, road users, local businesses, local residents, and public agencies who have responsibility for planning, design, operations, and maintenance. Real-time traffic flow data were taken from a SCATS (Sydney Coordinated Adaptive Traffic System) device. These data were then transferred to a computer server via a traffic controller.

4.1 Model purpose and boundaries

To build an SD model, the first step is to determine the model's purpose. The next step is determining the model boundaries, consisting of selecting the model components to generate the behavior of interest (Albin, 1997). In determining the model boundaries, the following previous researches were explored:

a. Kaparias and Bell (2011): mobility focused on travel time and ease of access.
b. Fiedler, Čáp and Čertický (2017): urban mobility leading to significantly increased levels of traffic congestion due to extra trips without passengers.
c. Bates *et al*., (2001): impact of mobility on traffic congestion representing the impact of mobility and transport system reliability on traffic congestion.
d. Liu and Sinha (2007) : explanation of several types of reliability, such as travel time reliability, headway reliability, and passenger wait time reliability.
e. Oort (2011) : access time reliability and egress time reliability influence travel time reliability.

There are a number of guidelines for selecting the model components (Albin, 1997) :

1) They should properly represent the system's behavior according to the model's purpose.
2) They should be aggregated to help avoid unnecessary complications.
3) They must have a directional name that can grow larger or smaller.
4) They should be divided into two groups: endogenous and exogenous components.

Based on the above researches, we defined a number of model components, consisting of endogenous and exogenous components, as shown in Table 2.

Table 2 Model Components For Urban Mobility and Traffic Congestion

Endogenous Components	Exogenous Components
Public Transport Supply	Public Transport Demand
Trip Frequency	Population
Modal Split	Urban Mobility
Delay Performance	
Reliability	
Daily Traffic	
Road Capacity	

4.2 Causal Loop Diagram (CLD) Development

CLD is a qualitative method for visualizing how different variables in a system are interrelated and influence each other. CLD explains the behavior of a system by presenting a collection of connected nodes and feedback loops, such as reinforcing and balancing loops. Reinforcing feedback loops (R) represent a change in a node in the same direction. Balancing feedback loops (B) represent a change in the opposite direction. In this research, the development of the CLD was performed by referring to previous researches related to urban mobility and congestion. **CLD of urban mobility and traffic congestion can be seen in Figure 1.**

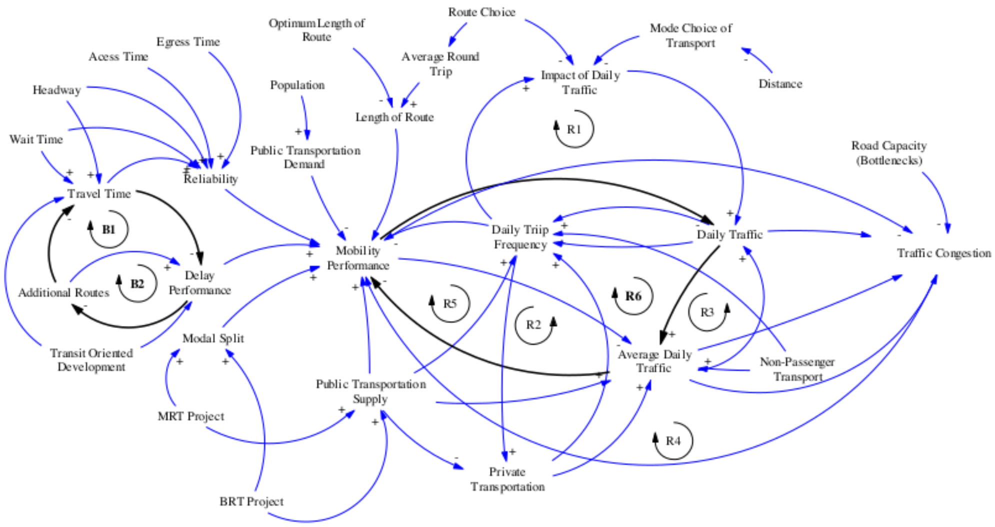

Figure 1. CLD of urban mobility and traffic congestion.

Mobility mainly refers to travel time on roads and ease of access (Kaparias and Bell, 2011). Factors that influence travel time and public transportation network are: public transportation demand and supply, modal split, length of route, daily traffic, delay performance of public transport, and reliability. Traffic congestion can be influenced by daily traffic and road capacity (Cambridge Systematics Inc., 2004). There are several strategies to reduce congestion (*Crowd Sourced Transport*, 2017) i.e.: a) providing traffic lanes for public transport; b) implementing traffic regulations and engineering for traffic control; c) MRT and BRT development. **As we can see from Figure 1, there are two balancing loops (B1, B2) and six reinforcing loops (R1, R2, R3, R4, R5, R6). An increase in additional routes results in a decrease in travel time, the increase in travel time results in the decrease in delay performance, an increase in delay performance results in a decrease in the need for additional routes (B1). An increase in additional routes results in an increase in delay performance. The increase in delay performance results in a decrease in the need for additional routes (B2).** A higher daily trip frequency results in an increase of the negative impact of daily traffic and daily traffic (R1). An increase in daily trip frequency will increase the volume of private transportation (R2). An increase in daily traffic results in an increase of average daily traffic (R3). Daily traffic, road capacity, and average daily traffic influence traffic congestion. Traffic congestion has an impact on mobility performance and mobility performance has an impact on traffic congestion (R4). An increase in mobility performance results in a reduction of average daily traffic. An increase of average daily traffic results in a decrease in mobility performance (R5). **An increase in mobility performance results in a decrease in daily traffic and the average daily traffic. An increase in the average daily traffic results in a decrease in mobility performance (R6).**

4.3 Urban Mobility and Traffic Congestion Model

Based on the CLD of urban mobility and traffic congestion, a stock and flow diagram (SFD) can be developed to characterize the accumulation of stock and flow quantities in the transport system. The general steps for converting the CLD to an SFD are: 1) identify the main factors giving rise to the problems in mobility and traffic congestion; 2) identify stock, flow, and auxiliary variables associated with the main factors; 3) provide the rate of change that governs each stock; 4) analyze the relationships between the controllable variables and their controllers as well as the impact of changes on the controllable variables.

The stock and flow diagram of urban mobility performance can be seen in Figure 2. Urban mobility has an impact on daily traffic, hence it influences traffic congestion. Daily traffic and road capacity are two factors that influence traffic congestion. Urban mobility performance, reliability, and public transportation percentage are factors that influence mobility. Urban mobility performance is determined by modal split (the percentage of public transportation); trip frequency (round trips), delay performance, and ratio of public transport supply and demand. The public transportation fulfillment ratio is determined by the supply and demand for public vehicles. The demand for public transport in Surabaya is around 11.8% of the total population (Utomo, 2011).

Reliability depends on additional waiting times, late or early arrivals at missed destinations and connections (Bates *et al*., 2001). It consists of travel time reliability, headway reliability and passenger wait time reliability (Liu and Sinha, 2007) . Travel time reliability depends on access time reliability and egress time reliability (Oort, 2011) . Based on these studies, we developed the reliability submodel shown in Figure 3. Reliability of public transport depends on travel time, headway, passenger wait time, access time, and egress time.

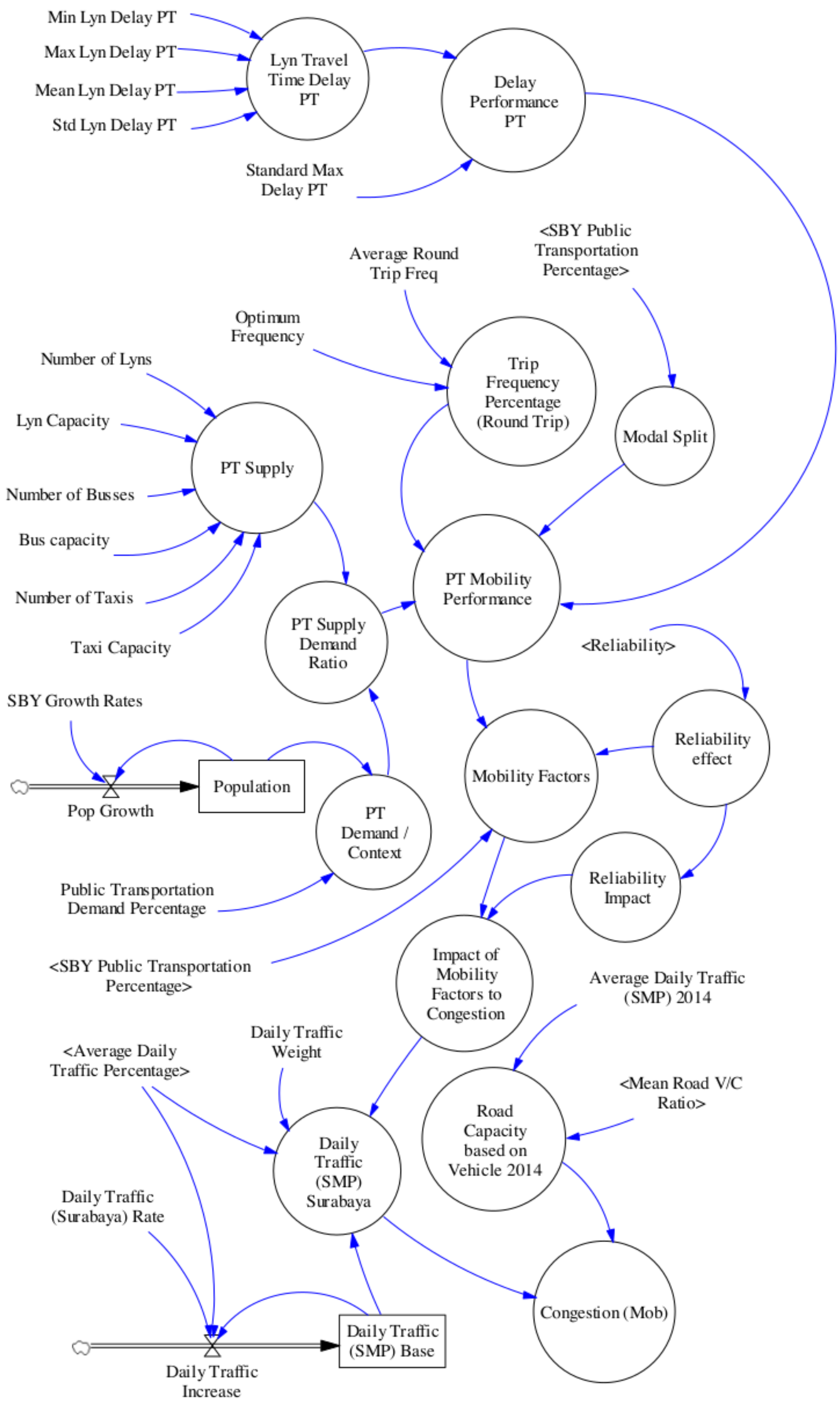

Figure 2. SFD of urban mobility and traffic congestion.

