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Dynamic scenario to mitigate carbon emissions of transportation system: A system thinking approach

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Abstract

The growth of vehicle use in Indonesia continues to increase, which is in line with the population growth. The increase in the number of vehicles, mostly using fossil fuels, has an impact on increasing pollution. Transportation is the biggest contributor to pollution. Therefore, it is necessary to increase the livability of the transportation system by reducing air pollution through the quality improvement of public transport. The research method used is a system thinking approach. The result of this study is the creation of a causal loop diagram that can be used as an input in mitigating carbon emissions.

Keywords: Air pollution; Air quality; carbon emissions; decision support; livability; system dynamics; transportation system

1. Introduction

Transportation plays an important role in the economic and social development of society. Transport provides access to employment, housing, service, and recreation centers, and opens up remote and rural areas [1]. The level of livability in transportation is about using the quality, location, and types of transportation facilities and services

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available to help achieve community goals. This includes addressing road safety and capacity issues through better planning and design, maximizing, and extending new technologies such as intelligent transportation systems (ITS) and quiet sidewalks, and using travel demand management (TDM) in system planning and operation. It also includes the development of high-quality public transportation to promote economic development that offers residents and workers a full range of transportation options [2].

The growth of vehicle use in Indonesia continues to increase, which is in line with the population growth. In 2017, *Badan Pusat Statistik* reported that there were at least 138 million vehicles in Indonesia: around 113 million (82%) were motorbikes and around 11% of which were cars [3]. The increase in the number of vehicles that mostly use fossil fuels will certainly have an impact on increasing pollution [4]. Transportation is the biggest contributor to pollution in Indonesia. The type of transportation used is directly influenced by the location in the urban center. In urban areas, there has been an increase in the frequency of public transport and an increase in cycling, while the suburban population is still dependent on cars and long trips to access workplace. Reducing the number of vehicles will improve environmental health [5]. Efficient and sustainable transportation with less congestion and emission levels enabling economic growth is prerequisite for sustaining a country's prosperity [6]. Livability is the impact of sustainability that directly affects city community, such as affordability, public health, social justice, economic development, and exposure to pollution [7]. Public transport is, therefore, an important component of the overall transportation approach.

System thinking is a causal approach to describe the reciprocal relationship between variables and the system. System dynamics quantifies the impact of interactions between variables and the system. The reason for using the thinking system is that system thinking is required as an initial study in the form of a concept to deal with complexity of carbon emissions mitigation that supports the livability of transportation system. Causal loop diagram (CLD) as a result of system thinking is the initial stage in the development of a system dynamics model, so that the CLD is the basic building block in developing a system dynamics model.

From the aforementioned problems and the previous research, it is necessary to increase the livability of transportation system that can be done by reducing air pollution through improving the quality of the transportation system that promotes the use of public transportation and improves safety, security, and reduces the level of accidents through the vehicle control system and safety. A strong causal relationship works between trust and the dynamics of variables over time. The relationship is mutually influential; beliefs determine behavior and behaviors reinforce as well as change beliefs [8]. System thinking is a method that can be used to represent strong causal relationships. This study presents a system thinking approach to understand the real conditions of transportation system livability. The result obtained from this research is a Causal Loop Diagram (CLD) which can be used as a scenario to mitigate carbon emissions of transportation system. This CLD was developed as generic as possible so that it can be applied in all cities in the world. This paper is organized as follows. Section 1 provides an introduction. Section 2 provides a literature review of the related studies. Section 3 describes the research methodology. Section 4 presents the results in a causal loop diagram. And finally, Section 5 explains the conclusion.

2. Literature review

2.1. The livability of the transportation system

The level of livability in transportation is about using the quality, location, and types of transportation facilities and services available to help achieve community goals [2]. The livable community concept is based on the principle of sustainable development which focuses on patterns of economic activity that result in environmental quality, economic welfare, and social justice. The livability initiative goes a step further by providing tools and resources to encourage communities to collaborate on finding new ways of managing land use, transportation, and other resources to ensure high quality of life and strong and sustainable economic growth. In this case, it is necessary to underline the importance of intermodalism to achieve high quality transportation services. The construction of intermodal facilities (physical integration) is only one intermodal component. Institutions, connectivity, and efficient fare systems must be developed if the transit system is to be improved. On the other hand, location is an indispensable factor to consider in designing intermodal assets [9].

