

Modeling the relationship between public transportation and traffic conditions in urban areas : a system dynamics approach

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Abstract. The goals of the paper were to describe were and find the relations between numbers of available public transportation and traffic congestion and other variables that can reduce traffic congestion in Jakarta. The data that used in the simulation were provided by DKI Jakarta Provincial Statistics Agency from view years ago. To analyze the problem, System Dynamics are used to simulate the condition in the future using the models created based on relations between several variables. The results of the analysis shows that numbers of available public transportation cannot reduce traffic congestion if the numbers of private transportation weren't decreased. It can be concluded that government must force their citizen to reduce the number of private transportation by increasing the inflation supported by increasing numbers of available public transportation to accommodate deficit in transportation while building new roads to accommodate transportation growth in the future.

1. Introduction

Jakarta as the capital of Indonesia is a city with high number of population. Also with urbanization which is so popular in rural areas in Indonesia. Most rural citizen wants to go to Jakarta to find better jobs and improve their lifestyle. Because of that, transportation is a vital point in Jakarta. Most people use private transportation like motorcycle or car for faster time in moving between places. Other than private transportation, there is public transportation available like buses and trains. Many people also use public transportation for moving between places because of many people coming from cities around Jakarta the public transportations can't cope up with the increased number of customer. Because of the factor above the traffic congestion in Jakarta is getting worse every day. The growth for private transportation in Jakarta from 2011 until 2013 was about 20.42% while the total length of the road only increased by 0.14% at the same time. [1]

The problem not only lies on the number of vehicles in Jakarta. The population count also increased every year which means the working force in Jakarta will increased every year which contributes to the increased numbers of commuter. With the average percentage of working force is about 54% with the total population is about 9 million people based on the data from 2009 until 2012. [1]

It can be expected that if the numbers of commuter in Jakarta keep using private transportation there will be a deadlock in Jakarta traffic in the future. If we look closely on the statistic of public transportation, we can see that the adoption of public transportation in Jakarta wasn't so bad. The



adoption of Bus Rapid Transit in Jakarta has been increasing steadily from 2009 until 2012 with about 364 million commuters using this type of public transportation in 2012. [2]

If the government can make the people that use private transportation to switch to public transportation it can be expected that traffic congestion in Jakarta can be reduced. The public transportation can hold a lot more people than private transportation which means reduced numbers of vehicles in urban area.

Literature Review

Systems archetypes seek to represent and classify the structure and behavior of systems, in particular, against intuitive behavior [7]. In other words, system archetypes describe the patterns of behavior that commonly occur in systems. When used as a diagnostic tool, system archetypes provide deeper insight into the underlying structure from which system behavior and events occur. On the other hand, the system archetype can be used as a prospective tool to highlight unexpected consequences in the future [8] [9]. Transportation policy formulation can be broadly classified into three categories, namely, strategic, tactical and operational issues. To improve the simulation and analysis of congestion control system policies, we categorize the problem of public transportation policy formulation into a socioeconomic- environmental problem (S2E).

The results of the simulation carried out were analyzed qualitatively. Variables in system dynamics are grouped into two types, namely level or stock and rate. The level states the system status at any time from the status of the system variable. Levels are the result of accumulation in the system, while the rate at which the system expresses activity. Level is the amount that accumulates over time and the rate is the activity or movement or flow that contributes to the change in level per unit unit of time. Each variable will be defined in an equation which is a level equation and aids equation or a constant expression. Based on the above grouping, the factors in the sub-system are grouped into variables with the following types of variables :

1. The level is the population, the length of the road. Availability of public transportation.
2. Rate: birth, death.
3. Assist: level of population density, road segment ratio, road building, increment of road segments, added regulations on public transportation, domestic consumption, behavior frugal, disciplined behavior.
4. Constants: crude birth rate, crude death rate, area, road availability, road infiltration power, increase in the level of government road management, pollution levels, per capita consumption, rate of increase in domestic consumption, rate of increase in non-domestic consumption.

Stages of the construction of the model is done as follows:

1. Developing the concept in a model of CLD.
2. Develop SFD model or flow charts.
3. Input data.
4. Simulation of a timing diagram and table time.
5. Model Validation.
6. Policy Analysis (Sensitivity Test).

