Risk analysis of traffic congestion due to problem in heavy vehicles: a concept

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Abstract. One of the most common problems on roads is traffic congestion caused by problems with heavy vehicles (e.g. trucks, trailers). The consequences of this problem often harm the wider community, both in material and non-material forms such as fuel waste and loss of time. Several previous studies have tried to look for factors that cause traffic congestion, but it has not been able to provide a complete understanding of the root causes and who are the stakeholders who must have an important role in solving this problem. This study aims to develop a research framework to get more better understanding about congestion caused by problems with heavy vehicles, which can be categorized as a type of non-recurrent congestion (NRC) that is dynamic and unpredictable. Risk management prioritizes a proactive approach before an event occurs, so the impact of risk can be minimized. Probability and Impact Matrix techniques are used to determine risk priority. Furthermore, to find the root causes of traffic congestion problems, the Fault Tree Analysis (FTA) method and Social Network Analysis (SNA) are considered to be quite potential to be used to describe complex patterns of relationships among stakeholders. The results of this study are expected to provide more complete information to understand the problem of congestion due to the problem of heavy vehicles, so that a more comprehensive solution can be formulated.

1. Introduction

The highway is one of the infrastructure facilities in the transportation system that has important functions to connect between the region to support accessibility, mobility, and provide many benefits in life [1]. However, the development of the construction industry sector also increased demand for highways, one of which can be seen from an increase in the number of heavy vehicles carrying logistics projects. This condition triggers a variety of serious problems on the highways, including traffic congestion.

Some conditions that can trigger and aggravate traffic congestion, i.e. population growth, economic growth, increased vehicle count, low road capacity, poor city planning and supervision, accidents, and natural factors [2]. Traffic congestion is a global phenomenon predicted to deteriorate in the future [3]. The impact of congestion can be material losses such as energy inefficiencies and pollution on non-material impacts such as time and opportunity wasted due to the psychological impact of increased pressure on human life [4][5]. If ignored, the traffic congestion problem will not only impact the productivity of a project, but it can also reduce the competitiveness of a country.

Although there are many factors that cause traffic congestion, in generally divided into
two categories, that is recurrent traffic congestion (RC) and non-recurrent (NRC). RC is a type of traffic congestion that occurs repeatedly or routinely [1]. An example is congestion caused by periods of busy times such as morning and evening [6]. Whereas NRC, is a type of congestion that occurs due to unpredictable events, i.e. traffic congestions that occur due to vehicle damage, accidents, weather conditions, natural disasters or human factors [7]. NRC traffic congestion problem is a dynamic and complex event.

Traffic congestion is a complex problem because of the many factors and stakeholders involved there. Stakeholders involved such as the government, environmental services, transportation departments, highway departments, traffic police, road users, communities and others [8]. The complexity of the congestion problem above is actually quite right when viewed from a risk management perspective. The risk management approach offers a fairly appropriate concept to see the dynamics and complexity of problems, especially the type of NRC traffic congestion. In addition, risk management is a more proactive approach and does not rely solely on reactive responses to risk issues. With this proactive perspective, it is expected that the negative impacts can be minimized or even eliminated. In addition, the risk management concept provides a way to respond to risk and make risk allocation to the most appropriate parties to better manage risk. The concept of risk management aims to increase the probability of a positive impact or opportunity and reduce the risk probability of a negative or threatening impact [9]. With the concept of risk management, congestion problems must be seen from a more comprehensive understanding by looking at all types of risks and what stakeholders influence efforts to solve problems while making the right risk allocation concept.

Efforts to understand NRC traffic congestion problem more comprehensively, the concept of risk management has several general stages such as risk identification, risk analysis, and risk response planning [10]. Fault tree analysis (FTA) is one technique that can be used in risk analysis to find the core of the problem. According to [11] FTA is an analytical technique carried out to find out the root causes and the possibility of an undesirable event. Social network analysis (SNA) is one approach to understanding the complex relationships between problems in a structured network system with mathematical foundations of graph theory [12]. Through the SNA the relationship between risk factors for congestion and its relationship with stakeholders can be well represented. Through the SNA the relationship between risk factors for congestion and its relationship with stakeholders can be well represented. SNA has been widely used in various construction industry areas such as construction management, transportation planning, and construction safety [13].

Based on the description of these conditions, this study proposes the concept of risk management in solving this problem by applying FTA to find the root cause of the problem. Then the SNA is used to illustrate the role of stakeholders in road traffic congestion issues, especially for NRC congestion due to problems with heavy vehicles. It is hoped that a complete understanding of the NRC congestion problems can be the basis for solving the problems that occur and allocating risks to those stakeholders who have the most ability to manage these risks.

