Dynamic Model to Increase the Efficiency and Affordability of Transport System

Erma Suryani[1], Rully Agus Hendrawan[2], Philip Faster Eka Adipraja[3], Basuki Widodo[4], Ulfa Emi Rahmawati[5], Ariani Dwi Wulandari[6], Shuo-Yan Chou[7]

{erma.suryani@gmail.com[1], ruhendrawan@gmail.com[2], philipfaster@gmail.com[3], bwdantr@gmail.com[4], ulfaemi@polije.ac.id[5], arianidwiw@gmail.com[6], sychou2@gmail.com[7]}

Institut Teknologi Sepuluh Nopember Surabaya Indonesia[1,2,4,6], Institut Teknologi dan Bisnis Asia Malang Indonesia[3], Politeknik Negeri Jember[5], Department of Industrial Management National Taiwan University of Science and Technology[7]

Abstract. The increasing number of motorized vehicles that exceed the road capacity, as well as the behavior of people who still ignore traffic regulations on the highway, have led to increasingly complex problems in the transportation system. A strategy is needed to improve the efficiency and affordability of the transportation system. The method used to improve the efficiency and affordability of the transportation system is system dynamics. The affordability of the transport system can be increased by introducing prices and priorities. This can be achieved by regulating fuel, road use, and parking prices to promote travel and mode efficiency. This strategy is designed to increase the demand for public transport.

Keywords: affordability, strategy, system dynamics, system thinking, transportation

1 Introduction

The low performance and capacity of transportation infrastructure is one of the most critical barriers hindering Indonesia's competitiveness. The increasing number of motorized vehicles exceeds the capacity of the road, and the behavior of people who still ignore traffic regulations on the highway, causing the complexity of problems in the transportation system. The failure of the transportation system can disrupt regional/city development and affect regional/urban economic efficiency. This raises the potential to create urban poverty because of the transportation system being unable to protect them [1]. Massive traffic congestion slows urban mobility. The delay will have a major impact on the economy and quality of life for the city's residents. The management and development of urban infrastructure is highly dependent on the urban transportation system. Without well-managed urban transport systems, cities will become more dependent on private transport. This will result in traffic congestion, as well as environmental degradation due to excessive traffic emissions and noise.

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Transporting people and goods to their destination is one of the crucial factors in economic growth. The effective transport system may result in lower travel time and its cost [2]. However, in developing countries including Indonesia, the effectiveness of transportation system may not be obtained. Because the mode selection of transport system depends on household budgets and the commuting distance [3]. By statistics, most of Indonesia population are on mid and low income [4] and the average transportation cost is uses more than 30% of their income [5].

Meanwhile, motorcycles have cheap base price, low maintenance requirements, and low operating costs. It makes the affordability of motorcycle higher than public transportation [6]. Due to this, more than 80% of the Indonesian population end up buying motorcycle [7] and most of them using it as a main transport mode. In Indonesia, the growth of private vehicles (especially motorcycle) demand is higher than public transportations. Commonly, the number of private vehicles will rise causing induced traffic or increasing traffic congestion in many of the city roads.

As traffic congestion increases, resulting in travel speed reduction, and increasing fuel consumption and vehicle emissions. Currently, with 40% energy demand, transportation is a sector with the highest energy consumption in Indonesia, followed by industrial sector at 36% [8], [9]. However, Indonesia has experienced a decline in crude oil production over the last 10 years. It is mostly because of the mature oil production wells and scarce new production wells. Therefore, some efforts are required to improve the efficiency of the transport system.

The mode selection of transport system depends on household budgets and the destination distance [3]. Furthermore, the affordability of motorcycle is higher than public transportation [6]. It means that using motorcycle is cheaper than using public transportation, so that the growth of private vehicles (especially motorcycle) demand is higher than public transportation. This will directly affect the volume of road traffic and reduce the efficiency and effectiveness of the transportation system. Currently, with 40% energy demand, transportation is a sector with the highest energy consumption in Indonesia [8], [9].

Transportation plays an important role in the economic and socio-cultural development of a region. The success of the transportation network system can be seen from the aspect of effectiveness related to security, accessibility, integration, sufficient capacity, smooth and fast, on time, comfortable, affordable, and safe. Provision of public transportation that is safe, comfortable, and affordable for the community by the Government is very necessary. Good and ideal interactions between transportation components (passengers, goods, facilities, and infrastructure) will create an effective and efficient transportation system so that it will be able to optimize transportation functions in an urban area.

