Proceedings of the Eastern Asia Society for Transportation Studies, Vol.11,2017

A Model to Evaluate the Robustness of Interurban Road Network

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Abstract: The road network is a vital infrastructure for society that aims to transport people or goods to fulfill the necessities of life which is largely determined by the availability of a viable road network. Continuity of logistics distribution and the daily movement needs in disaster conditions should also be considered because it comes to the economy and quality of life of people in the area. This work focus on robustness analysis with failure condition of road network components is total damage. Several studies analyze the robustness of the network using topology approach, but do not consider the reliability aspects of the transportation as well as roads characteristics. Therefore, this study aims to develop an existing model that employs topological index and network performance. The study begins by reviewing the relevant studies, mapping as well as formulating problems, and proposing the formulation of future studies.

Keywords: robustness, road networks, topological index, network performance, disaster

1. INTRODUCTION

The government is very concerned with things related to disaster, as shown by the laws and regulations related to the disaster. Disasters are always been a special concern for the government because of the impact that could be caused to the life and activity of the community. Disaster is an event or series of events that threaten and disrupt the lives and livelihood caused by both natural factors and/or factors of non-natural or human factors that lead to the emergence of human lives, environmental damage, loss of property, and the psychological impact (UU. No. 24 of 2007). Furthermore, disasters are categorized into three, namely: natural disasters (such as earthquakes, tsunamis, volcanic eruptions, floods, landslides, etc.); non-natural disaster (such as technological failure and others); and social disaster (social conflicts between groups, terror, etc.).

The road network which is vulnerable to natural disasters such as earthquakes, tsunamis, landslides, floods, blizzards large (heavy snow fall), forest fires and volcanic eruptions can cause severe damage to the infrastructure that affecting travel on the damaged road network. In general, areas affected by the disaster will be difficult to be reached or passed, it can be caused due to road network which totally end, as well as the impact of the earthquake and tsunami in Aceh Province, Indonesia (Indian Ocean earthquake and tsunami) in 2004 (Ikhsan *et al.*, 2010), the collapse of the bridge due to the earthquake in Kobe, Japan (Chang and Nojima, 2001) or the closed roads due to landslides in the Province of Reggio Calabria, Italy (Cirianni, *et al*., 2012).

Road network system serves the movement of people and goods from one location to another, which typically uses a mode. Road network system provides optional routes to support the movement of people and goods. The routes link locations of production to locations of consumption or forming a series of supply chain structure in the framework of the distribution of people and goods in order to fulfill the subsistence. The road network is one of the critical infrastructures in accelerating and expanding economic development, with its connectivity equitable and reliable, it can lower the cost of transportation and logistics costs in order to improve product competitiveness, and accelerate the growth of the economy (Hong *et al*., 2011; Napitupulu *et al*., 2011).

On the other hand, Konstantinidou *et al*., (2014) stated that in disaster conditions, roads network/transport is essential infrastructure in supporting activities in emergencies (evacuation, emergency response, relief and recovery operations); transportation network is the only way leading to the location affected by the disaster as physically access; and transportation infrastructure has a nature prone to disasters, which if affected by a disaster it will experience degradation performance both in capacity and services provided. Considering the importance of the road network in providing access to key locations, we need a road network which is solid to disturbances (natural disasters, acts of non-natural and social disasters) in order to maintain business continuity and supply chain as under normal conditions, as well as the rescue process goes smoothly, recovery and reconstruction of communities after catastrophic events. The absence of a solid road network directly affects the transportation system and can spread to other sectors, such as economic and social community, one of them is the increase in the price of goods (Bocarejo *et al*., 2015).