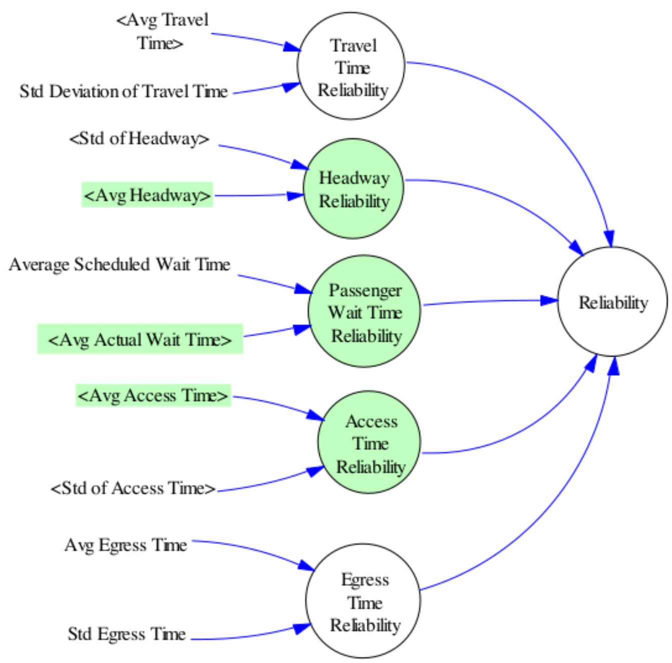

Figure 3. SFD of reliability.

The submodels of headway reliability, passenger wait time reliability, and access time reliability can be seen in Figure 4-6.

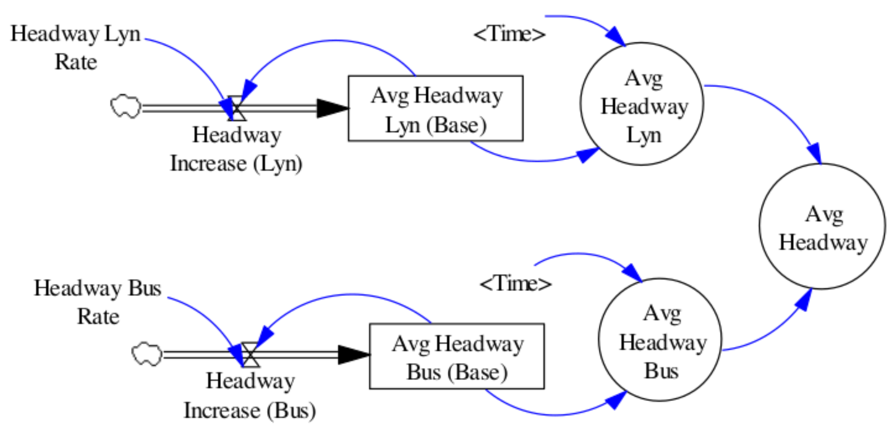

Figure 4. SFD of average headway.

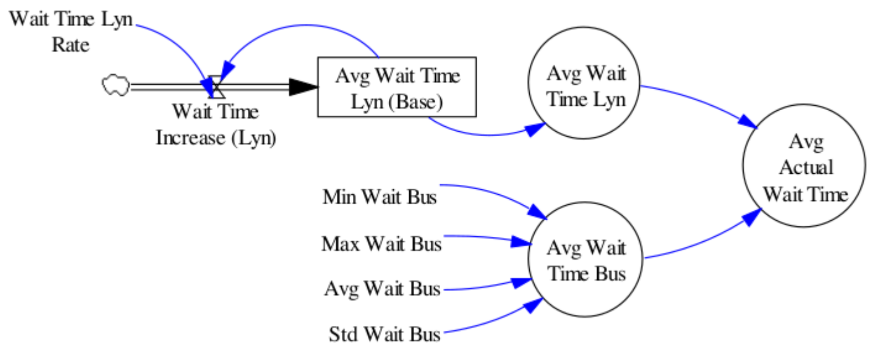

Figure 5. SFD of average actual wait time.

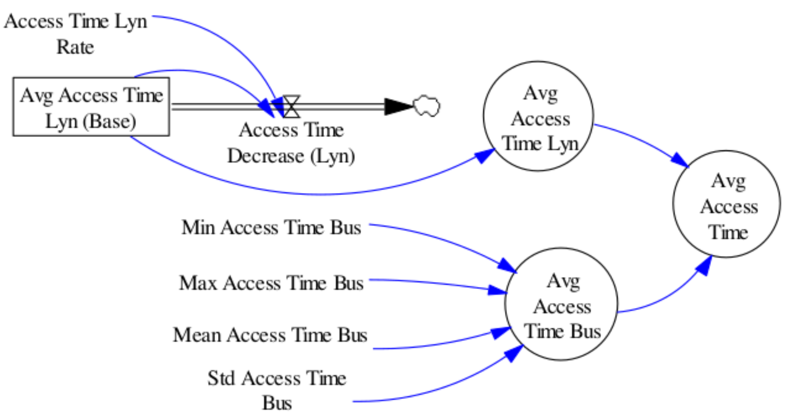

Figure 6. SFD of average access time.

Headway represents the time between vehicles in a transit system. In this study, headway was calculated based on the average headway of bus and Lyn (public transportation in the city of Surabaya with a capacity of 15 passengers per vehicle). Model formulation of population, public transport fulfillment ratio, and reliability can be seen in Equations (1)-(13).

Formulations and comments	**Units**	**No.**
Population (t) = $\mathbf{2.6e+006+\int_{t0}^{t} Population\ Growth\ (t)\ dt}$	People	(1)
Population **accumulates the population growth**		
Public Transportation Fulfillment Ratio (t) = $\mathbf{\frac{Public\ Transportation\ Supply\ (t)}{Public\ Transportation\ Demand\ (t)}}$	Percent	(2)
Public Transportation Fulfillment Ratio is a comparison between public transportation supply and demand		
Reliability (t) = $\mathbf{\frac{1}{5} * (Headway\ Reliability(t)\ +}$	Percent	(3)

$\text{Passenger Wait Time Reliability (t)} + \text{Travel Time Reliability (t)} + \text{Access Time Reliability (t)} + \text{Egress T. Reliability (t))}$		
Reliability is the average **condition of** Headway Reliability, **Passenger Wait Time Reliability, Travel Time Reliability, Access Time Reliability, Egress Time Reliability**		
Headway Reliability (t) = $\frac{\text{Std of Headway (t)}}{\text{Avg Headway (t)}}$	Percent	(4)
Headway Reliability is a comparison between the standard deviation of headway and the average headway		
Travel Time Reliability (t) = $\frac{\text{Std deviation of Travel Time (t)}}{\text{Avg Travel Time (t)}}$	Percent	(5)
Travel Time Reliability is a comparison between the standard deviation of travel time and the average travel time		
Waiting Time Reliability (t) = $\frac{\text{Average Scheduled Wait Time (t)}}{\text{Avg Actual Wait Time (t)}}$	Percent	(6)
Wait Time Reliability is a comparison between the average travel scheduled wait time and the average actual wait time		
Access Time Reliability(t) = $\frac{\text{Avg Access Time (t)}}{\text{Std of Access Time (t)}}$	Percent	(7)
Access Time Reliability is a comparison between the average access time and the standard deviation of access time.		
Egress Time Reliability (t) = $\frac{\text{Avg Egress Time (t)}}{\text{Std Egress Time (t)}}$	Percent	(8)
Egress Time Reliability is a comparison between the average egress time and the standard deviation of egress time.		
Average Headway Lyn (Base) (t) = 15.43 + $\int_{t0}^{t}$ **Headway Inrease (Lyn) (t) dt**	Minutes	(9)
Average Headway **Lyn (public transport) accumulates the headway increase of Lyn**		
Average Headway Bus (Base) (t) = 30 $+ \int_{t0}^{t}$ **Headway Inrease (Bus) (t) dt**	Minutes	(10)
Average Headway Bus **accumulates the headway increase**		
Average Wait Time Lyn (Base) (t) = 5.36 + $\int_{t0}^{t}$ **Wait Time Increase (Lyn) (t) dt**	Minutes	(11)
Average Wait Time **Lyn accumulates the wait time increase**		
Avg. Access Time Lyn (Base) (t) = 15 – $\int_{t0}^{t}$ **Access Time Decrease (Lyn) (t) dt**	Minutes	(12)
Average Access Time **Lyn accumulates the decrease** in **access time**		
Average Access Time Bus (t) = **RANDOM NORMAL(Min Access Time Bus, Max Access Time Bus, Mean Access Time Bus, Std. Deviation Access Time Bus, 0)**	Minutes	(13)
Average Access Time Bus **has a random normal** distribution **with a minimum of 86 minutes,**		

maximum of 108 minutes, an average of 94 minutes, with a standard deviation of 9 minutes

A condition where the daily traffic exceeds the road capacity will result in traffic congestion (Federal Highway Administration, 2017). The model formulation of traffic congestion is explained in the Eq. 14-15.

Formulations and comments	**Units**	**No.**
$\text{Congestion} = \frac{\text{Daily Traffic}}{\text{Road Capacity}} * 100$	Percent	(14)
Congestion is a comparison of daily traffic and road capacity		
$\text{Daily Traffic} = (\text{Daily Traffic Base} + (\text{Daily Traffic Base} * (100 - \frac{\text{Impact of Mobility Factors to Congestion}}{100})) * \text{Daily Traffic Weight}$	Vehicles	(15)
Daily Traffic **depends on the average daily traffic, impact of mobility, and daily traffic weight**		

5. Results and Discussion

This section presents the results and discussion of the model simulation for urban mobility and traffic congestion. In a previous study, conducted by (Wang, Lu and Peng, 2008) an SD model of an urban transportation system was utilized to improve the sustainability of the transportation system. (Raux, 2003) has developed SD models to simulate the effects of urban transport policies to achieve sustainable travel. The model ran in Vensim software using data from the Department of Transportation in Surabaya, Indonesia.