Furthermore, in chart form, the steps above can be presented as Figure 1.

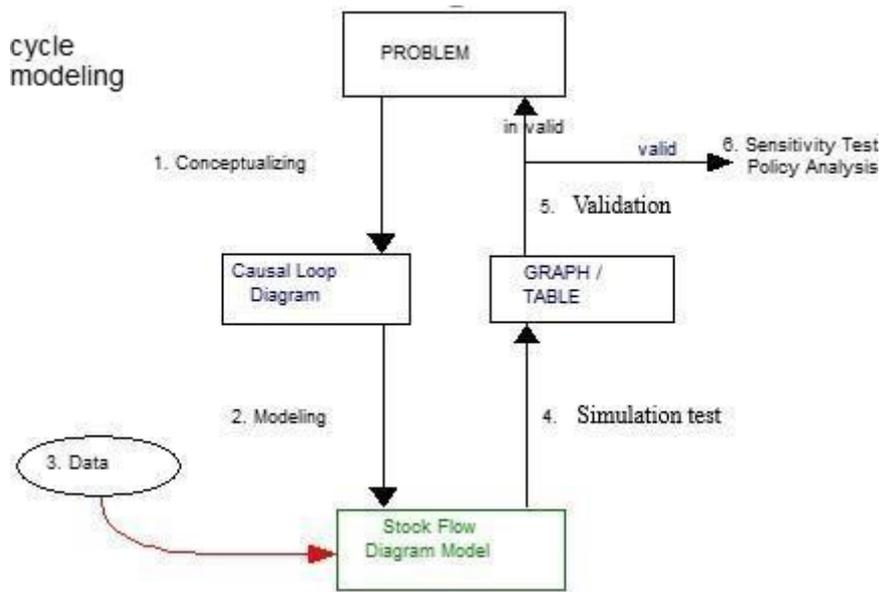


Figure 1. System Dynamics Cycle Model

2. Methodology

System dynamics is a method to learn about the world around us. In system dynamics we used different approach to solve the problem. While in other research people usually try to breakdown the problem into small parts, system dynamics solve the problem by seeing the big picture of the problem. The main concept of system dynamics is understanding how objects in a system interacts with each others. [3] System dynamics simulate the world by using the causality relationship between variables and mathematical equations. This relationship requires variables to create a closed loops. [4] In other words, the variables used in system dynamics can be divided into 3 types:

1. Level variable which shows the changes continuously
2. Rate variable which shows the changes in certain times
3. Auxiliary variable which influence rate variable

To use system dynamics, we need to create a model which consists of Causal Loop Diagram that used to describe the hypothesis about basic mechanism from causality relationship that happen inside the system in certain times [5] and Stock Flow Diagram which describe the causality relationship in the model that will be used in the simulation. Figure 2

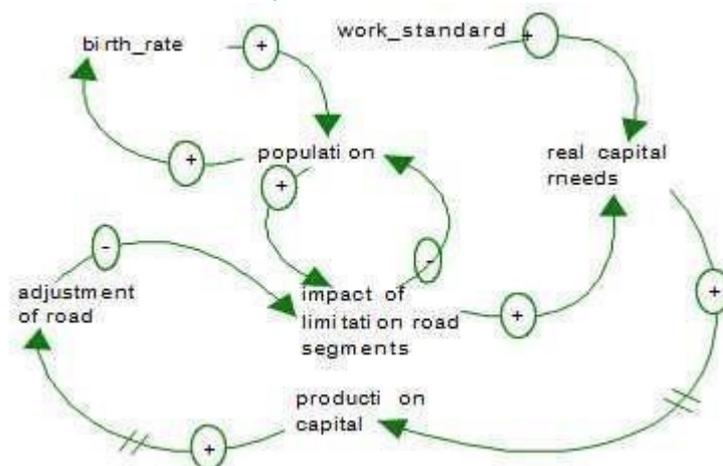


Figure 2. Causal Loop Diagram

To simulate the model, author used several data released by DKI Jakarta Provincial Statistics Agency such as population, public transportation (buses), gross domestic product, road length and traffic accidents.