The time saved by a more efficient transport infrastructure can boost economic growth. This will have an impact on total economic output through increasing access to employment, expanding business opportunities and the efficiency of the movement of goods, and reducing traffic congestion. The cost of transportation in urban areas is quite large, both in the form of private vehicles and rental cars, which will lead to a waste of money in the long run. If there is a city transportation system that is cheap, affordable, and convenient, it will reduce the use of private cars. The cost savings from the transportation sector can be used in other types of investments that have the potential to increase economic growth. Based on the background of these problems, a strategy is required to improve the efficiency and affordability of the transportation system.

One solution to improve the effectiveness and efficiency of the transport system is by reducing the demand for private vehicles. By encouraging people to use public transportation as their main mode, it will reduce traffic congestion. Furthermore, the encouragement of using battery electric vehicles for road transportation may reduce fuel consumption and vehicle emissions. The scientific contribution of this research is to formulate causal relationships between system variables that affect the efficiency and affordability of transport systems to support policy formulation.

2 Literature review

This study draws upon a diverse range of prior research literature to establish its theoretical framework. The methodology employed in this study, as well as the analysis of research findings, is intricately woven with insights gleaned from relevant previous studies.

2.1 The efficiency of transportation system

A safe, efficient, and reliable transportation system in a sustainable environment, and the availability of a network of bus routes at low costs will increase the operational efficiency of the transportation system [10]. The sustainability of the transportation system requires a transportation system that is more efficient, fair, and sensitive to the environment [11]. Livability-centered transport planning can help identify short-term improvements, while creating a long-term vision for revitalizing corridors, neighborhoods and cities that make transportation systems more accessible, efficient, and equitable [12]. Intermodals consists of combining and coordinating the operation of different modes of transport to offer a sustainable service [13]. The efficiency of a city is determined by the effectiveness of its transportation system that shows urban mobility. A poor transportation system will hinder economic growth and development [14].

2.2 The affordibility of transportation system

The affordability of public transportation in Indonesia is the main choice for the community. The pandemic has had an impact on human mobility given the expansion of movement restrictions related to COVID-19. Safer, more efficient, and more inclusive transport services can increase citizen mobility. More attractive public transport will make fewer people use private cars. Meanwhile, better access to safe and efficient transportation will increase the mobility of citizens.

Policy makers need to consider reforming public transport fare policies and demographic factors to increase passenger, service availability, accessibility, and affordability [15]. Affordable transportation is very important, especially for low-income people. An increase in affordability equates to an increase in income. Affordability needs to be evaluated relative to household income or budget. Many experts recommend that households spend less than 20% of their budget on transportation. Affordability tends to increase in more accessible multi-modal environments. The simplification of the fare scheme contributes to increasing travel

demand [16]. Traveling without private motorized vehicles reduces pollution and congestion, requires less land use for road infrastructure, and allows the development of knowledge economy-based centers due to their greater spatial efficiency [17]. The ride-sharing service not only provides a highly personalized mobility experience, but also increases efficiency and sustainability using large-scale vehicles [18].

3 Research method

The method used to increase the efficiency and affordability of the transport system is system thinking. This is because the efficiency and affordability of the transport system is a complex and non-linear system. Furthermore, systems thinking is used because it facilitates causal relationships and interactions between system variables that form feedback. As the initial stage in the system thinking method is problem definition. After the problems have been identified, the second stage is the identification of variables that are significant to the efficiency and affordability of the transport system. In this stage, the process of collecting data, information, and some supporting references is also carried out. Some supporting data, information, and references can be obtained from previous research related to the efficiency and affordability of the transport system. After identifying the significant variables and collecting relevant data and information, the next step is to design dynamic hypotheses. The dynamic hypothesis is described in the form of a causal loop diagram. Causal loop diagram illustrates the causal relationship between system variables that have a significant influence on the efficiency and affordability of the transport system. Each relationship has an arrow that has a positive (+) and negative (-) polarity. A positive relationship shows the same direction (strengthens) the relationship between the variables that cause it. While the negative relationship shows the opposite direction (weakens) the relationship between the variables that cause it. Causal loop diagrams can consist of multiple balancing loops (B) and reinforcing loops (R). Loop balancing describes a balancing relationship, while loop reinforcing shows a mutually reinforcing relationship.

4 Result and discussion

This section describes the research result and discussion of the internal and external variables that affect the efficiency and affordability of transport system based on previous literature studies, the relationship of each variable in the causal loop diagram, the stock and flow diagram of the models, as well as the simulation results.

4.1 Research result

The results of this study include the system boundary which contains a list of internal and external variables that affect the efficiency and affordability of the transport system and a causal loop diagram that describes the causal relationship between system variables.