5.1 Urban Mobility

Urban mobility is a complex system with multiple variables and nonlinear feedback loops that is influenced by modal split, trip frequency, delay performance, and the ratio of public transport supply and demand. **The demand for public transport depends on the population and the percentage of public transport demand**. Modal split represents the percentage of public transportation. The trip frequency percentage for a round trip depends on the average round trip frequency (32 times in 24 hours) and optimum frequency (41 times in 24 hours). Delay performance is a comparison of standard maximum delay and Lyn travel time delay. Public transportation fulfillment ratio is a comparison between public transport supply and demand. Demand for public transport is determined by the population and the percentage of the population. **According to Utomo (2011) public transportation demand in Surabaya is around 11.8% of the total population.**

Simulation results of urban mobility performance and the factors delay performance, modal split, and the ratio of public transport supply and demand can be seen in Fig. 7-10. As we can see from Fig. 7, urban mobility performance in 2000-2018 was around 43% on average. This was due to decreases in modal split and the ratio of supply and as well as fluctuations in delay performance. Modal split tended to decline from 23.3% to 3.1%, as can be seen in Figure 8. This was due to a decrease in the public transport percentage, which continued to decline by 4.7%. The simulation result shows that the ratio of public transport supply and demand tended to decline and hence in 2018 only reached 16.5%, as seen in Figure 9. **It requires a comprehensive urban transportation policy that includes demand and capacity management, and the development of facilities and infrastructure that is fast and has a large capacity such as the Mass Rapid Transit (MRT).** The simulation result shows that delay performance fluctuated at a minimum 50% and a maximum of 84% due to some fluctuations in travel time delay, as shown in Figure 10. Mobility fluctuation is influenced by delay performance, modal split, and the ratio of public transport supply and demand. By referring to Figures 7-10, it can be seen that the trend in mobility fluctuation was similar to the trend in delay performance, hence delay performance highly influences mobility.

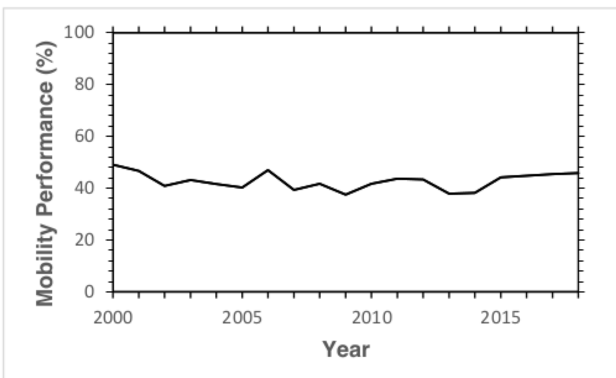

Figure 7. Mobility performance.

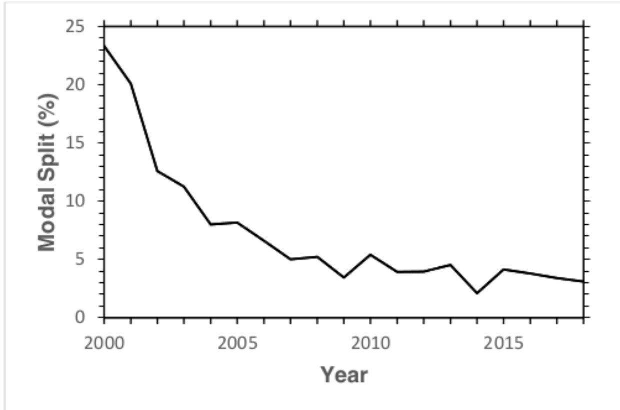

Figure 8. Modal split.

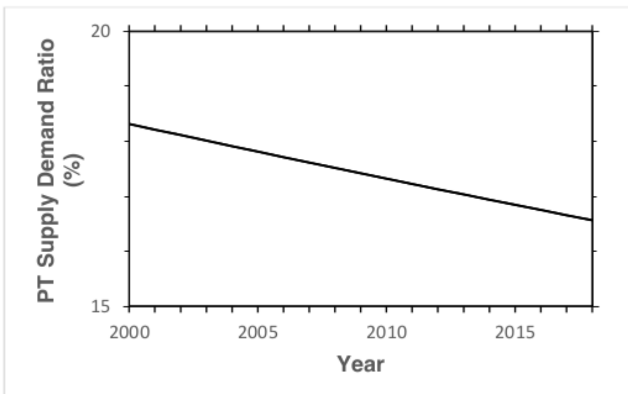

Figure 9. The ratio of public transport supply and demand.

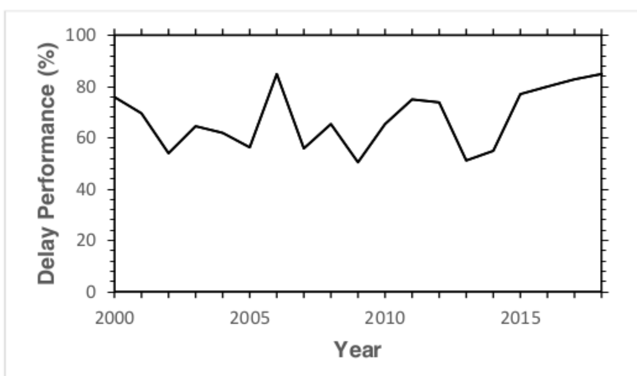

Figure 10. Delay performance.

5.2 Traffic Congestion

Traffic congestion is characterized by lower speeds, longer travel times, and increased vehicular queueing. Daily traffic and road capacity are factors that influence traffic congestion. Daily traffic depends on the average daily traffic, impact of mobility on traffic congestion, and daily traffic weight. Mobility depends on urban mobility performance, reliability, and public transportation percentage. Reliability is the average condition of headway reliability, passenger wait time reliability, travel time reliability, access time reliability, and egress time reliability. Headway reliability is a comparison between the standard deviation of headway and average headway. Travel time reliability depends on the standard deviation of travel time and average travel time. Access time reliability depends on average access time and the standard deviation of access time. Meanwhile, egress time reliability is a comparison between the average egress time and the standard deviation of egress time.

The simulation results of traffic congestion and daily traffic as a cause of traffic congestion can be seen in Figures 11-12. The graph in Figure 11 shows that the traffic congestion in 2018 reached 86% because of the daily traffic volume and road capacity. Daily traffic volume in 2018 reached 1.91 million vehicles while road capacity was only 2.13 million vehicles, as shown in Figure 12. Daily traffic in Surabaya has increased with an average growth of 4.27% per year due to the increase in the volume of private vehicles and declining mobility performance. **The increasing use of private vehicles is due to the lack of interest of travelers to use public transportation because of delay and inconvenience.**

According to Hale and Courage (2002) the maximum saturation level of congestion is 85%. As we can see from Fig. 11-12, congestion fluctuation followed the same trend as daily traffic, so daily traffic is an important factor in traffic congestion. Increasing the daily traffic volume increases congestion, thereby reducing mobility performance. Therefore, we need a strategy to increase mobility and reduce congestion through the development of scenario planning as demonstrated in Section 7 (Scenario Development).

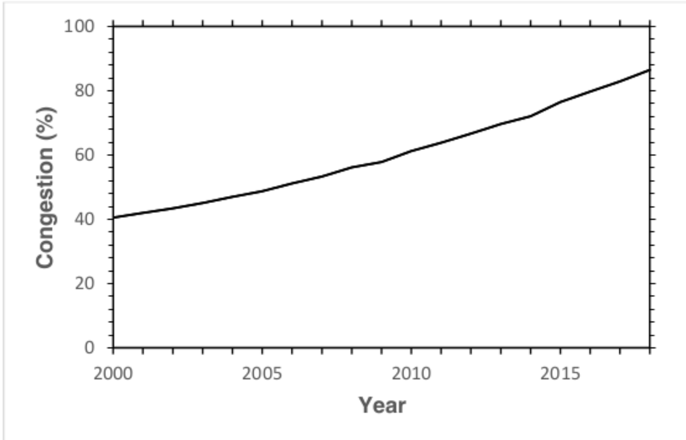

Figure 11. Traffic congestion based on the existing conditions.

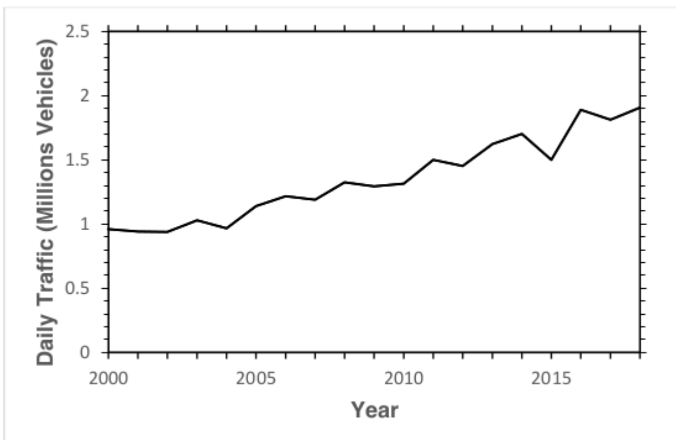

Figure 12. Daily traffic in the existing conditions.

6. Model Validation

Model validation requires historical data and information covering the time horizon of the simulation (2000-2018). We considered this time frame based on data availability and system behavior. The information about daily traffic and headway was collected through surveys to accumulate the traffic volume on the main road segments in Surabaya. A traffic counting survey was carried out for 16 hours from 05.00 to 21.00 with 10-minute intervals. Meanwhile, historical data of the Surabaya population were obtained from *Badan Pusat Statistik Kota Surabaya*. According to Barlas (1996), a model is valid if the error rate is ≤ 5% and the error variance is ≤ 30%. We validated the model by checking the error rate and error variance as shown in Eq. 16-17.

Formulations and comments	Units	No.
Error Rate $= \frac{[\bar{S} - \bar{A}]}{\bar{A}}$	Percent	(16)
Error Rate **is a comparison of the difference between the average of the model and the average of** the **data**, and **the average of** the **data**		
Error Variance $= \frac{[Ss - Sa]}{Sa}$	Percent	(17)
Error Variance **is a comparison of the difference between the standard deviation of the model and the standard deviation of data**, and **the standard deviation of** the **data**		

The software used for the model development was Ventana Simulation (Vensim) based on some considerations (Vensim Inc., 2015): 1) Vensim allows modelers to easily mix SFD and CLD with its functionality; 2) Vensim contains a set of analysis tools that use the structure of the model to present information quickly. The error rate of some variables such as daily traffic, population, and headway Lyn are as follows:

Error rate 'daily traffic' $= \frac{[\ 1{,}371{,}369 - 1{,}359{,}463\ ]}{1{,}359{,}463} = 0.0087$

Error rate of 'population' $= \frac{[2{,}745{,}283 - 2{,}748{,}525\ ]}{2{,}748{,}525} = 0.0012$

Error rate of 'headway Lyn' $= \frac{[\ 20{,}98 - \ 21.09]}{21.09} = 0.0052$

Error variance of daily traffic, population, and headway of Lyn are as follows:

Error variance 'daily traffic' $= \frac{[\ 334766 - 337362\ ]}{337362} = 0.0077$

Error variance of 'population' $= \frac{[46{,}415 - 46{,}606\ ]}{46{,}606} = 0.0041$

Error variance of 'headway Lyn' $= \frac{[4.36 - 4.41\ ]}{4.41} = 0.0099$

A comparison between the simulation results and the historical data of daily traffic, population, and headway can be seen in Figures 13-15.