Table 1. Population, Birth rate and Death rate

Year	Population	Birth	Death
2009	8,523,157	1.61%	0.07%
2010	8,524,152	1.74%	0.08%
2011	10,187,595	1.51%	0.07%
2012	9,761,407	1.66%	0.07%
Average		1.63%	0.07%

Table 2. Road length and road length growth

Year	Road length (m)	Growth
2009	7,208,538	-
2010	6,866,040	-4.75%
2011	6,932,294	0.96%
2012	6,955,842	0.34%
Average		-1.15%

Table 3. Gross domestic product, growth and inflation

Year	GDP	Growth	Inflation
2009	82,079,958	-	2.34%
2010	89,414,557	8.94%	6.21%
2011	100,750,977	12.68%	3.97%
2012	111,912,540	11.08%	3.70%
Average		10.90%	4.05%

Table 4. Numbers of public transportation and growth

Year	Public Transportation	Growth
2009	32,403	-
2010	32,387	-3.14%
2011	30,351	-3.30%
2012	28,619	-5.71%
Average		-4.05%

Table 5. Traffic accidents and growth

Year	Traffic accidents	Growth
2009	7,329	-
2010	8,235	12.36%
2011	8,079	-1.89%
2012	8,020	-0.73%
Average		3.25%

By using the Casual Loop Diagram author can develop Stock Flow Diagram that describe more specific model that can be simulated to achieve see changes in the variables used in this research. Figure 3.