This study focuses on disaster mitigation efforts through the evaluation of the robustness of inter-city road network, with different characteristics of the road network, both technical and geometrical characteristics. The movement of traffic flows between cities is a movement on a regional scale and with a sparse road network conditions/less, then the congestion is not a significant issue, so in this study the traffic flow capacity shall be declared. This study also specializes in the movement of the truck, which has a high dependence on a particular road network, so that if one or more segments may experience malfunction, there will be an increase in travel time, which would certainly have an impact on the increasing of cost as well. In addition, truckloads (certain commodities) has a dependence on the maximum travel time from the original location to the destination location and it adds to the vulnerability of the road network. This paper is a follow-up of the review articles have been carried out by Konstantinidou *et al*., 2014 and Faturechi and Miller-Hooks (2014) of the previous studies, related to the robustness of the road network. This article is a series of research process which aims to propose an evaluation robustness model of the road network through the development of previous existing model introduced by Sakakibara *et al*., (2004), which still have shortcomings on the model. Some of the shortcomings of the model is only focusing on connectivity between regions (Konstantinidou *et al*., 2014), and was unable to give the reliability of the transport, i.e. reliability of travel time (Li, 2008).

Some of the benefits derived from the process of writing is a research position among the studies that has been done, and the collection and synthesis of the literature related to the topic of research, as well as produce a framework for further research stage. In addition, opportunities for future research related to the robustness of the road network.

2. LITERATURE REVIEW

2.1 Analysis of Disaster in Transportation Systems

This type of analysis refers to the concept and mechanisms underlying the expression of post-disaster network performance. There are five concepts identified in the analysis conducted by Konstantinidou Riview *et al*. (2014), namely: vulnerability, reliability, risk, robustness and resistance. While the results of a review conducted by Faturechi and Miller-Hooks (2014), there are two more analysis concepts than those described above, namely flexibility and survivability. However, there are the same definitions of concepts, so that the definition obtained from the literature will vary among researchers.

Vulnerability is a concept that is often used to assess the sensitivity of the network of a disruptive event, where the network affected by the disaster will be measured through accessibility or ease of reaching the destination, Niemeier (1997). Meanwhile, Kurauchi *et al*. (2009), Taylor *et al*. (2006) and Taylor and Susilawati, (2012), considers vulnerability as a result of the failure is not the probability of occurrence. Reliability is the probability of success to travel between points in a road network by considering the possibility of happening distraction and the consequences that will be accepted, Berdica, (2002) and Al-Deek and Emam, (2006). The risk is associated with reliability, where the risk is associated with the probability of a disruptive event and the impact resulted, Berdica, (2002). Robustness is the opposite of vulnerability, which is the level at which the network is able to maintain its performance when roads impaired the capacity, Sullivan *et al*. (2010). Robustness is a level of network which still able to serve road network without suffering significant performance degradation. Berdica, (2002) resistance is the ability of a network to regain its normal functions after a disturbance caused by the disaster. Resilience is also defined as a temporary overload on the network, Snelder *et al*. (2012).

The concept of robustness road network is a road network which is able to maintain its function as well as possible after an interruption, and was able to restore function as soon as possible of damages, partial or total (Li, 2008). The other study was conducted by Billington and Allan (1992) and Wakabayashi and Iida (1992) defines reliability as the probability of road network that provides adequate service levels for a certain period of time under operational conditions encountered. Furthermore Snelder (2010) writes that reliability is often divided into three categories: the reliability of connectivity means that the network is reliable if there is at least one way to operate, for each pair of points; reliability of capacity defined as probability of maximum capacity on a network greater than or equal to level of demand happening, where capacity segment is random variation; and reliability of travel time is a trip probability between OD matrixes which can be reached within a specific time interval (Chen *et al*., 2002). Unlike the terminal reliability, travel time reliability is affected by the impact caused by network damage (Nicholson *et al*., 2001).

2.2 Robustness Study on Road Network

Immers *et al*. (2002) states that robustness is the level of a system to function as its design specifications when having serious disturbances. Immers *et al*. (2002) divided robustness into four aspects:

1) Redundancy
Redundancy or spare capacity in a system is possible to be improved, lack of redundancy in a road network can lead to a decline in service quality. This condition may cause a problem in an emergency situation, for example when evacuating victims affected by a disaster.
2) Dependency/interdependency
Dependency of location node is as important as the road network itself. Robustness of a road network is reflected on the level of its dependency on certain roads, if interdependency is huge the road network will not robust.
3) Elasticity/Resiliency
Elasticity is the ability of the transportation system to resume its original condition in a short time from a temporary overload.
4) Flexibility
Flexibility is the adjustment to the new conditions, whereby the system is able to provide more services and have the other functions of the designed purpose. So, flexibility is a property that allows the system to develop with the new conditions.