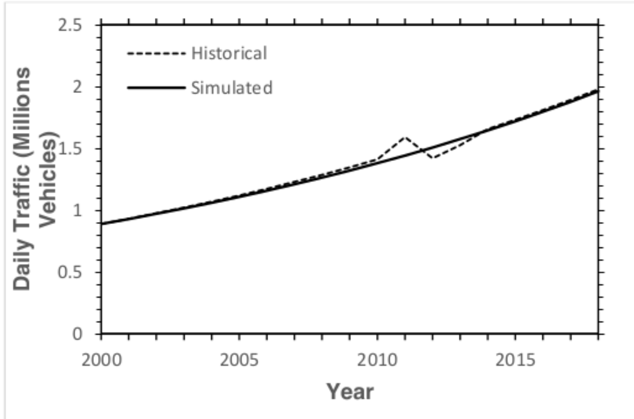

Figure 13. Comparison of simulation result and historical data of daily traffic.

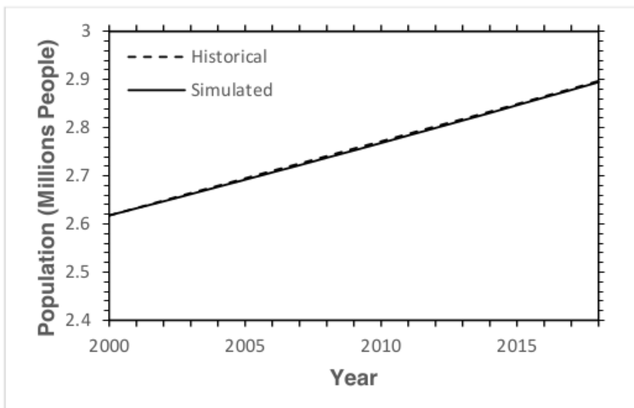

Figure 14. Comparison of simulation result and historical data of the population.

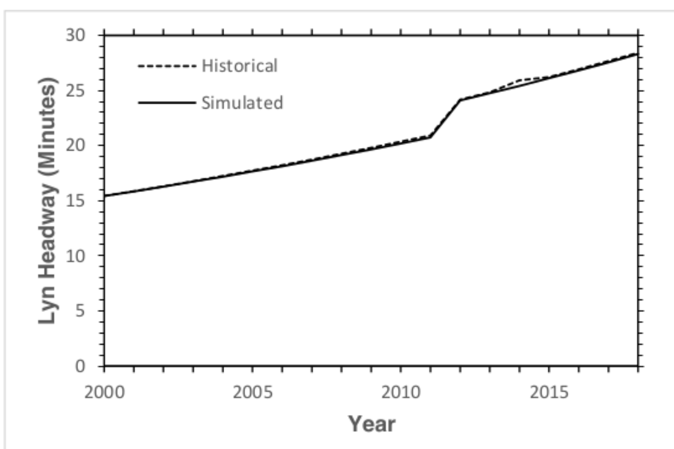

Figure 15. Comparison of simulation result and historical data of Lyn headway.

7. Scenario Development

This section presents several scenarios that can be carried out to increase urban mobility and reduce traffic congestion. Scenario development is a method for strategic planning to demonstrate and analyze several projections of key factors (Brose *et al*., 2013). Scenarios can be developed to forecast demand and evaluate policy scenarios to learn about nonlinear dynamics (Suryani, Chou and Chen, 2010). The scenarios can be developed by modifying the model's structures and parameters (Suryani, 2011) . Several strategies can be implemented, such as MRT and BRT development and public transport delay reduction. **This study shows the impact of various policies on transportation management that can potentially be implemented to increase urban mobility and reduce traffic congestion**.

7.1 MRT Development Scenario

MRT is a modern urban public transport system that moves a large number of people on short to medium length journeys. The MRT development scenario was designed to improve urban mobility and reduce traffic congestion. **Challenges in MRT development include land acquisition for the relocation of public utilities, such as the removal of gas pipes, raw water pipes, and electricity cables**. **In developing the MRT project, policies are required in managing the authority to administer railroad facilities and infrastructure. Policies that were previously controlled by the Central Government through a State-Owned Enterprise (BUMN) need to be adjusted so that the policy can be implemented by a Business Entity formed by the Regional Government (MRT Jakarta, 2014). MRT capacity depends on how many passengers per hour it can be expected to carry.** The maximum capacity can be defined as (MacKechnie, 2019) = 100 passengers per vehicle * 10 vehicles per train * 30 vehicle sets per hour = 30,000 passengers per hour. Currently, the average daily traffic in Surabaya is around 1.85 million vehicles and the percentage of private vehicles is about 43%. We assumed that each private vehicle was occupied by 1 person based on the tendency of people to travel for personal interest purposes, hence the average number of passengers in private vehicles is around 0.43 * 1.85 million = 795,500 passengers per day, i.e. around 795,500 / 24 = 33, 146 passengers per hour. The maximum capacity of MRT is 30,000 passengers per hour, hence the maximum absorption capacity of MRT would be able to reduce private car use by = 30,000 / 33.146 * 100% = 90%. Based on the maximum capacity of MRT and the expectation that not all private vehicles users will switch to MRT, as happened after the implementation of Light Rail Transit in Palembang, we assumed that there would be around 35-45% of private vehicle users who will switch to MRT. The SFD of the MRT Development Scenario can be seen in Figure 16. With the existence of an MRT there will be a shift in passengers from private vehicles to MRT (MRT rate). This MRT rate is accumulated in 'Change to MRT (Base)', which then becomes an input for 'Change to MRT Scenario (SCN)'. The model formulation of the number of private vehicle users switching to MRT can be seen in Eq. 18.

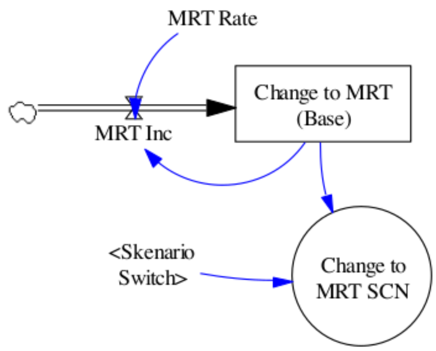

Figure 16. SFD of the MRT Development Scenario.

Formulations and comments	Units	No.
Change to MRT (Base) (t) = 27 + $\int_{t0}^{t}$ **MRT Inc (t) dt**	Percent	(18)
Change **to MRT accumulates the MRT user** increment from private vehicle users		

The simulation result shows that the existence of MRT will reduce the number of private vehicle users as shown in Figure 17. 35.8% of private vehicle users will switch to MRT initially, after which this number will grow at around 1.5% per year.

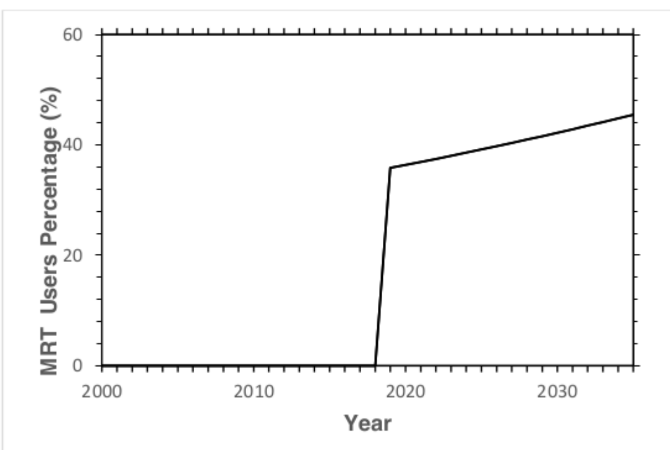

Figure 17. Percentage of MRT users.

7.2 BRT Development Scenario

BRT is a high-quality bus transit system that can provide services that are fast, convenient and cost-effective (Institute for Transportation and Development Policy, 2019). In the construction of BRT developments in Indonesia, a large amount of funding is required, where a 5-km BRT development would cost US$ 5 million (Sari, 2015). This scenario was developed based on the proposed strategy of the Head Executive of Surabaya City Transportation (Faiq, 2016). In the initial BRT implementation in Surabaya, the bus will be operated once every 10 minutes departing from Purabaya terminal (Faiq, 2016). The bus will stop at every center stop in Surabaya and immediately deliver passengers from the middle of the city to Perak. The initial number of buses is estimated around 30 (based on the number of buses owned by government company Perum DAMRI, with a capacity of 30 people per vehicle. The maximum capacity of BRT in 1 day is = number of buses * passenger capacity of one bus * operating hours for 1 day * bus frequency in trips per hour. Hence, the maximum capacity of BRT = 30 * 30 * 10 * 6 = 54,000 passengers. The total volume of daily traffic of all transport modes = 1.85 million passengers and the percentage of private vehicles = 43%, hence the total number of people transported in private vehicles = 0.43 * 1.85 million = 795,500 passengers. Therefore, the BRT project will be able to decrease the number of private vehicle users by 54,000 / 795,000 = 0.068 = 6.8% (or about 7%). This value can be utilized to determine the initial percentage of private vehicle users that switch to BRT. The percentage of BRT users is projected to grow 2% annually due to changes in user behavior and the addition of buses. We assumed this growth percentage based on the initial value of the BRT user percentage of around 6.8% and bus passenger utilization, which is only 1/3 of the total bus capacity (Nugraha, 2018). The SFD of the BRT Development Scenario can be seen in Figure 18, showing ‘Change to BRT (Base)’, which accumulates ‘BRT Rate’. ‘Change to BRT (Base)’ is then used as feedback for ‘Change to BRT SCN’, which represents the percentage of private vehicle users that switch to BRT after the implementation of the BRT Development Scenario.

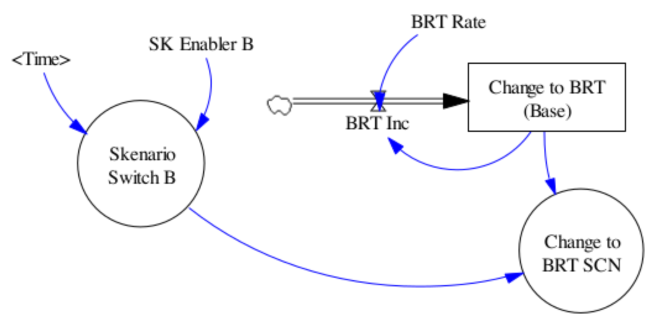

Figure 18. SFD of the BRT Development Scenario.

The model formulation for the BRT Development Scenario can be seen in Eq. 19.