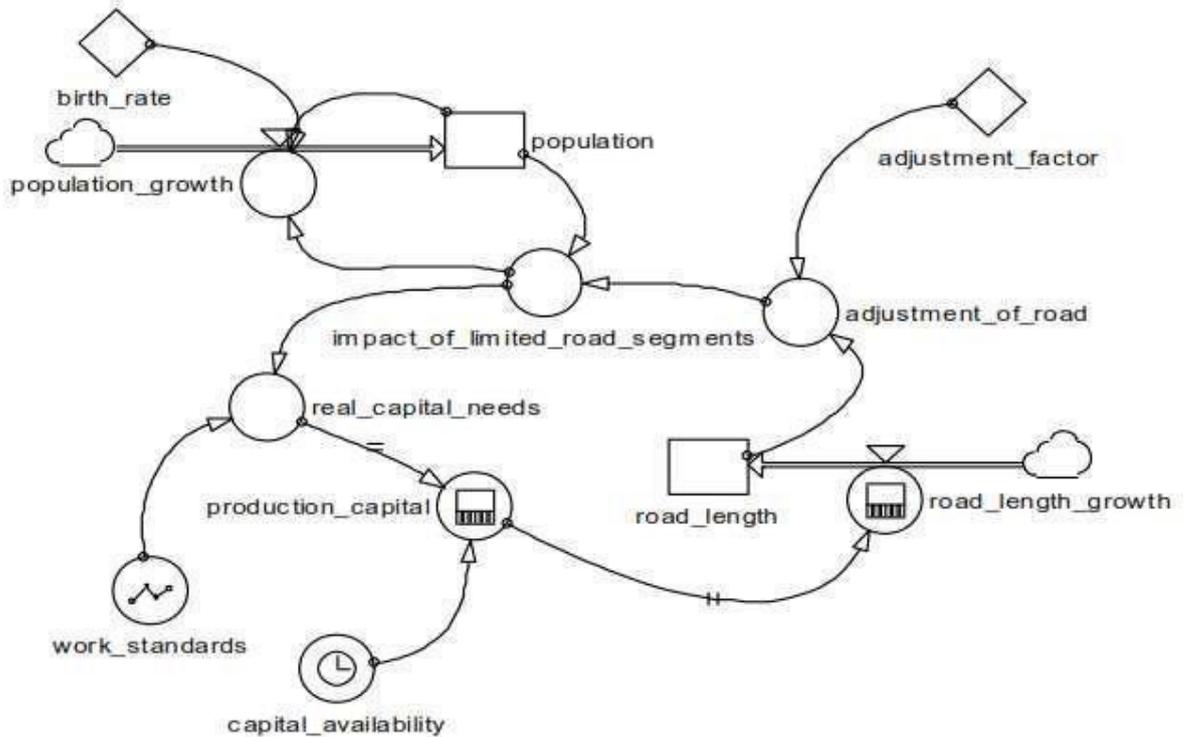


Figure 3. Stock Flow Diagram

To get the results from simulation, author used several mathematical equations to find the changes in each variables. Some of the equation are listed below:

```

init      population = 1000
flow     population = -dt*population_growth
doc      population = Number of population
init     road_length = 1000
flow     road_length = +dt*road_length_growth
doc      road_length = length of road
aux      population_growth = (population-impact_of_limited_road_segments)*birth_rate
doc      population_growth = growth of population
aux     road_length_growth = DELAYINF(production_capital,1,1,0)
doc      road_length_growth = road length enhancement
aux     adjustment_of_road = road_length*adjustment_factor
doc      adjustment_of_road = road adjustment
aux     capital_availability = IF(TIME<120,1,0.1)
doc      capital_availability = Total capital availability
aux     impact_of_limited_road_segments = population-adjustment_of_road
doc      impact_of_limited_road_segments = limited road segmen impact
aux     production_capital = capital_availability*DELAYINF(real_capital_needs,1,1,0)
doc      production_capital = Capital availability for production capital
aux     real_capital_needs = impact_of_limited_road_segments/work_standards
doc      real_capital_needs = capital requirement
aux     work_standards = GRAPHCURVE(TIME,0,20,[10.7,7.6,1.5,4.1,3.3,2.6,1.5,1.1,0.8]"Min:0;Max:10")
doc      work_standards = road utility performance
const   adjustment_factor = 0.9
doc      adjustment_factor = rasio between population and road availability
const   birth_rate = 0.0075
doc      birth_rate = value of birth rate
    
```

The simulation results in graphical form can be seen very clearly, Figure 4.

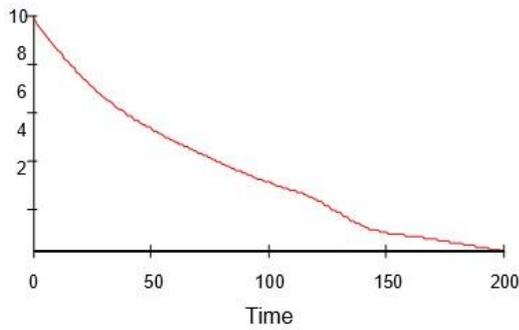


Figure 4. Initial state of average speed

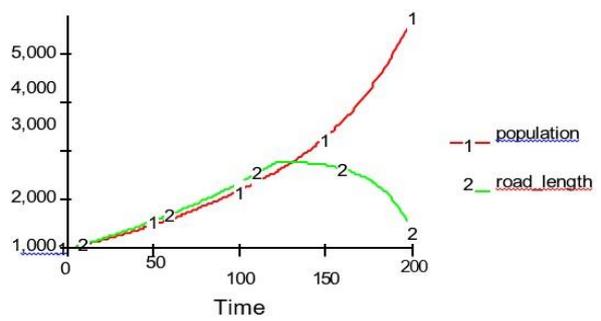


Figure 5. Comparison between population and road space available

The initial state of average speed above indicates that traffic congestion is getting worse in the future. Figure 5.

Initial conditions where the road is still possible to accommodate the needs of the community, but in line with increasing population growth, it is seen that the carrying capacity of the road is no longer possible to accommodate the needs of the community so that inevitable congestion will occur

3. Results

To reduce traffic congestion in the future author wants to find the variable that influence the traffic congestion. Based on previous research, there is several strategies that usually used to reduce traffic congestion in several places. The strategies were:

1. Improve traffic operations
2. Shift urban traffic to public transport
3. Modify existing infrastructure
4. Provide new infrastructure

In this research, after the formulation of the model is formed and the relationship between the population and the availability of carrying capacity of the road can be described, then the simulation test can then be carried out to obtain the ideal results as expected so that optimal sustainable results are achieved. The simulation can be done by increasing the number of public transportation to see whether an increase in public transportation can overcome traffic congestion and change some variables to meet the criteria described in the previous research. The intervention of the model and the addition of new variables is very possible to make the sensitivity of the model in order to achieve a balance until the end can be produced policy analysis related to congestion control in big cities. For example numbers of public transportation after increase of public transportation. Figure 6.