2. Literature Review
The theory that underlies this research includes road traffic congestion problems and the concept of risk management as an alternative solution to this problem.

2.1 Highway traffic congestion
The traffic congestion often occurs especially on highways are the main access between regions and are a very serious problem experienced by many big cities in developing countries including Indonesia. Traffic congestion is a condition of highway traffic flow that stops or moves very slowly [8]. The highway in question is a form of paths on the surface of
the earth made by humans with the size and type of construction so that it can be used to channel traffic for people, animals and vehicles that transport goods from one place to another easily and quickly [14]. Two circulation domains on the road, such as passengers and goods that use the same road infrastructure, result in road infrastructure use that exceeds capacity [2]. This is reflected in the decline in speed, increase in travel time, and queue of vehicles. [3] Argues that are two perspectives of traffic congestion problems, first perspective is that congestion can be considered as an indicator of a region's economic growth and the second perspective is an indicator of the decline or shortcomings of a region.

Traffic congestion problems that occur generally are caused by an imbalance between supply (available transportation facilities) and demand (transportation demand). Availability of transportation facilities influenced by history and geography; Transport and operational management; And the level of investment on highways, while demand is affected by the level of travel concentrations in space and time [1].

According to [2] which mention some conditions that can cause and worsen the condition of road congestion, such as population growth, economic growth, increased employment opportunities, lack of investment in road infrastructure, increased number of vehicles, low road capacity, road layout, poor traffic management, violations of road rules, lack of parking lots, poor city planning and supervision, inadequate public transportation, increased use of private vehicles, accidents, an event, road works, bad weather.

Traffic congestion problems in developing countries are caused by several reasons such as; unplanned cities, poor road user discipline, alternative traffic, ancient traffic management systems, improper track management [1]. The results of other studies conducted by [15] find several lengths of traffic congestion affected by conditions such as; pedestrian crossing by 0.4%, road works by 4.5%, bottlenecks at 9.3%, traffic accidents by 12.9%, crossroads at 72.9%, besides, factors the weather is also the cause where traffic conditions increase by 20% and the snow conditions increase by 45%. Overall [15] also concluded that traffic congestion that often occurs is due to time and work schedules reaching 82.6% of total traffic congestion. While congestion caused by unpredictable things such as accidents and road works is only 17.4% of total traffic congestion.

In general it according to [1] dividing highway congestion into two categories: (1) Recurrent traffic congestion (RC), are repetitions that occur repeatedly because of busy periods such as morning and evening. (2) Non-recurrent traffic congestion (NRC), which are congestion that occur due to unexpected events such as accidents; damage to the vehicle; road repair; bad weather; an event that causes a sudden surge in demand; and natural disasters or human errors. NRC traffic congestion can trigger new bottlenecks if they occur within a period of time that is not busy, but it is also possible to aggravate congestion conditions if they occur during periods of busy time.

2.2 Traffic congestion review of the risk management concept
The NRC traffic congestion problem is quite appropriate for review from the risk management perspective. This type of congestion is caused by events that are dynamic or contain uncertainty. Risk in the scope of the project is an event that can occur and will have an influence on the project objectives, which in this risk has an impact on loss or profit [16]. Risk in the operational scope refers to things that have a negative impact on the project that is already operating [17]. Traffic congestion affects travel costs, travel time, mobility, accessibility, productivity, and also impacts on the environment such as air pollution and global warming [1].

More about NRC traffic congestion issues, especially on roads that are passed by various types of vehicles such as light vehicles, heavy vehicles, and motorbikes. This often raises several unpredictable events such as damage to vehicles to accidents that have an impact on the obstacles of a road. Some of the problems that often occur in vehicles, especially in the
heavy vehicle class such as over-loading that can trigger damage on tire, damage on vehicle braking system, damage on machine system [18][19][20].