Formulations and comments	Units	No.
Change to BRT (Base) (t) = 5 + $\int_{t0}^{t}$ **BRT Inc (t) dt**	Percent	(19)
Change **to BRT accumulates the BRT** user increment from private vehicle users		

The simulation result of the percentage of BRT users is shown in Figure 19. The initial BRT user percentage is predicted at 7.28% and will grow with an average growth rate of 2% due to changes in user behavior and the addition of buses.

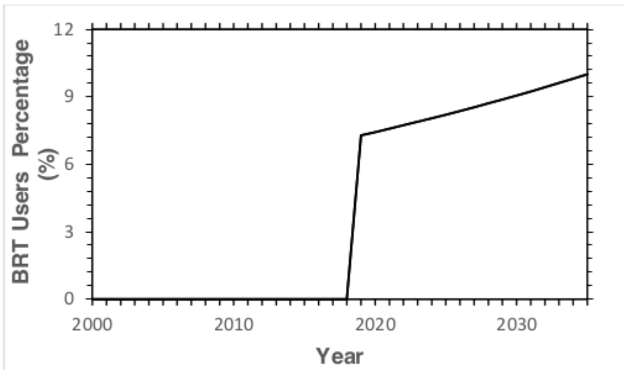

Figure 19. Percentage of BRT users.

7.3 MRT and BRT Development Scenario

The results of the MRT and BRT Development Scenarios were then used as feedback for the Private Vehicles Scenario, as shown in Figure 20. With MRT and BRT development, the percentage of private vehicles can initially be reduced by 50% and it will continue to decrease at around 1.4% per year due to private vehicle users switching to MRT and BRT, as can be seen in Figure 21. The percentage of average daily traffic (ADT) is initially reduced by 35.4% and is predicted to decrease by 21.2% in 2035. The model formulation of the percentage of private vehicles after BRT and MRT development can be seen in Eq. 20.

Formulations and comments	Units	No.
SBY Private/Shared **Transportation Percentage SCN = (SBY Motorcycle Percentage + SBY Private Car Percentage) - ((SBY Motorcycle Percentage + SBY Private Car Percentage)** * $\frac{\textbf{Change to MRT SCN}}{\textbf{100}}$ **) - ((SBY Motorcycle Percentage + SBY Private Car Percentage)** * $\frac{\textbf{Change to BRT SCN}}{\textbf{100}}$ **)**	Percent	(20)
The percentage of private/shared transportation after BRT and MRT development is the difference between the percentage of the number of motorcycles and **private** cars, **and the percentage of the number of** private vehicle **users** switching **to MRT and BRT.**		

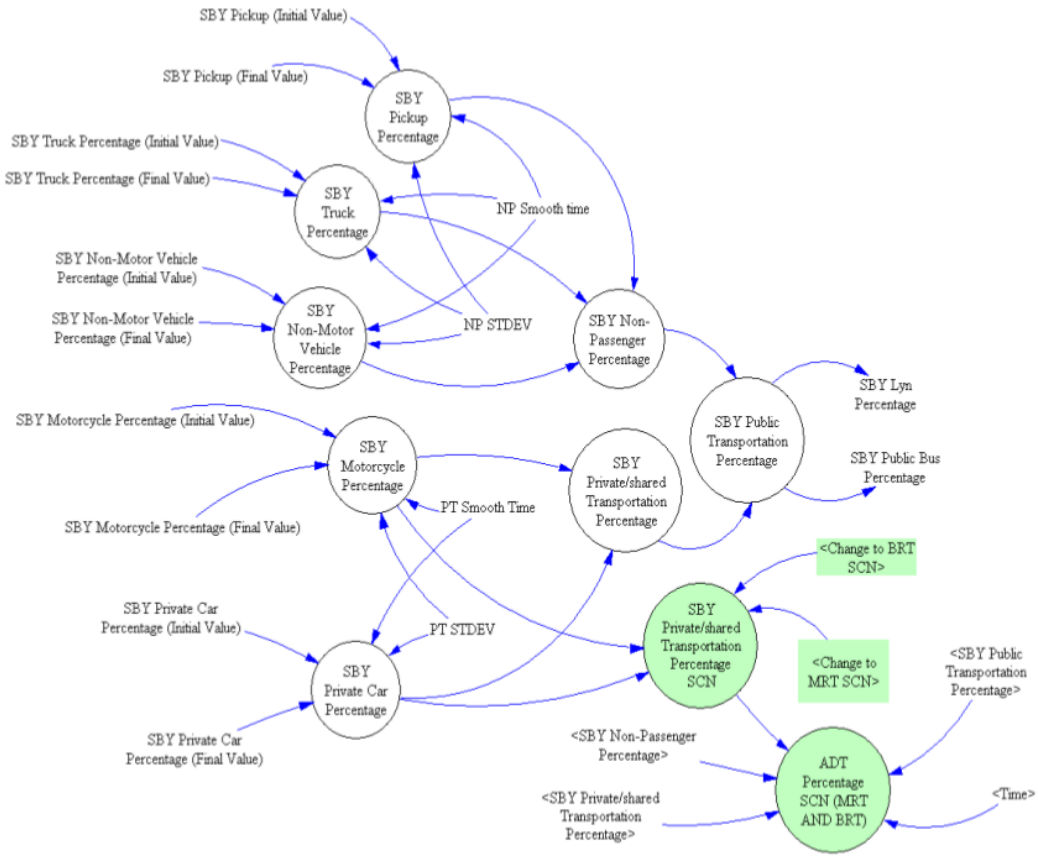

Figure 20. SFD of the impact of MRT and BRT development on the percentage of private vehicles and average daily traffic.

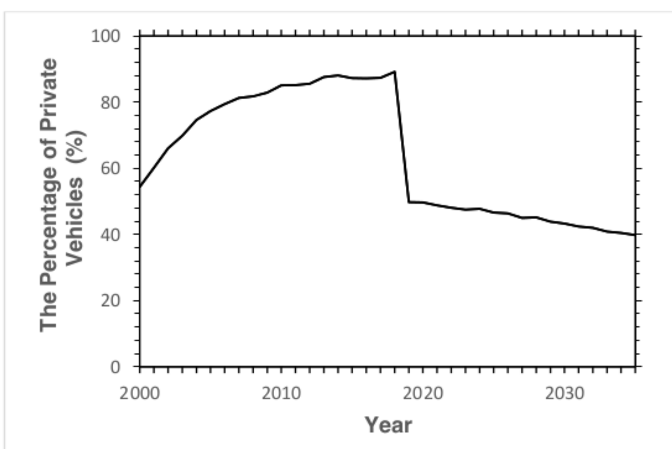

Figure 21. Percentage of private vehicles after BRT and MRT development.

7.4 Public Transport Delay Reduction Scenario

Another strategy to increase urban mobility and mitigate congestion is reducing public transport delay. We designed this scenario based on proposed strategies for reducing traffic congestion (Sari, 2016) through: 1) addition of public transport routes; 2) extension of the public transport fleet; 3) transit-oriented development (TOD). The SFD of public transport delay reduction can be seen in Figure 22. The model formulation of delay performance as an impact of public transport delay reduction can be seen in Eq. 21. The reduction in public transport delay results in a decrease in travel time delay and an increase in delay performance, as can be seen in Figure 23-24.

Formulations and comments	Units	No.
Delay Performance (SCN) (t) $= \frac{\textbf{Standard Max Delay (t)}}{\textbf{Lyn Travel Time Delay(t)}} * \mathbf{100}$	Percent	(21)
Delay Performance is a comparison between standard maximum delay and Lyn (public transport) travel time delay.		

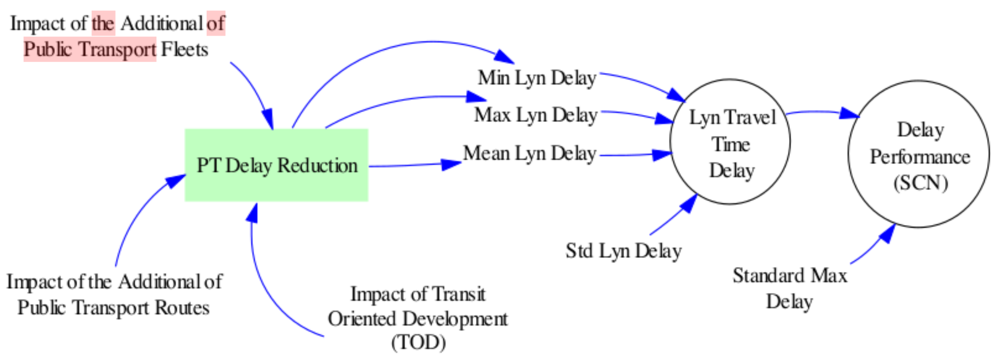

Figure 22. SFD of decreasing public transport delay.

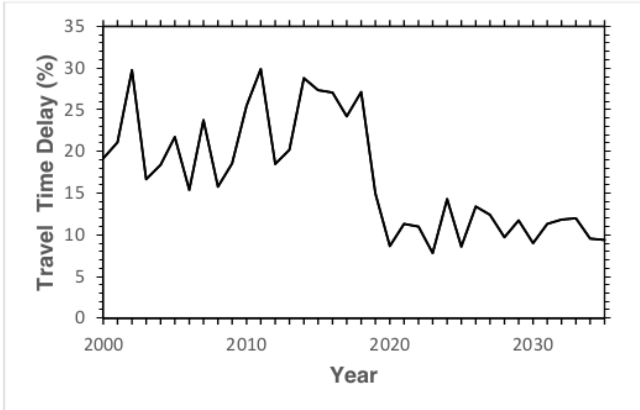

Figure 23. Travel time delay reduction.

Travel time delay can be reduced from an average of 24 minutes to an average of 10 minutes by a decrease in public transport delay, hence it can increase delay performance by an average of 67.5% to an average of 137%.

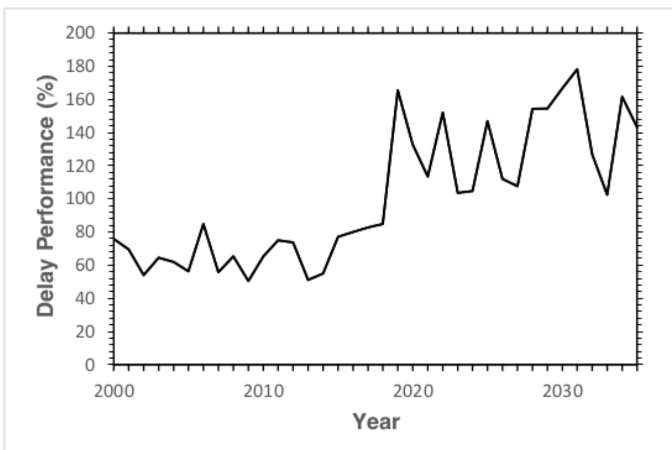

Figure 24. Delay performance increase.