Immers *et al*. (2002), describes the ways of four aspects of robust network can be improved. First, by updating secondary network, so it can be considered as an independent subsystem that will be able to increase the robustness of the road network due to reduction of interdependency; second, optimal reserve capacity on the network segment accounted for. These two examples show how the robustness can be translated as the characteristics of the network. However, designing and developing the road network is a difficult task. Snelder (2010) argues that it must consider many different aspects, such as different goals, different actors, period (short or long), rules and procedures, politics and interaction.

Immers *et al*. (2002) consider reliability as a user reference on transportation performance while the robustness is character of the road network itself. The robustness of the network has an important role in providing reliable travel time for road users. Ukkusuri *et al*. (2007) with the methodology of Genetic Algorithm (GA) result two important contributions as the literature on network design. First, robust network design solution is significantly different from deterministic Network Design Problem (NDP) and there will be potentially incorrect assessment to the impact of extensive networks. Second, the systematic evaluation of model performance and solution algorithm is performed to the network and different counting to explore the effectiveness of this approach.

2.3 Road Network Performance

Road network system planning has to consider many things, including where the location will be built, how much its capacity, whether the road network in the neighborhood, and others. Those things are very influential if the road is inside/crosses potentially disastrous region, so consider these things may be able to avoid the isolation area as the impact of disaster.

Nojima (1998), the estimation of the performance categorized into two, namely free flow traffic and non-free flow traffic, where the non-free flow traffic trying to capture the phenomenon of congestion while free flow traffic only requires data relating to the physical condition of network. Chang and Nojima (2001), argues that non-free flow traffic is not used on a limited basis in the post-disaster environment, it is because of lack of available data. Instead, the free flow traffic trying to avoid the uncertainty in estimation of post-disaster and prioritize measurements with the parameters that are easy to measured. Selection of performance measures that will be used in accordance with the initial impact arising and severity of network damage. Furthermore, Chang and Nojima (2001) used three free traffic flow measurements to calculate the performance, firstly, the total length of the network is open (still accessible); second, the total length of the accessibility of the initial range of components, damage, and connectivity should be considered in assessing the accessibility; and third, the same concept, but accessibility is based on the minimum distance segment and minimum load factor for the accessibility of the OD data area that appropriate with location before the disaster.

Ukkusuri and Yushimito (2009), stated that using the shortest distance is the proper way to calculate the performance of the network after a disaster. Important/critical network is obtained by reducing the capacity of segments and analyze the User Equilibrium (UE). Performance measures are built is the total travel time based on the results of the EU. Using the same components, such as distance that is used in a different framework will produce different estimation, this shows the importance of perspective in calculating network performance.

Sakakibara *et al*. (2004) state that in the event of disasters such as earthquakes throughout the region, the transportation network can be destroyed. So, it is very important each region can provide a minimum level of service not only as evacuation and rescue lines, but can also provide continuity of life of citizens. The transportation network is expected designed to improve the functioning of mutual reciprocity between the areas, one with Topological Index that provides a combination of a number of inter-regional connectivity. Topological Index can also be used in association with conventional network performance as a disaster mitigation efforts through the evaluation of road network robustness in disaster-prone areas.

Konstantinidou *et al*. (2014) identified a number of performance measures used in the study related to the disaster. The measurements of network performance mentioned are connectivity, accessibility, total network travel time, total network travel time increase, travel time (link-, path-, od-based), travel time increase (link-, path-, OD based), satisfied/unsatisfied demand, maximum total flow, system surplus and others performance measurements. While Faturechi and Miller-Hooks (2014) grouped into five performance measures, namely: travel time/distance, throughput/capacity, accessibility, topological measures, and economic measures.

2.4 Research Position among others Studies (State of the Art)

The following are a number of studies that have been done and the position of this research among other studies. With their state of the art research, it will be seen freshness and the position among other research studies.