System Boundary

The system boundary is the boundary of the system structure required to produce attractive behavior. From this system boundary, all system variables can be identified into endogenous and exogenous variables. Endogenous variables are internal variables that are the cause and solution within the system boundary. Exogenous variables are variables outside the system limits that affect or cause system solutions but are not affected by the system. The boundary system of increasing the efficiency and affordability of transport can be seen in **Table 1**. As can be seen from **Table 1**, this system is divided into four subsystems to make it easier to build the causal loop diagram gradually based on the several variables that are significant in increasing the efficiency and affordability of transport system. Boundary system of increasing the efficiency and affordability of transport system.

Table 1. Boundary system of increasing the efficiency and affordibility of transport system.

Sub-system	Endogenous variable	Exogenous variabe	Reference
Affordability of Transport System	Workability of Transport System	Public Transport Demand	[11], [12], [19], [17]
	Private/Share Vehicles Usage	Socio Economic Impact	[20], [14], [21], [18]
	Resource Conservation		[11]
	Efficient Pricing		[11]
	Battery Electric Vehicle		[11]
Transport System Efficiency	Public Transport Hierarchy	Introduce Cashless Payments	[10], [16]
	Resource Conservation	System Integration and Intermodal	[11], [12], [13]
Transport Mobility and Accessibility	Transport System Efficiency	Land Use Accessibility	[11], [12], [22], [10], [23], [24]
	Public Transport Driver's Contract		[17]
Public Transport Demand	Resource Conservation	Efficient Pricing and Prioritization of Transport System	[11]
	Transport Mobility and Accessibility		[12], [24]

Causal Loop Diagram (CLD) to increase the efficiency and affordability of transport system

Figure 1 represents the causal loop diagram (CLD) to increase the efficiency and affordability of transport system. An efficient transportation system creates the movement of people and goods that minimizes time, cost, and energy. The affordability of transportation is an important factor in the economic and social aspects. Transport affordability can be measured by the proportion between the population's income and expenditure on public transportation. As we can see from **Figure 1**, the causal loop diagram of increasing efficiency and affordability of a transport system has two balancing loops (B1 and B2) and two reinforcing loops (R1 and R2). Loop balancing describes a relationship that balances each other, while loop reinforcing shows a mutually reinforcing relationship. Some of these loops can be described as follows:

- *B1 loop*: Workability of Transport System–Private/Share Vehicles Usage–Resource Conservation–Efficient Pricing–Public Transport Demand–Affordability of Transport System–Workability of Transport System
- *B2 loop*: Workability of Transport System–Private/Share Vehicles Usage–System Integration and Intermodal–Transport System Diversity–Public Transport Hierarchy–Transport System Efficiency–Transport Mobility and Accessibility–Public Transport Demand–Affordability of Transport System
- *R1 loop*: Transport Mobility and Accessibility–Transport and Land Use Planning Integration–Directness of Route Coverage–Land Use Accessibility–Transport Mobility and Accessibility
- *R2 loop*: Public Transport Demand–Public Transport Driver's Contract–Transport Mobility and Accessibility–Public Transport Demand

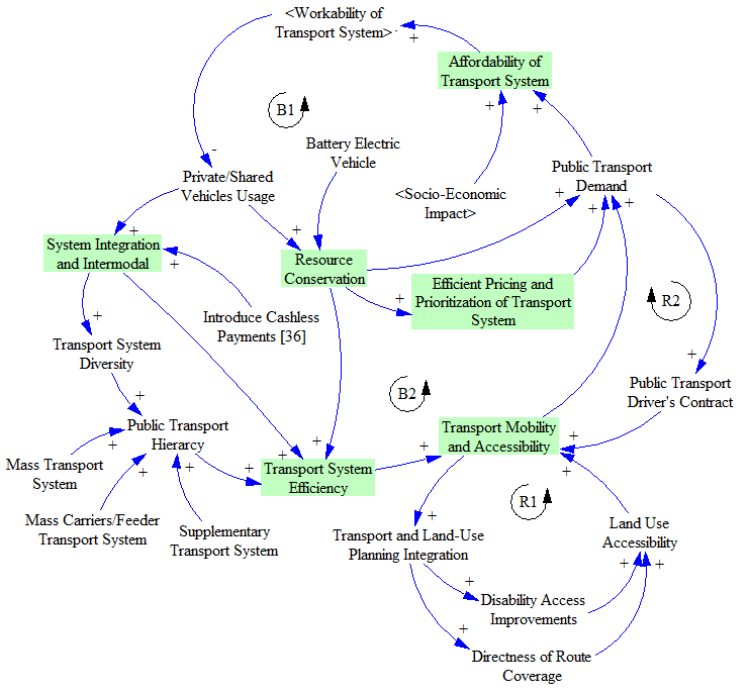

Fig. 1. CLD of increasing the efficiency and affordability of transport system.