7.5 Urban Mobility and Traffic Congestion Scenario

This scenario demonstrates the impact of three strategies, i.e. MRT and BRT development and public transport delay reduction, on urban mobility, average daily traffic, and traffic congestion. The stock and flow diagram of the scenario of increasing urban mobility and reducing traffic congestion can be seen in Figure 25. The improved delay performance as an impact of the reduction of public transport delay was then used as feedback to increase urban mobility. Meanwhile, the MRT and BRT development influences the average daily traffic.

The model formulation of traffic congestion as an impact of urban mobility improvement can be seen in Eq. 22.

Formulations and comments	Units	No.
Congestion SCN (Mobility) (t) = $\left(\frac{\textbf{Average Daily Traffic(SMP)Surabaya(t)}}{\textbf{Road Capacity based on Vehicle 2014 (t)}} * \textbf{100}\right.$ **-** $\left(\left(\frac{\textbf{Average Daily Traffic(SMP)Surabaya(t)}}{\textbf{Road Capacity based on Vehicle 2014(t)}}\right) * \right.$ $\left.\left.\textbf{Impact of Mobility Factors to Congestion (t)}\right)\right)$	Percent	(22)
Congestion SCN is a comparison of the average daily traffic as an impact of mobility improvement and road capacity enhancement		

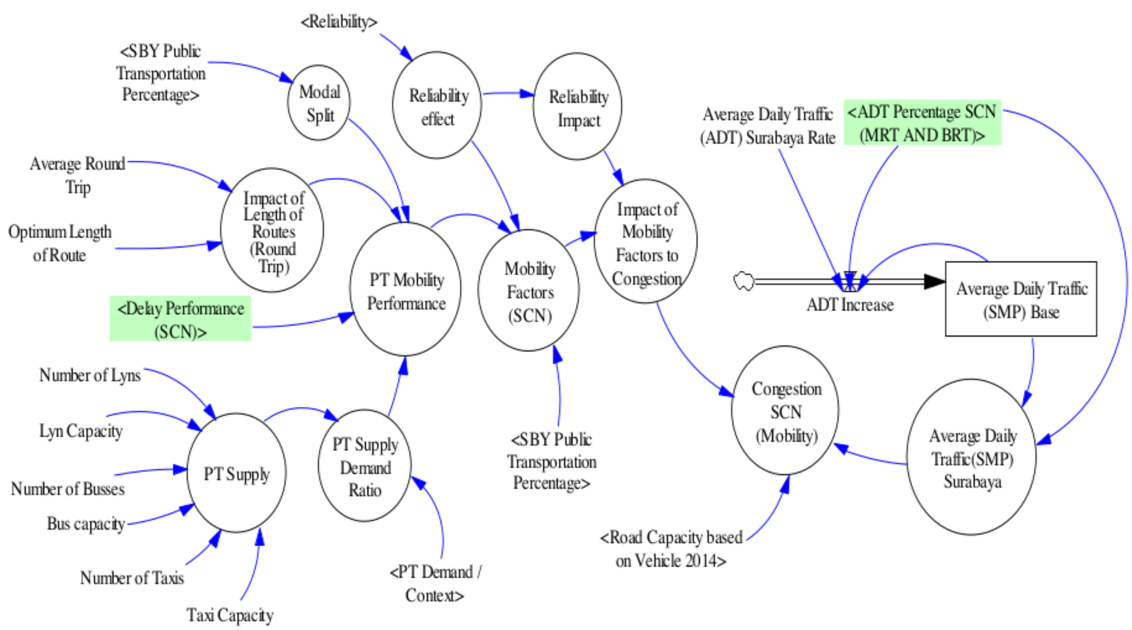

Figure 25. SFD of urban mobility improvement to reduce traffic congestion.

The simulation result shows that MRT and BRT development could decrease the average daily traffic. The average daily traffic after MRT and BRT development is projected to be reduced by 1.3 M vehicles by 2020 and 1.55 M vehicles by 2035, as shown in Figure 26. Meanwhile, the urban mobility performance (after the reduction of public transport delay) is projected to increase by a minimum of 50% and a maximum of 70%, as shown in Figure 27.

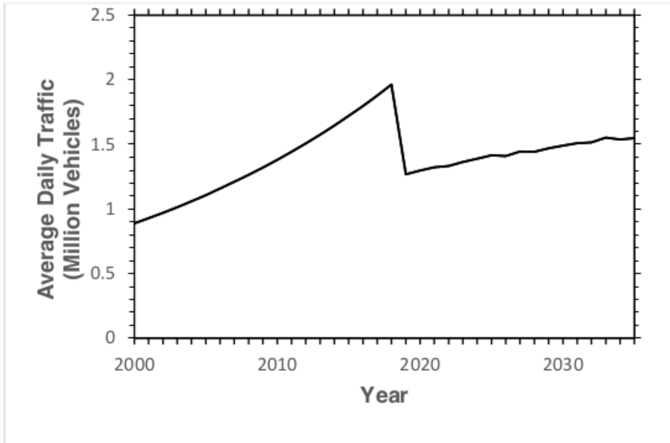

Figure 26. Average daily traffic after MRT and BRT development.

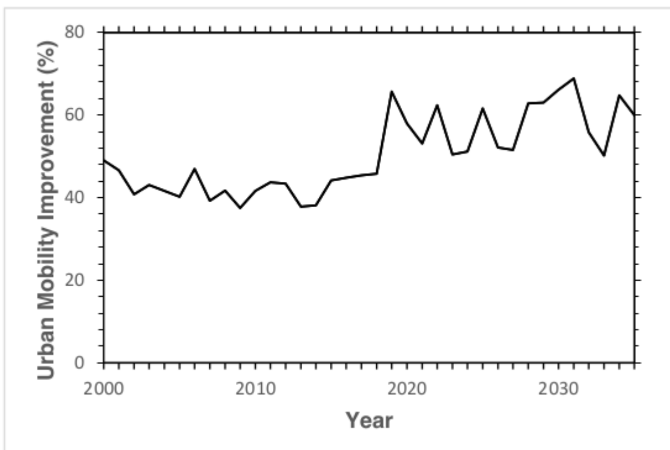

Figure 27. Urban Mobility Improvement Scenario.

With the increase in urban mobility and the decrease in average daily traffic, traffic congestion is predicted to decrease by a minimum of 57.6% and a maximum of 69%, as shown in Figure 28. These values indicate that traffic congestion will be reduced under the maximum saturation of 85% (Hale and Courage, 2002).

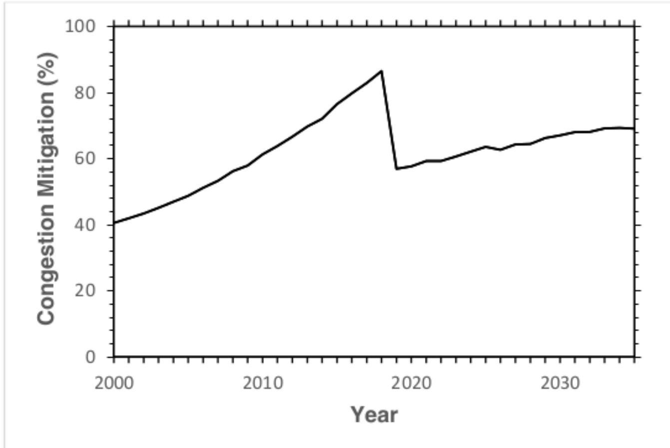

Figure 28. Traffic congestion mitigation after urban mobility improvement.

A summary of the results of the scenarios can be seen in Table 3.

Table 3 Summary of Scenario Results

Scenario	Summary Results
MRT Development Scenario	The percentage of private vehicle users switching to MRT is predicted to be 35.8% initially and then will grow at an average rate of around 1.5% per year.
BRT Development Scenario	The percentage of private vehicle users switching to BRT is predicted to be 6.8% initially and then will grow at an average rate of 2% due to changes in user behavior and the addition of buses.
MRT and BRT Development Scenario	The percentage of private vehicles will be reduced by 50% initially due to private vehicle users switching to MRT and BRT and it will continue to decrease at an average rate of around 1.4% per year. The percentage of average daily traffic (ADT) is reduced by 35.4% initially and is predicted to decrease by 21.2% in 2035.
Public Transport Delay Reduction Scenario	The travel time delay can be reduced from an average of 24 minutes to an average of 10 minutes due to the decrease in public transport delay and hence it can increase delay performance from an average of 67.5% to an average of 137%.
Urban Mobility and Traffic Congestion Scenario	MRT and BRT development will decrease average daily traffic. The average daily traffic after MRT and BRT development is projected to be reduced to 1.3 M vehicles by 2020 and to 1.55 M vehicles by 2035. Urban mobility performance after MRT and BRT project development and public transport delay reduction is predicted to increase by a minimum of 50% and a maximum of 70%. With the increase in urban mobility and the decrease in average daily traffic, traffic congestion is predicted to decrease by a minimum of 57.6% and a maximum of 69%.

8. Conclusion and Further Research

This research was designed to provide a comprehensive and objective assessment of improving urban mobility and its impact on traffic congestion through the use of simulation models. As a method to build and simulate the models, we utilized system dynamics based on the consideration that systems dynamics can be developed at macroscopic and microscopic levels of traffic to explore transportation interactions, urban mobility, and traffic congestion. This study was conducted in Surabaya City, East Java, Indonesia, which is the fourth most congested city in the world. The novel contributions of this research are: formulating relationships between variables, building the dynamic behavior of urban mobility and traffic congestion, building scenario models to improve mobility and reduce traffic congestion. This paper contributes to the literature by theoretically and empirically investigating these relationships through the use of models and experimental scenarios (e.g. MRT and BRT development and public transport delay reduction), thereby addressing research gaps found in the literature. The scenarios enabled us to test some alternative policies and observe the overall impact of the proposed solutions by modifying the model structures and parameters.