Sakakibara *et al*. (2004), assessing the robustness based on the topological index (TI) with the aim to form a solid road network to prevent the isolation of a location/region. Besides the use of TI, they also involve the characteristics of health care in identifying road sections that are important or potentially the movement in the evacuation process of victims when disaster strikes. As with Sakakibara *et al*., *Ikhsan et al.* (2010) and *Suherna et al.* (2014) also uses TI in evaluating and analyzing the robustness of the road network in disaster-prone areas.

In Review conducted by Konstantinidou *et al*. (2014), the use of TI only describes connectivity between regions through the indexed values generated. Similarly, Li (2008) state the use of TI without involving components of the network performance will be stiff, where there is no measure indicated of the magnitudes of (time, distance, cost, etc.) to take any steps in evacuating the victims to the health service. In addition, the authors look at the use of TI by engaging characteristics of the health service only provides an illustration of the point/node/location without considering the characteristics of the network (supply), as is well known, the network characteristics greatly affect the performance of the network. By involving the characteristics of the network will provide an overview of more measured on the segment which is faster/better to evacuate the victims and thus also for the distribution logistics for disaster victims. From these researches, the author will use the TI method for assessing the robustness of the network and involving the performance of the network as an attempt to illustrate the quality of a journey.

Snelder *et al*. (2012) using macroscopic Dynamic Traffic Assignment Model with indicators losing travel time caused by an occurrence. The study focuses on the method of route selection by considering the behavior of the driver, the road network that wide in big cities which the technical characteristics for each road segment is likely to be the same. In this case, the authors have differences with them, both in terms of methodology and orientation of the region. This study will examine the road network is still scarce, the movement of regional and the diverse of technical characteristics, thus the method used would have been different.

Ukkusuri *et al*. (2007) to design a solid network by combining the concept of Network Design Problem (NDP) thus producing methods Robust Network Design Problem (RNDP) to optimize the to optimize capacity expansion policy (improving the performance of the transport network). The resulting model focuses on the movement of uncertain demand (demand uncertainty), further by applying the principle of user equilibrium will be obtained performance transport networks (total travel time system). The model does not take into consideration the structure/morphology of transport networks, so the stochastic nature of the combination of several catastrophic events/occurrences have not been accommodated, so it can't identify the potential isolation of an area.

Faturechi and Miller-Hooks (2014), examines resilience (resilience) travel time on the condition of a disaster (pre-disaster, disaster relief and post-disaster) and just observing the behavior of road users are affected by any disaster (some road users) and considering the road network improvement actions as an effort to improve network performance. Although both using the approach bilevel, but the basic concepts of analysis is different so the methods used are also different, Faturechi and Miller-Hooks used the concept of resilience as described above, whereas in the study used the concept of analytical robustness on pre-disaster condition and travel costs into variable used to measure network performance..

Valenzuela *et al*. (2014) examines the importance of contingency planning in disaster-stricken areas, especially in planning the robustness of the logistics center of the road network in the region. Variables used to calculate the robustness of the logistics center is the minimum travel time on the network and is examined using Dijkstra's algorithm. The study does not apply to some structures of road network including real cases in the disaster affected areas in the Philippines, the characteristics of the road network consists of distance and width of the road, assumptions and scenarios put forward. In contrast to the study focused on robust logistics center, this work focuses on efforts to create a robust road network against to disaster threats.

Balijepalli and Oppong (2014), examines the vulnerability by methods of network vulnerability index (VNI), which measures the ability to serve (serviceability) and the importance of each link in the road network. The ability to serve a segment obtained by comparing the total capacity available with a standard maximum flow rate per hour. VNI is obtained by calculating the difference in the ability to serve a segment on its pre-disaster with post-disaster condition, while to calculate the importance of a segment used analysis Guidance. The fundamental difference between the study and this work is the concept analysis, Balijepalli and Oppong use vulnerability approaches that consider the hierarchy of the road (based on capacity) on network performance (ability to serve) and the importance of a segment (analysis Guidance), whereas in this work using robustness analysis packaged in the NDP, that consider the hierarchy of road (on the technical characteristics of road, heaviest axis load) on network performance (general cost) and the importance of a segment reflected in changes in the value Tological Index.