Several elements affect the livability of the transportation system, namely: reliable and legible information, travel and waiting times, the existence of facilities, and a sense of safety and security. Other factors such as priority of pedestrian flow, intensive use of travelators, and aspects related to sustainability must also be considered [9].

2.2. Carbon emissions from the transportation system

The increasing number of vehicles that mostly use fossil fuels has an impact on increasing pollution [4]. Transportation is the biggest contributor to pollution. Traffic congestion problems arise when levels of air pollution increase due to increased traffic volume and road expansion [10]. Air quality is a health risk. Heavy metal levels (Pb, Cr, Ni, Cd, and V), NOx, and SO2 released from motor vehicle exhaust along the road are relatively high [11]. In addition, road expansion causes particulate matter emission which negatively impacts the respiratory tract [10]. Closing roads to private traffic, renewing bus fleets, and reorganizing public transport significantly benefits air quality for air pollution reduction [12].

2.3. System dynamics

The system dynamics is a problem analysis method where time is an important factor and includes understanding how a system can be maintained from disturbances outside the system or made according to the objectives of the system modeling [13]. The system dynamics is a field for understanding how things change over time. This system is formed by differential equations used for biophysical problems which are formulated as future conditions depending on the present situation [14]. The system dynamics is a method for solving a problem from a complex system, which allows us to see the dynamic interactions between the factors that exist in the system. There are five steps in developing system dynamics model [15] including: 1) articulation problem, 2) dynamic hypothesis, 3) model formulation, 4) testing, and 5) policy formulation and evaluation. System thinking is a causal approach to describe the reciprocal relationship between variables and the system. System dynamics quantifies the impact of interactions between variables and the system. The reason for using the thinking system is that system thinking is required as an initial study in the form of a concept to deal with complexity of carbon emissions mitigation that supports the livability of transportation system.

3. Research methodology

This study uses system thinking approach since it deals with complex system in mitigating carbon emissions of transportation systems. In addition, all components have a relationship or interaction with one another, since it is based on a loop or feedback process on a part of the system [15][16].

The first stage is problem articulation, in which a problem will be determined to be used as a research topic. Then, each variable of the problem is analysed and identified. Data and information collection are also carried out at this stage. In this case, data are obtained through literature studies from relevant sources such as credible journals or papers, government agencies such as the *Badan Pusat Statistik*, and several reliable sources such as website articles and mass media.

The next stage is the dynamic hypothesis. At this stage, the modelling begins by forming a causal loop diagram. The causal loop diagram contains the linkages between each predefined variable to form a feedback cycle. Each relationship describes the causality between these variables. Each relationship also has a polarity of both positive (+) and negative (-) to describe how the relationship between these variables affects each other. In addition, feedback in the causal loop diagram has two types, namely the reinforcing loop which describes the reinforcement of a cycle, and the balancing loop which describes the stability of a cycle.

4. Discussion and research result

This section describes the discussion and research results of internal and external factors that affect the transportation system based on previous literature studies, as well as the relationship of each variable in the causal loop diagram.

4.1. Discussion

This system thinking approach is designed to provide the concept of dynamic scenario to mitigate carbon emissions. Transportation is one of the sources of air pollution. Higher levels of air pollution are generally found in large developing cities. Generally, private vehicles or shared vehicles are the largest contributor to air pollution because they are more numerous than public and non-passenger vehicles. This is because the need for public transportation is lower than owning and using private vehicles. To reduce air pollution, the scenario concept that can be developed is to increase the use of public transportation by increasing perceptions, convenience, security, healthy transportation, affordability, diversity, price, priority, mobility, and accessibility. Land use accessibility, system integration, and intermodal can improve the accessibility and convenience of using public transportation, thereby reducing the use of private transportation, and ultimately reducing the carbon emissions of the transportation system.

4.2. Research result

The results of literature studies from articles in journals or papers, government agencies such as the Badan Pusat Statistik, as well as websites and mass media obtained internal and external factors that influence the transportation system. The following is the projection of the results of this study:

4.2.1. Boundary adequacy

Internal and external factors, both influencing variables and supporting variables that influence each other in developing the conceptual model of the carbon emission of transportation system, are listed in boundary adequacy as seen in Table 1. This model is divided into four submodels to make it easier to build a model gradually based on several variables that are significant in determining carbon emissions of transportation system and to build scenario model to mitigate carbon emissions.