Several factors influence urban mobility, i.e. modal split, trip frequency, delay performance, reliability of public transport, and the ratio of public transport supply and demand. The public transportation fulfillment ratio is determined by the supply and demand of public vehicles. Fluctuation in mobility is influenced by various factors, such as delay performance, modal split, and the ratio of public transport supply and demand. Referring to Figures 7-10, it can be seen that the trend in mobility fluctuation is similar to the trend in delay performance, hence delay performance is highly influences mobility. Urban mobility is one of several factors that affect traffic congestion. Congestion fluctuation follows the same trend as daily traffic, so daily traffic is an important factor in traffic congestion. Increasing the daily traffic volume will increase traffic congestion, thereby reducing the mobility performance. The imbalance between daily traffic, road infrastructure, and declining public inclination to use public transportation have caused traffic congestion in urban areas. Demand for public transport is determined by the total population and the percentage of the population who need public transport. To increase urban mobility, several strategies can be implemented, such as MRT and BRT development and public transport delay reduction. With the introduction of MRT, a portion of private vehicle users will switch to MRT. It is predicted that there will be at least 35-45% of private vehicle users who will switch to MRT with a growth of 1.5% per year. BRT is another solution to reduce traffic congestion because of its speed, affordability, and comfort. It is predicted that 6.8% of private vehicle users will switch to BRT, after which the percentage of BRT users will grow 2% annually due to changes in user behavior and the addition of buses. We assume this annual growth percentage based on the initial value of the BRT user percentage (6.8%) and bus passenger utilization, which is only 1/3 of the total bus capacity. With MRT and BRT development, the percentage of private vehicles can be reduced by 50% initially and will continue to decrease by around 1.4% per year due to private vehicle users switching to MRT and BRT. The delay reduction in public transport will result in a decrease in travel time delay and an increase in delay performance. All these strategies were used as feedback to increase urban mobility and reduce average daily traffic. The urban mobility performance after MRT and BRT development as well as reduction of public transport delay is predicted to increase by a minimum of 50% and a maximum of 70%. With the increase in urban mobility and the decrease in average daily traffic, traffic congestion will be reduced by a minimum of 57.6% and a maximum of 69%, which indicates that traffic congestion will be reduced under the maximum saturation level (85%). Further research is required to develop a sustainable transport system by considering economic (e.g. infrastructure, energy, pricing, and competitiveness), social (e.g. operations, access, safety, and health), and environmental factors (e.g. air quality and land use).

Acknowledgment

This work was supported by ITS (Institut Teknologi Sepuluh Nopember) Research Center, Enterprise Systems Laboratory, City Transportation Office of Surabaya, and Faculty of Information and Communication Technology of ITS.

References

Abbas, K. and Bell, M. (1994) 'System dynamics applicability to transportation modeling', *Transportation Research Part A: Policy and Practice*, 28(5), pp. 373–390.

Alam, M. and Ahmed, F. (2013) 'Urban transport systems and traffic congestion: a case study of Indian cities', *Transport and Communications Bulletin for Asia and the Pacific*, 82, pp. 33–43.

Albin, S. (1997) *Building a system dynamics model – Part 1: conceptualization*. Massachusetts: The Massachusetts Institute of Technology.

Arifiyananta, R. D. and Fanida, E. H. (2015) 'Strategi Dinas Perhubungan Kota Surabaya untuk Mengurangi Kemacetan Jalan Raya Kota Surabaya', *Publika*, 3(6), p. 2015.

Armah, F., Yawson, D. and Pappoe, A. (2010) 'A systems dynamics approach to explore traffic congestion and air pollution link in the city of Accra, Ghana', *Sustainability*, 2(1), pp. 252–265.

Barlas, Y. (1996) 'Formal aspects of model validity and validation in system dynamics. System Dynamics Review', *The Journal of the System Dynamics Society*, 12(3), pp. 183–210.

Bates, J. *et al*. (2001) 'The valuation of reliability for personal travel', *Transportation Research Part E: Logistics and Transportation Review*, 37(2–3), pp. 191–229.

Batur, I. and Muammer Koç (2017) 'A Review of System Dynamics Applications in Sustainable Urban Transportation', in *The European Conference on Sustainability, Energy & the Environment*. The International Academic Forum.

Beimborn, E. *et al*. (1999) *An overview: land use and economic development in statewide transportation planning*.

Brailsford, S. and Hilton, N. (2001) 'A comparison of discrete event simulation and system dynamics for modelling health care systems', in *Proceedings of the 26th meeting of the ORAHS Working Group 2000*. Glasgow, Scotland, pp. 18–39.

Brose, A. *et al*. (2013) *System dynamic enhancement for the scenario technique*. Berlin.

Cambridge Systematics Inc. (2004) *Traffic congestion and reliability: linking solutions to problems*. Massachusetts. Available at: https://ops.fhwa.dot.gov/congestion_report_04/congestion_report.pdf.

Cambridge Systematics Inc. (2005) *Traffic congestion and reliability: trends and advanced strategies for traffic congestion mitigation*. Massachusetts. Available at: https://ops.fhwa.dot.gov/congestion_report/congestion_report_05.pdf.

Crowd Sourced Transport (2017) 'Reduce Traffic Congestion'. Available at: http://crowdsourced-transport.com/working-pages/improve-public-transport/reduce-traffic-congestion/.

European Comission (2013) *Mobilising intelligent transport systems for EU cities*. Brussels. Available at: https://ec.europa.eu/transport/sites/transport/files/themes/urban/doc/ump/swd%282013%29527-communication.pdf.

European Foresight Platform (2010) *System Dynamics*, *Foresight Platform*. Available at: http://www.foresight-platform.eu/community/forlearn/how-to-do-foresight/methods/gaming-simulation-and-models/system-dynamics/.

Faiq, N. (2016) 'Warga Surabaya Rindukan Bus Rapid Transit yang Murah dan Nyaman', *Surya*, 11 December. Available at: https://surabaya.tribunnews.com/2016/12/11/warga-surabaya-rindukan-bus-rapid-transit-yang-murah-dan-nyaman?page=all.

Fiedler, D., Čáp, M. and Čertický, M. (2017) 'Impact of mobility-on-demand on traffic congestion: Simulation-based study', in *IEEE 20th International Conference on Intelligent Transportation Systems (ITSC)*, pp. 1–6.

Forrest, J. (1998) 'System dynamics, alternative futures, and scenarios', in *The 16th International Conference of The System Dynamics Society*. Canada.

Gary, M. *et al*. (2008) 'System dynamics and strategy. System Dynamics Review', *The Journal of the System Dynamics Society*, 24(4), pp. 407–429.

Goh, Y. and Love, P. (2012) 'Methodological application of system dynamics for evaluating traffic safety policy', *Safety science*, 50(7), pp. 1594–1605.

Hale, D. and Courage, K. (2002) 'Prediction of traffic-actuated phase times on arterial streets', *Transportation research record*, 1811(1), pp. 84–91.

Herrero, L. M. J. (2011) 'Transport and mobility: the keys to sustainability', *Lychnos*, 4. Available at: http://www.fgcsic.es/lychnos/en_EN/past_issues/lychnos_04.

Institute for Transportation and Development Policy (2019) *What is BRT?* Available at:

https://www.itdp.org/library/standards-and-guides/the-bus-rapid-transit-standard/what-is-brt/.

Jovic, J. J. (2000) 'Modal Split Modelling - Some Experience', *Engineering*. Available at: https://pdfs.semanticscholar.org/cbee/754a5e2f1f81c855d34b243d8ea8ce70a5ac.pdf?_ga=2.158361085.676696151.1572283838-1062841753.1567971999.

Kaparias, I. and Bell, M. G. H. (2011) *Key Performance Indicators for traffic management and Intelligent Transport Systems Deliverable*. Imperial College London.

Litman, T. (2003) 'Measuring Transportation Traffic, Mobility, and Accessibility', *ITE Journal*, 73(10), pp. 28–32. Available at: https://www.vtpi.org/measure.pdf.

Liu, R. and Sinha, S. (2007) 'Modelling Urban Bus Service and Passenger Reliability', in *In : The Third International Symposium on Transportation Network Reliability*. The Hague: White Rose Research Online.

Macababbbad, R. J. R. M. and Regidor, J. R. F. (2011) 'A Study on Travel Time and Delay Survey and Traffic Data Analysis and Visualization Methodology', in *Proceedings of the Eastern Asia Society for Transportation Studies*. J-Stage.

MacKechnie, C. (2019) 'What Is the Passenger Capacity of Different Modes of Transit?', *Liveabout*, 25 January. Available at: https://www.liveabout.com/passenger-capacity-of-transit-2798765.

MRT Jakarta (2014) *Overcoming Challenges to Build the Mega Project*.

Nugraha, S. (2018) 'Proposal to add two BRT stops (Usulkan Tambah Dua Halte BRT)', *Radar Surabaya*. Available at: https://radarsurabaya.jawapos.com/read/2018/05/19/74825/usulkan-tambah-dua-halte-brt.

Oort, N. Van (2011) *Service reliability and urban public transport design*. Netherlands TRAIL Research School.

Papageorgiou, G. *et al*. (2009) 'Modelling and Simulation of Transportation Systems: a Scenario Planning Approach', *Automatika*, 50(1–2). Available at: https://hrcak.srce.hr/index.php?show=clanak&id_clanak_jezik=59574&lang=en.

Raux, C. (2003) 'A systems dynamics model for the urban travel system', in *European Transport Conference 2003*. Strasbourg. Available at: https://halshs.archives-ouvertes.fr/halshs-00092186.

de Rozari, A. and Wibowo, Y. (2015) 'Factors causing traffic congestion on the main streets of Surabaya City (Faktor-faktor yang menyebabkan kemacetan lalu lintas di jalan utama Kota Surabaya (Studi Kasus Di Jalan Ahmad Yani Dan Raya Darmo Surabaya)).', *JPAP: Jurnal Penelitian Administrasi Publik*, 1(1).

Sa'diyah, H. (2013) 'Here are 9 causes of traffic congestion in Jakarta (Ini 9 penyebab kemacetan di Jakarta)', *Republika*, 19 December. Available at: https://www.republika.co.id/berita/nasional/jabodetabek-nasional/13/12/19/my13jf-ini-9-penyebab-kemacetan-di-jakarta.

Sari, K. D. R. (2015) 'The challenges of implementing BRT in Indonesia for the next 10 years (Tantangan penerapan BRT di Indonesia untuk 10 tahun ke depan)', *Kompasiana*, 30 December. Available at: https://www.kompasiana.com/demography-urbanplanning/568314f570977369048b4568/tantangan-penerapan-brt-di-indonesia-untuk-10-tahun-ke-depan?page=all.

Sari, N. (2016) 'This is the strategy of Ahok-Djarot, Anies-Sandi, and Agus-Sylvi overcoming traffic congestion in Jakarta (Ini strategi Ahok-Djarot, Anies-Sandi, dan Agus-Sylvi atasi kemacetan di

Jakarta)', *Kompas*, 14 October. Available at: https://megapolitan.kompas.com/read/2016/10/14/14054621/ini.strategi.ahok-djarot.anies-sandi.dan.agus-sylvi.atasi.kemacetan.di.jakarta .

Shepherd, S. (2014) 'A review of system dynamics models applied in transportation', *Transportmetrica B: Transport Dynamics*, 2(2), pp. 83–105.

Shigeru, M. and Acharya, S. R. (2013) *Transport Development in Asian Megacities, A new perspective*. Springer.

Sterman, J. D. (2002) *System Dynamics : Systems Thinking and Modelling for A Complex World*. Cambridge. Available at: https://www.researchgate.net/publication/44827001_Business_Dynamics_System_Thinking_and_Modeling_for_a_Complex_World.