Li (2008) analyze the robustness based on network performance (travel time and deployed with queue model measurement) by using dynamic traffic assignment (DTA) model and the analysis considering the hierarchical structure of the road (based on travel speed). The model does not include a hierarchy of road from the technical characteristics of the road (tonnage permitted). In contrast to research conducted Li, this study aims to design a robust network, using the approach of Network Design Problem (NDP), which has advantages in the search for the optimal functioning (the best) of some objective function (performance and robustness of the network). Furthermore, the study will take network performance (general cost of trucks) which is influenced by the hierarchy of road, especially on the technical characteristics of the road (tonnage permitted).

Christensen (2003), using the NDP in analyzing the road network which aims to determine the roads priority to be maintained (investment), while most of the road network is becoming left out (unused) as the result of the agglomeration warehouse agricultural commodities. In line with this study, the NDP approach to function optimization and maintenance priorities (investment) is also applied in this study but differ in purpose. NDP approach used in this work aims to determine the roads that give robustness to the catastrophic events, so that the methods used are also different.

Chootinan *et al*. (2005), Hua *et al*. (2011), Gao *et al*. (2004), and Zhang and Gao (2008) a number of others researchers are using the NDP approach to analyze the network affected by the disaster. Chootinan *et al*. (2005) and Hua *et al*. (2011) using the Continuous Network Design Problem (CNDP) with bi-level program formulation, but each of these studies had a different concept analysis, respectively, using the concept of reliability analysis and robustness analysis concepts. The concept of reliability is more focused on user behavior while the robustness concept focusing on network characteristics. Gao *et al*. (2004) using the Discrete Network Design Problem (DNDP) with bi-level program formulation and apply the concept of robustness analysis, the lower level specified minimizing the cost of road construction and the upper level set as the problems of minimizing total system costs. Zhang and Gao (2008) using the Mixed Network Design Problem (MNDP) which is a blend between the CNDP and DNDP, in MNDP will consider increasing the capacity and the addition of new sections simultaneously. Referring to the four NDP approach, this work adopted CNDP methods and robustness analysis concepts, but there are a number of differences compared to the fourth study, among others; the concept of robustness analysis using methods Topological Index, involves problems of road hierarchy, and the movement of a number of commodities.

Taking into consideration the results of the synthesis and the things that are not contained in the above study, the researchers proposed a new method of measuring robustness through modification of the methodology ever before and the formulation of an empirical study on the model. Observing the condition of case study areas with different characteristics such as the condition of road network is sparse, differences of road classification, potential and variety disaster, and socioeconomic regions as well as budget constraints to road construction spending. Therefore, CNDP model approach used is because it has the optimization function to a number of objective function. Modification of the methodology follows the concept of the game/ Stackelberg games, with the upper level (the leader) applied Topological Index method and the lower level (followers) is applied to network performance (total general cost).