Table 1. Boundary adequacy of reducing carbon emissions.

Sub Model	Endogenous	Exogenous	Reference
Vehicle emission	• Vehicle emission reducing technology • Public transportation emission • Private/shared vehicle emission • Non-passenger vehicles emission • Euro emission standard	• Population	[10], [2]
Private/shared vehicle usage	• High quality public transportation	• Public transportation demand	[2], [17]
Public transportation demand	• Private/shared vehicle usage • High quality public transportation		[2]
High quality public transportation	• Public transportation safety • Healthy public transportation • Affordability • Transport system diversity • System integration & intermodal • Efficient pricing & prioritization • Land use accessibility (smart growth) • Public transportation comfort	• Resource conservation • Transport mobility & accessibility • Public transportation perception	[2], [7], [17], [8], [18], [9], [19], [12]

4.2.2. CLD to reduce carbon emissions

Fig. 1 presents a general structure for reducing carbon emissions. Air pollution is a factor that has a significant effect on health risks [20]. Meanwhile, one of the sources of air pollution is transportation [10]. Public transportation emission, private/shared vehicles emission, non-passenger vehicles emission are some variables which are decision variables that affect vehicles emission and pollution. High quality public transportation, public transport demand, and vehicle's emission reducing technology are scenario variables that can mitigate the carbon emissions of transportation system.

Higher levels of air pollution are generally found in large developing cities. This air pollution comes from the burning of solid fuels, the lack of diesel emissions in the city, the use of coal in the surrounding rural areas for heating and household cooking, as well as high oxidizing power due to complex chemistry [21], [22], [23], [24], [25]. Generally, private, or shared vehicles are the biggest contributor to air pollution because they are more numerous than public and non-passenger vehicles [4]. This is because the need for public transport is lower than owning and using a private vehicle. There are many factors that influence the demand for public transport including perception, comfort, safety, healthy transportation, affordability, diversity, price, priority, mobility, and accessibility [2], [7], [8], [9], [12], [17], [18], [19]. In addition, accessibility of land use, system integration, and between modes can improve accessibility and convenience of using public transportation.

Indonesia is a developing country that may have a high level of pollution in its big cities due to the transportation system [4]. Currently, because the highest vehicle emission standard in Indonesia is only EURO 2, the reduction in pollution may not be effective, leading to reduced convenience of using public transportation [7], [12], [17]. Thus, it can indirectly affect the demand for public transport.