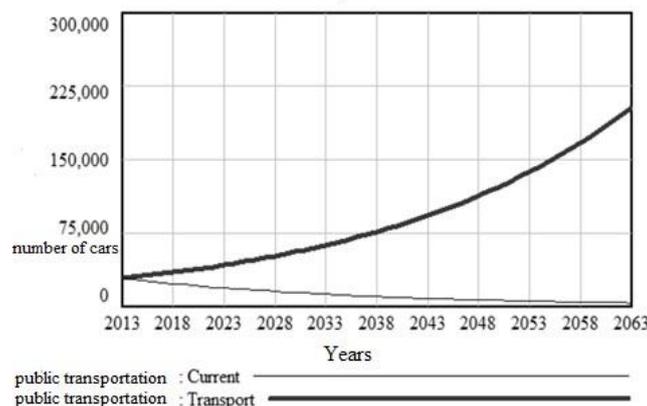


Figure 6. Numbers of public transportation after increase of public transportation

In the first case, author try to increase the growth of public transportation from -4.05% to 4% to see if there is any effect of this massive increase of public transportation to the traffic congestion and other variables. The result after simulation of average speed after increase of public transportation. Figure 7.

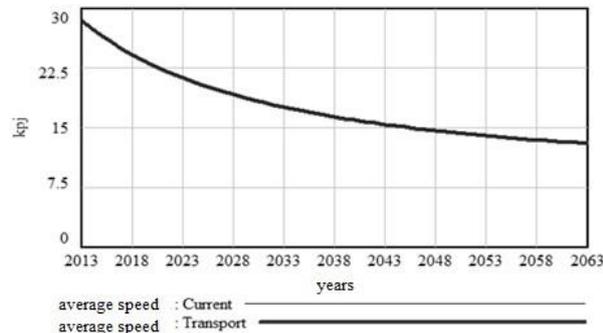


Figure 7. Average speed after increase of public transportation

We can see from figure above that the average speed is not getting better after the increase of public transportation. The average speed even decreased slightly from the results of the initial state. This is happened because even when there is more numbers of available public transportation. The negative growth of road length and the increasing number of private transportation will keep making the traffic congestion worse. Figure 8.

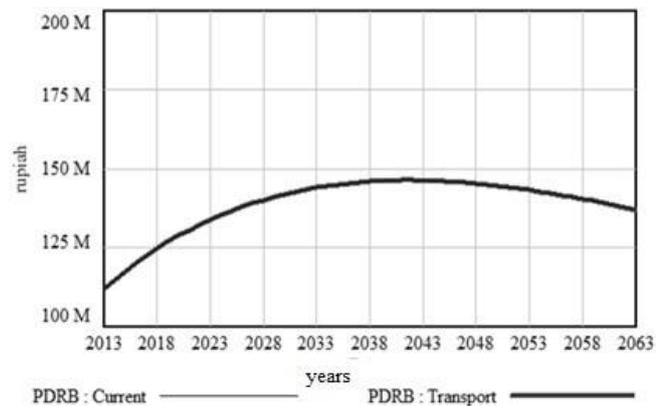


Figure 8. Gross domestic product after increase of public transportation

4. Discussion

The gross domestic product also follows the same trends with the average speed with the increasing traffic congestion in Jakarta, the economic condition of the people will get worse than the initial state. Because the increase of public transportation did not solve the traffic congestion, author trying the second case where there are several variables that changed, such as: inflation from 4.05% to 8%, road length growth from -1.15% to 3% and public transportation growth from -4.05% to 1%.

In this case, author try to simulate what happen if purchasing power of the people in Jakarta is reduced in order to reduce the numbers of private transportation. While doing so, the numbers of public transportation must be increased slightly to accommodate the sudden surge of people that can't afford private transportation anymore. To accommodate if in the future somehow the economic growth of the people in Jakarta are getting better there is an added growth for road length so the traffic congestion won't be a problem anymore.