Furthermore, some variables on NRC traffic congestion risk related to problems in heavy vehicles were identified based on some of the literature presented in Table 1.

| Risk Code | Risk event                                                                 | Source   |
|-----------|----------------------------------------------------------------------------|----------|
| R1        | Failure of tire parts such as; Flat tire or blow-out                       | [18][19]|
| R2        | Engine part failure such as; the engine is off and cannot be turned on     | [20][18][19]|
| R3        | Damage on the axle                                                        | [18]     |
| R4        | Vehicle braking systems failure                                            | [19][21]|
| R5        | Vehicle lighting systems failure                                           | [19]     |
| R6        | Disruption of vehicle electrical systems such as; battery doesn’t work     | [18]     |
| R7        | Damage on the bearing part of the wheel                                    | [18]     |
| R8        | Involved in a crashes with another vehicle                                 | [18]     |
| R9        | The vehicle is overturned or crashes into the road divider                 | [18]     |
| R10       | The vehicle spills dangerous material on the highway                       | [17]     |

In addition, it is also necessary to identify stakeholders involved in the highway as presented in Table 2. This aims to explore information and find roles or ownership of the risks that occur on the highways.

| Category      | Stakeholder                                                   | Source |
|---------------|---------------------------------------------------------------|--------|
| Government    | National development planning agency (BAPPENAS)               | [8]    |
|               | Regional planning and development agency (BAPPEDA)            | [8]    |
|               | Directorate general of regional development (BANGDA)          | [8]    |
|               | Local government (PEMDA)                                      | [8]    |
|               | Department of transportation (Dishub)                         | [8]    |
|               | Department of highways (Bina Marga)                            | [8]    |
|               | Road traffic and transport service (DLLAJ)                     | [8]    |
|               | Traffic police                                                | [8]    |
|               | Transport organization (Organda)                              | [8]    |
| Road User     | Vehicle driver                                                | [15]   |
|               | Bicyclist                                                     | [15]   |
|               | Pedestrians                                                   | [15][2]|   }
|               | Passengers                                                    | [15]   |
|               | Community                                                     | [15][8]|

3. Research methodology
The concept of the proposed framework consists of three main steps, that is measuring the magnitude of risk, root cause analysis, and analyzing the role of stakeholders as presented in Figure 1. The application of this methodology is expected to produce a more comprehensive understanding of NRC traffic congestion problems mainly due to heavy vehicle problems.
3.1 Risk magnitude (step 1)

Risk measuring is an important part in risk management, Figures 2 showing the flowchart models proposed to analyze potential risks.
According to [10] who argues that risk has 2 (two) main components in each risk event, namely the probability of occurrence of a risk event, and the consequences or impacts of that risk. From these 2 (two) components, can be defined through Equation 1. as follows:

\[
Risk = f(P, I)
\]  

where;  
\( P \) = Probability,  
\( I \) = Impact.

3.2 Root causes analysis (step 2)
FTA is an analytical technique that is carried out to find out the root cause and the possibility of unwanted events [9]. The FTA diagram presents a logical graphical relationship between the problem and its causes. [22] It states that FTA is deductive, where analysis begins with system failure or peak events and then works backwards from top to bottom as the main cause. The steps proposed to analyze the root of the problem using Fault Tree analysis (FTA) are presented in Figure 3.

3.3 Stakeholder analysis (step 3)
This stage applies the method of analyzing social networking (SNA) to provide information about the role of stakeholders involved in the problem of NRC traffic congestion, as
presented in Figure 4. SNA is a social network structure consisting of a set of connected social units. Two basic components are defined in social network: sets of actors (nodes) and sets of ties depicting the interconnections [23]. The relationship between sets of components produces a social network structure. The social network can be established with investigating the ties and the strength of the ties between actors based on interviewing stakeholders involved [23].

The key concept of SNA is centrality, can be measured by the degree of centrality (DC). DC is the number of connections that nodes have and describes the level of connection with other actors [23]. DC can be shown in Equation 2. as follows:

\[
C_D (N_i) = \sum_{j=1}^{g-1} X_{ij}
\]  

(2)

where:

\[C_D (N_i)\] = Denotes the degree centrality for node \(i\),

\[\sum_{j=1}^{g-1} X_{ij}\] = Sum of the intensity of direct ties that node \(i\) to the \(g-1\) but excluding \(j\) (exclude node itself).

![Figure 4. Stakeholders analysis model flowchart](image-url)
4. Conclusion and recommendation

Based on the background of the problem and the literature review conducted, there is no study that comprehensively analyzes the problem of traffic congestion especially for NRC traffic congestion due to problems in heavy vehicles. Therefore, this study proposes the concept of risk management in solving this problem by applying FTA to find the root of the problem. Then SNA is used to visualize and map NRC traffic congestion problems because of problems with heavy vehicles. The hope is that this research provides a complete understanding of the problem of traffic congestion NRC can be a basis for addressing the problems that occur and allocating risks to stakeholders who have the greatest ability to manage this risk.

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