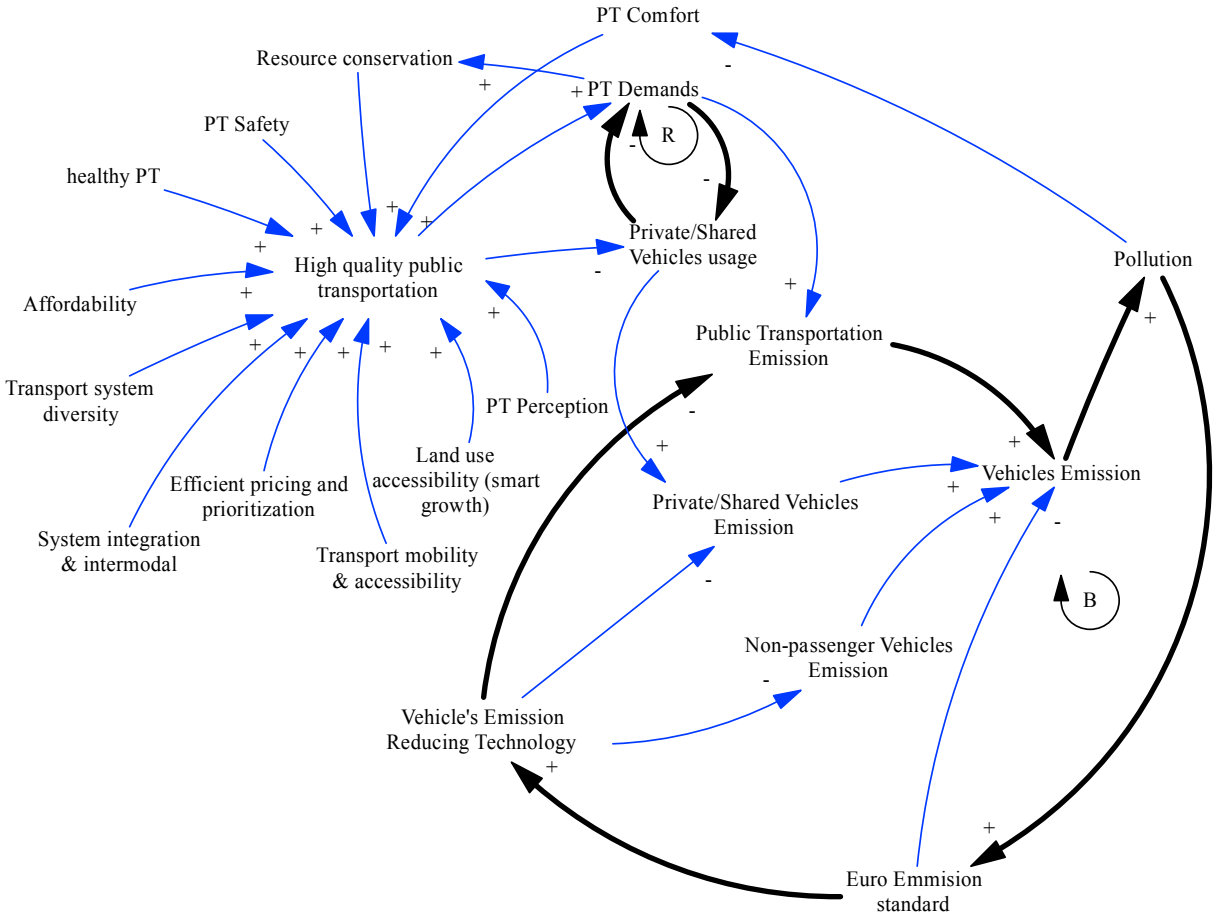

Fig. 1. CLD to reduce carbon emissions.

The result obtained from this research is the development of the concept of dynamic scenarios in the form of causal loop diagrams that can be used to mitigate carbon emissions from transportation system. Some of the variables considered include several decision variables and scenario variables which include public transportation emission, private/shared vehicles emission, non-passenger vehicles emission, high quality public transportation, public transport demand, and vehicle's emission reducing technology. The previous study by [7] found that affordability, public health, social justice, economic development, and exposure to pollution will affect the livability of the transportation system. [6] found that efficient and sustainable transportation with less congestion and emission levels enables economic growth for sustaining a country's prosperity. Therefore, the result of our research is a continuation of their research, where we focus more on mitigating carbon emissions in the transportation system.

5. Conclusion and further research

The growth in the use of vehicles in Indonesia continues to increase, which is in line with the population growth. The increase in the number of vehicles, mostly using fossil fuels, has an impact on increasing pollution. Transportation is the biggest contributor to pollution in Indonesia. The type of transportation used is directly influenced by the location in the urban center. In urban areas, there has been an increase in the frequency of public transport and an increase in cycling, while the suburban population is still dependent on cars and long journeys to access work. Reducing the number of vehicles will improve environmental health. Public transport is, therefore, an important component of the overall transportation approach. Increasing the livability of the transportation system can be done by reducing air pollution through the quality improvement of the transportation system that promotes the use of public transportation and improves safety, security, and reduces the rate of accidents through the vehicle control system and safety. Strong causal relationships work between belief and fashion use over time. The systems thinking approach is a method that can be used to represent strong causal relationships. This study presents a system thinking approach to understand the real conditions of livability of transportation system.

The air pollution comes from the burning of solid fuels, the lack of diesel emissions in the city, the use of coal in the surrounding rural areas for heating and household cooking, and the high oxidizing power due to complex chemistry. Generally, private or shared vehicles are the biggest contributor to air pollution because they are more numerous than public and non-passenger vehicles. This is because the need for public transport is lower than owning and using a private vehicle. There are many factors that influence the demand for public transport including perception, comfort, safety, healthy transportation, affordability, diversity, price, priority, mobility, and accessibility. In addition, accessibility of land use, system integration, and between modes can improve accessibility and convenience of using public transportation. Indonesia is a developing country that may have a high level of pollution in its big cities due to the transportation system.

Further research is required to build system dynamics model to increase the livability of transportation system by considering the causal loop diagram that has been developed in this research.

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