With the changes in road length growth, we can see that the road length in Jakarta will increased drastically after the changes. This is good because it will accommodate more vehicles that means more private and public transportation that can move around Jakarta without the need to experience traffic congestion. Figure 9.

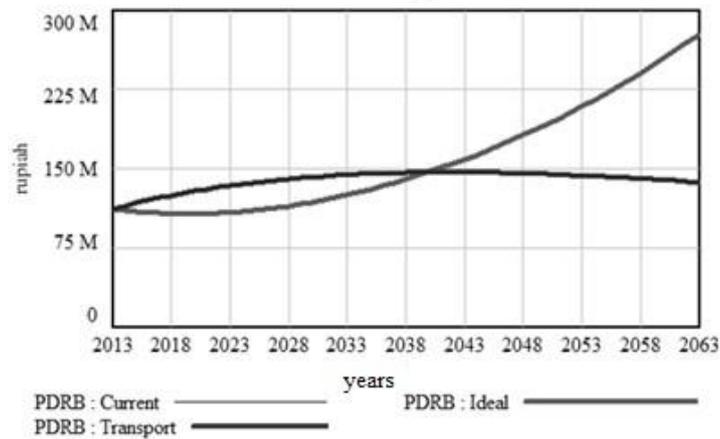


Figure 9. Gross domestic product in ideal condition

However, when the ideal condition is applied there is a sudden drop in gross domestic product that caused by increased in inflation. But after few years, the economic growth will overpower the effect of inflation and after several years, the gross domestic product is far better that the current condition which means that economic growth in Jakarta is getting better. Figure 10

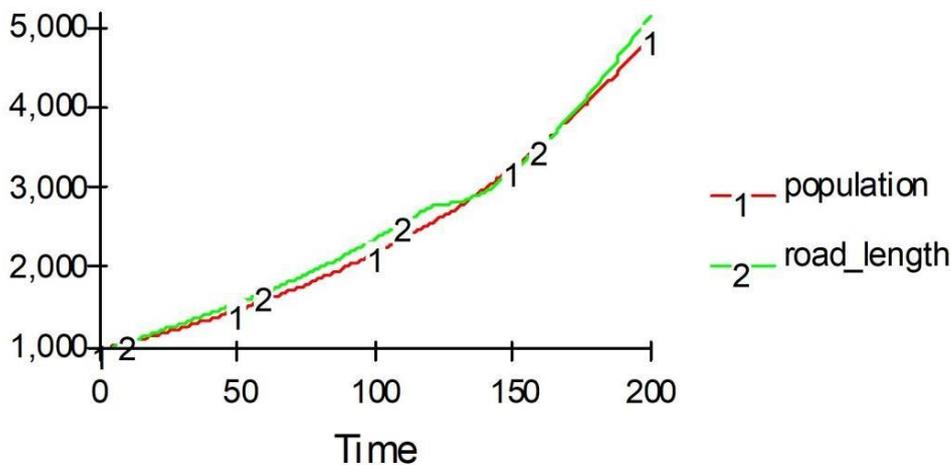


Figure 10. Total road length in ideal condition

Because of the reduced private transportation caused by the high inflation, the average speed in Jakarta increased at the start of the simulation. However, after several years the numbers of private transportation is increasing again, but this time there is already road available to be used for transportation so the average speed doesn't drop at all.

5. Conclusion

Based on the results of simulation, process and assumptions, it can be said that:

1. Community activities in general are one of the factors that increase traffic congestion, although using public transportation will be able to bring more people than private transportation. This is expected to be used to reduce traffic congestion because the number of private transportation is reduced and people choose to use public transportation rather than private transportation, but in reality traffic congestion still occurs.
2. Changes in people's paradigms in working and doing activities in certain offices need to be tried to be able to work and do activities from outside the office by utilizing the concept of the industrial revolution 4.0 and green information technology, so that congestion can be automatically reduced

including decreasing energy needs, pollution and CO₂, and will have a positive impact on the global warming and climate change program.

Acknowledgments

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