Stock and flow diagram of affordability of transport system

The stock and flow diagram (SFD) of affordability of transport system can be seen in **Figure 2**. The affordability of the transport system depends on the average cost per trip, number of trips, and per capita income. The simulation result of the affordability of transport system can be seen in **Figure 3**. The affordability of the transport system tends to increase by an average of 0.18 per year so that in the year 2040, it is projected to reach 96.3%. The SFD of efficiency of transport system can be seen in **Figure 4**. The efficiency of the transport system depends on the labor productivity, public transport hierarchy, energy conservation, cost efficiency, and

vehicle utilization. The simulation result of the efficiency of transport system can be seen in **Figure 5**. The efficiency of the transportation systems is projected to increase from an average of 53% to 55% by 2040. This is due to cost efficiency, labor productivity, and vehicle utilization.

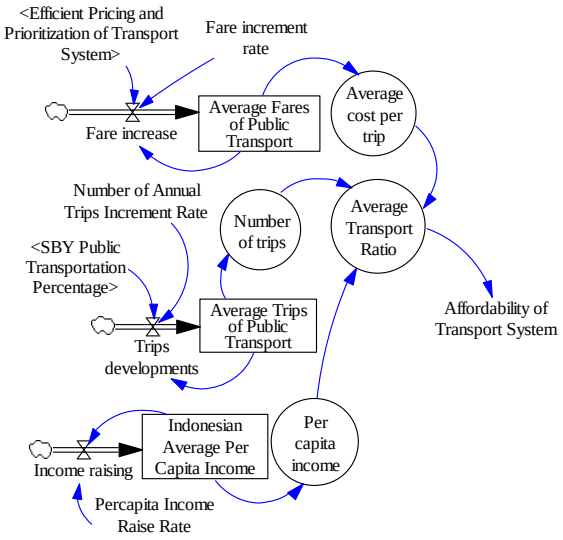

Fig. 2. SFD of Affordability of Transport System.

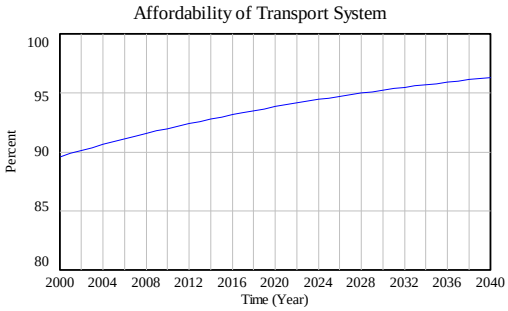

Fig. 3. Simulation result of Affordability of Transport System.

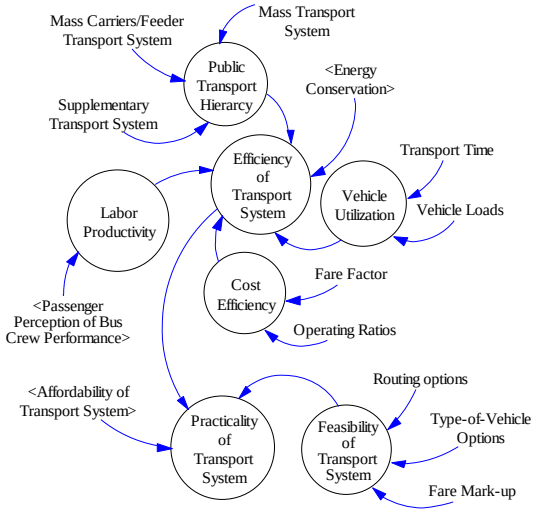

Fig. 4. SFD of Efficiency of Transport System.

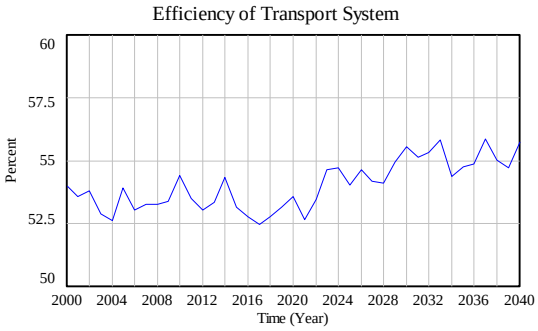

Fig. 5. Simulation result of the Efficiency of Transport System.