Suryani, E. (2011) 'Dynamic Simulation Model of Demand Forecasting and Capacity Planning', in *Proceedings of the Annual Meeting of Science and Technology Studies (AMSTECS'11).* Tokyo. Available at: https://pdfs.semanticscholar.org/f852/21efab2e44922674bef75dea0f0f0a943b88.pdf.

Suryani, E., Chou, S. and Chen, C. (2010) 'Air passenger demand forecasting and passenger terminal capacity expansion: A system dynamics framework', *Expert Systems with Applications*, 37(3), pp. 2324–2339.

Suryani, E., Chou, S. and Chen, C. (2012) 'Dynamic simulation model of air cargo demand forecast and terminal capacity planning', *Simulation Modelling Practice and Theory*, 28, pp. 27–41.

Torres, J., Kunc, M. and O'Brien, F. (2017) 'Supporting strategy using system dynamics', *European Journal of Operational Research*, 260(3), pp. 1081–1094.

Utomo, M. S. (2011) *Kebutuhan Transportasi Publik di Surabaya*, *Yayasan Lembaga Perlindungan Konsumen*. Available at: http://ylpkjatim.or.id/kebutuhan-transportasi-publik-di-kota-surabaya/ (Accessed: 19 August 2019).

Vensim Inc. (2015) *How does Vensim compare to other system dynamics software?*, *Vensim Inc*. Available at: https://vensim.com/faqs/how-does-vensim-compare-to-other-system-dynamics-software/ (Accessed: 4 February 2019).

Wang, J., Lu, H. and Peng, H. (2008) 'System Dynamics Model of Urban Transportation System and Its Application', *Journal of Transportation Systems Engineering and Information Technology*, 8(3), pp. 83–89.

Zainuddin (2015) 'Kemacetan Surabaya Masuk Empat Besar Dunia', *Surya*, 6 February. Available at: https://surabaya.tribunnews.com/2015/02/06/kemacetan-surabaya-masuk-empat-besar-dunia.

Appendix

Formulations and comments	Units	No.
Population (t) = $2.6e+006+\int_{t0}^{t} \textbf{\textit{Population Growth}}\ (t)dt$	People	(1)
Public Transportation Fulfillment Ratio (t) = $\frac{\textbf{Public Transportation Supply (t)}}{\textbf{Public Transportation Demand (t)}}$	Percent	(2)
Reliability (t) = $\frac{1}{5} * (\textbf{Headway Reliability}(t) + \textbf{Passenger Wait Time Reliability}(t) + \textbf{Travel Time Reliability}(t) + \textbf{Access Time Reliability}(t) + \textbf{Egress T. Reliability}(t))$	Percent	(3)
Headway Reliability (t) = $\frac{\textbf{Std of Headway (t)}}{\textbf{Avg Headway (t)}}$	Percent	(4)
Travel Time Reliability (t) = $\frac{\textbf{Std deviation of Travel Time (t)}}{\textbf{Avg Travel Time (t)}}$	Percent	(5)
Waiting Time Reliability (t) = $\frac{\textbf{Average Scheduled Wait Time (t)}}{\textbf{Avg Actual Wait Time (t)}}$	Percent	(6)
Access Time Reliability(t) = $\frac{\textbf{Avg Access Time (t)}}{\textbf{Std of Access Time (t)}}$	Percent	(7)
Egress Time Reliability (t) = $\frac{\textbf{Avg Egress Time (t)}}{\textbf{Std Egress Time (t)}}$	Percent	(8)
Average Headway Lyn (Base) (t) = 15.43 + $\int_{t0}^{t} \textbf{Headway Inrease (Lyn) (t) dt}$	Minutes	(9)
Average Headway Bus (Base) (t) = 30 + $\int_{t0}^{t} \textbf{Headway Inrease (Bus) (t) dt}$	Minutes	(10)
Average Wait Time Lyn (Base) (t) = $5.36 + \int_{t0}^{t} \textbf{Wait Time Increase (Lyn) (t) dt}$	Minutes	(11)
Avg. Access Time Lyn (Base) (t) = 15 $- \int_{t0}^{t} \textbf{Access Time Decrease (Lyn) (t)dt}$	Minutes	(12)
Average Access Time Bus (t) = RANDOM NORMAL(Min Access Time Bus, Max Access Time Bus, Mean Access Time Bus, Std. Deviation Access Time Bus, 0)	Minutes	(13)
Congestion (t) = $\frac{\textbf{Daily Traffic (t)}}{\textbf{Road Capacity (t)}} * \textbf{100}$	Percent	(14)
Daily Traffic = (Daily Traffic Base (t)+ (Daily Traffic Base (t) * (100 – $\frac{\textbf{Impact of Mobility Factors to Congestion (t)}}{\textbf{100}}$)) * **Daily Traffic Weight**	Vehicles	(15)
Error Rate = $\frac{[\bar{S} - \bar{A}]}{\bar{A}}$	Percent	(16)
Error Variance = $\frac{[\textbf{Ss} - \textbf{Sa}]}{\textbf{Sa}}$	Percent	(17)

Change to MRT (Base) (t) = 27 + $\int_{t0}^{t} \textbf{MRT Inc (t) dt}$	Percent	(18)
Change to BRT (Base) (t) = 5 + $\int_{t0}^{t} \textbf{BRT Inc (t) dt}$	Percent	(19)
SBY Private/shared Transportation Percentage SCN (t) = (SBY Motorcycle Percentage (t) + SBY Private Car Percentage (t)) - ((SBY Motorcycle Percentage (t)+ SBY Private Car Percentage (t)) * $\frac{\textbf{Change to MRT SCN (t)}}{\textbf{100}}$) - ((SBY Motorcycle Percentage (t) + SBY Private Car Percentage (t)) * $\frac{\textbf{Change to BRT SCN(t)}}{\textbf{100}}$)	Percent	(20)
Delay Performance (SCN) (t) = $\frac{\textbf{Standard Max Delay (t)}}{\textbf{Lyn Travel Time Delay (t)}} * \mathbf{100}$	Percent	(21)
Congestion SCN (Mobility) (t) = ($\frac{\textbf{Average Daily Traffic(SMP)Surabaya(t)}}{\textbf{Road Capacity based on Vehicle 2014 (t)}} * \mathbf{100}$ **- ((**$\frac{\textbf{Average Daily Traffic(SMP)Surabaya(t)}}{\textbf{Road Capacity based on Vehicle 2014(t)}}$) * **Impact of Mobility Factors to Congestion (t)**)	Percent	(22)
Average Daily Traffic (ADT) Surabaya Rate = 0.045	Dmnl	(23)
Avg Actual Wait Time (t) = $\frac{\textbf{(Avg Wait Time Bus (t) + Avg Wait Time Lyn (t))}}{\textbf{2}}$	Minutes	(24)
Avg Egress Time = 1	Minute	(25)
Avg Headway (t) = $\frac{\textbf{Avg Headway Bus (t)+ Avg Headway Lyn(t)}}{\textbf{2}}$	Minutes	(26)
Avg Travel Time (t) = $\frac{\textbf{(Lyn BM Travel Time (t)+ Lyn N Travel Time (t)+ Lyn T2 Travel Time (t))}}{\textbf{3}}$	Minutes	(27)
Avg Wait Time Bus (t) = RANDOM NORMAL (Min Wait Bus, Max Wait Bus, Avg Wait Bus, Std Wait Bus, 0)	Minutes	(28)
Avg Wait Time Lyn (t) = RANDOM UNIFORM (Avg Wait Time Lyn (Base) (t) * 0.95, Avg Wait Time Lyn (Base) (t) * 1.05, 0)	Minutes	(29)
BRT Inc (t) = Change to BRT (Base) (t) * BRT Rate (t)	Percent	(30)
BRT Rate = 0.02	Dmnl	(31)
Headway Increase (Bus) (t) = Avg Headway Bus (Base) (t) * Headway Bus Rate (t)	Minutes	(32)
Headway Increase (Lyn) (t)= Avg Headway Lyn (Base) (t)* Headway Lyn Rate (t)	Minutes	(33)
Headway Lyn Rate = 0.0273	Dmnl	(34)
Lyn ‘BM’ Travel Time (t) = RANDOM UNIFORM (63, 67, 0)	Minutes	(35)
Lyn ‘N’ Travel Time (t) = RANDOM UNIFORM (38, 42, 0)	Minutes	(36)
Lyn ‘T2’ Travel Time (t) = RANDOM UNIFORM (50, 54, 0)	Minutes	(37)
Lyn Travel Time Delay (t) = RANDOM NORMAL (Min Lyn Delay, Max Lyn Delay, Mean Lyn Delay, Std Lyn Delay, 0)	Minutes	(38)
Max Lyn Delay (t) = 30 - (30 * $\frac{\textbf{PT delay Reduction (t)}}{\textbf{100}}$)	Minutes	(39)

Max Road V/C Ratio = 1.13	Dmnl	(40)
Max Wait Time Bus = 21.21	Minutes	(41)
Mean Lyn Delay (t) = 20 - (20 * ($\frac{\textbf{PT delay Reduction (t)}}{\textbf{100}}$)	Minutes	(42)
Min Access Time Bus= 86.4	Minutes	(43)
Min Lyn Delay (t) = 15 - (15 * $\frac{\textbf{PT delay Reduction (t)}}{\textbf{100}}$)	Minutes	(44)
Min Road V/C Ratio = 0.5	Dmnl	(45)
Min Wait Bus = 20.78	Minutes	(46)
Mobility Factors (SCN) (t) = SBY Public Transportation Percentage (t) + ($\frac{\textbf{PT Mobility Performance (t)+ Reliability effect(t)}}{\textbf{2}}$)	Percent	(47)
MRT Inc (t) = Change to MRT (Base) (t) * MRT Rate (t)	Percent	(48)
MRT Rate = 0.015	Dmnl	(49)
Reliability (t)= $\frac{1}{5}*$ (Headway Reliability (t) + Passenger Wait Time Reliability (t) + Travel Time Reliability (t) + Access Time Reliability (t) + Egress Time (t))	Percent	(50)
Modal Split = 100 - (‘SBY Private/shared Transportation Percentage (T)’ + ‘SBY Non-Passenger Percentage (t)’)	Percent	(51)
Trip Frequency Percentage (Round Trip) (t) = ($\frac{\textbf{Average Round Trip Freq (t)}}{\textbf{Optimum Frequency (t)}}$) * 100	Percent	(52)

Urban Mobility Modeling to Reduce Traffic Congestion in Surabaya: A System Dynamics Framework

ORIGINALITY REPORT

10%	5%	7%	3%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

MATCH ALL SOURCES (ONLY SELECTED SOURCE PRINTED)

4%

★ www.ijsimm.com

Internet Source

Exclude quotes	On	Exclude matches	< 1%
Exclude bibliography	On		