4.2 Discussion

Headings, or heads, are organizational devices that guide the A system thinking approach is designed to provide the concept of dynamic model to increase the efficiency and affordability of transport system. Transporting people and goods to their destination is an important factor in economic growth. An effective transportation system can result in faster travel times at a more affordable cost. However, the effectiveness of transportation system in Indonesia is a challenge that needs to be solved.

By using intermodal system integration and resource conservation, it will increase the level of transportation system efficiency. The use of smart cards as non-cash payments for public transportation will make public transport fares more manageable and increase the

attractiveness of payment methods. In addition, the Implementation of system and intermodal integration can be used to facilitate the selection of public transportation modes. Currently, there are various modes, services, and destinations that refer to the diversity of transportation. With the availability of various modes, it is possible for the government to plan a hierarchy of public transportation related to its efficiency and function. For example, to connect two cities, we can use mass transportation systems such as trains with high-capacity and efficient services. Buses can be used as a connector for each sub-district which functions as a feeder for the mass transportation system. Furthermore, in districts, suburbs, or rural areas, lighter vehicles such as light buses can be used as an additional facility. The mobility and accessibility of the transportation system can also be more easily managed with this hierarchy. Meanwhile, improving mobility and accessibility requires integration between transport and land use policies. Increasing its mobility can be achieved by increasing route coverage so that public transport can access more destinations. Meanwhile, increasing accessibility can be achieved by increasing disability access in each destination to increase land accessibility. Mobility and accessibility can affect the demand for public transport. Efficiency of the transportation system can also be achieved by using battery-powered electric vehicles for transportation.

The affordability of the transport system can be increased by introducing prices and priorities. This can be achieved by regulating fuel, road use, and parking prices to promote travel and mode efficiency. This strategy is expected to increase the demand for public transportation.

Previous studies [11], [12], [19], [17], [10], [23], [22], [24] only explained the concept of interrelationships between factors, without conducting simulations, so the impact of several related factors could not be determined clearly. In this study, several strategies generated from the dynamic model have gone through a simulation process so that the simulation results can provide an overview of the impact of the proposed strategy.

5 Further research

The low performance and capacity of transportation infrastructure and the increasing number of motorized vehicles that exceed road capacity have created complex problems in the transportation system. The affordability of using motorbikes is higher than public transportation, so the growth in demand for private vehicles is higher than public transportation. This affects the traffic volume and reduces the efficiency and effectiveness of the transportation system. The energy demand from the transportation sector is quite high, which is around 40% of the total energy consumption in Indonesia and the high cost of transportation in urban areas can result in wastage of costs in the long run. This encourages the design of a transportation system that is cheap, affordable, and convenient, to reduce the use of private cars. The cost savings from the transportation sector can be used in other types of investments that have the potential to increase economic growth. To overcome some of these problems, a strategy is needed to improve the efficiency and affordability of the transportation system. The method used to improve the efficiency and affordability of the transportation system is systems thinking, because the efficiency and affordability of the transportation system is a complex and non-linear system. Systems thinking is used because it facilitates causal relationships and interactions between system variables that form feedback.

The systems thinking approach is a method designed to provide a dynamic model concept in increasing the efficiency and affordability of the transportation system. An effective

transportation system can result in faster travel times at a more affordable cost. By using intermodal system integration and resource conservation, it will increase the efficiency of the transportation system. The use of smart cards as non-cash payments for public transport will make public transport fares more controllable and increase the attractiveness of payment methods. The application of the system and intermodal integration can be used to facilitate the selection of public transportation modes. With the availability of these various modes, it is possible to design a hierarchical plan for public transport related to its efficiency and function. The mobility and accessibility of the transportation system can also be more easily managed with this hierarchy. Improving mobility and accessibility requires integration between transport and land use policies. Increased mobility can be done by increasing the route coverage so that public transport can access more destinations. Improved accessibility can be achieved by increasing disability access in each destination to increase land accessibility. Mobility and accessibility can affect the demand for public transport. Transport system efficiency can also be achieved by using battery-powered electric vehicles for transportation. The affordability of transport systems can be increased by introducing prices and priorities, thus by regulating fuel, road use, and parking prices to promote travel and mode efficiency. This strategy is expected to increase the demand for public transportation. All relationships between system variables are described in the form of causal loop diagrams (CLD).

Further research is required to develop a system dynamics model generated from causal loop diagrams to improve the efficiency and affordability of the transportation system. The system dynamics model is represented in the form of stock and flow diagram (SFD). SFD is a way to represent the structure of a system with more detailed information. SFD can help determine the types of variables that are important in system behavior to improve the efficiency and affordability of the transportation system.

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