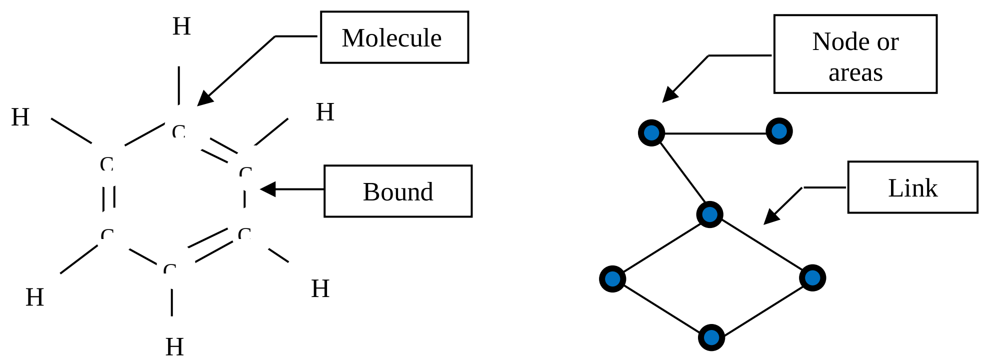
3. MODEL DEVELOPMENT

Given the role of the network on a major road in reaching the important objects, both in normal conditions (daily activities) or in an emergency, as previously described, then evaluate the robustness of the road network is an appropriate action as the disaster mitigation efforts in the area disaster-prone. The results of the evaluation of the robustness of the road network on the possibility of catastrophic events can be used as a reference in the implementation of priority activities (improvement, maintenance or new construction) to the road network by the relevant agencies. Priority implementation can also be adjusted with the available budget so then the prioritized road network can be built and useful in times of emergency or disaster. Priority implementation of activities on the road network cannot be separated from the assessment of the importance/critical of a road segment in the road network system, in which a road section has important levels that vary in terms of the road section to function as a network of roads affected by the disaster. Freiria *et al*. (2015) examines the most important road in the network through the application of engineering bi-clustering, identify patterns of attributes (measuring the performance of the road) and road pattern (pattern of connectivity). On the other hand, Sakakibara *et al*. (2004) assessed the road is more important for the functioning by Topological Index (TI) value, the greater the change in the TI value due to the addition or subtraction of a road, the more important of these roads, while Balijepalli and Oppong (2014) consider the level of service (serviceability) to examine the importance of a road section on the city road network is congested.

Formed a robust road network generally used performance measurement of road network system affected by disaster that aim to overcome or mitigate the negative impact of the disaster. Determination of selected performance estimation must be based on the impact of disasters caused, instead of the kind of disasters. In this study, the examined of the movement is the movement on a regional scale so that the reliability of travel time (general costs) are very influential and types of disaster assumed general disaster that resulting in loss of function of roads (the road cannot pass-through).

3.1 Topological Index

Topological Index (TI) was originally proposed to classify the structure of molecules in chemical compounds that aim to estimate molecular bonds (Hosoya, 1971). The concept is very popular in chemistry and are widely used in various fields of science, one of them on the field of transport (Sakakibara *et al*., 2004). Topological Index is possible combination of two or more nodes/ cities that still remain connected with various patterns combination of disconnectedness. This method is in accordance with the conditions of the road network is still sparse and in the development stage.



a. Molecular C6H6 bond graph

b. Road network bond graph

Figure 1. Analogy of structure between road network and molecules (*Ikhsan et al.*, 2010)

Network expressed as a graph G has in common with the atomic bonds in a molecule and, like a knot or binding area on the road network. Similarities can be seen in Figure 1. According to Sakakibara *et al*. (2004), Topological Index (TI) can be used to calculate a morphology of the road network. The road network can be represented as a graph showing the relationship between vertices and segments. On the network (Graph G), vertices represent regions and segments that represent the road. Graph G is translated as follows:

$$G = (X, A) \tag{1}$$

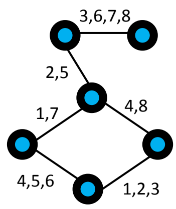
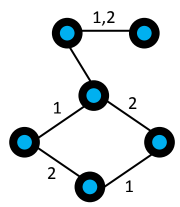
Where X is expressed as a set of vertices or town, and A is the set of segments or road (A = X × X). The number of vertices and segments are each represented by n and l. Hosoya (1971) proposed a Topological Index of a graph G (TI (G)) as follows:

$$TI(G) = \sum_{k=0}^{m} P(G, k) \tag{2}$$

With m = n / 2 (if n is even) or m = (n - 1) / 2 (if n is odd). P (G, k) is the sum of the set of k "not connected" segments.

Table 1 below gives an overview of TI calculations with segments non-connected in class 0, 1, 2, and 3 (maximum class (m) = 6/2 = 3) in Gi.

Tabel 1. Topological Index measurement for G_i, (*Ikhsan et al. et al.*, 2010)

k = 0	$P(G_i,0) = 1$	
k = 1	$P(G_i,1) = 6$	
k = 2	$P(G_i,2) = 8$	
k = 3	$P(G_i,3) = 2$	

So, TI for Gi in Table 1 are:

$$\begin{aligned} TI(G_i) &= P(G_i,0) + P(G_i,1) + P(G_i,2) + P(G_i,3) \\ &= 1 + 6 + 8 + 2 \\ &= 17 \end{aligned}$$

If two segments meet on the same node, then this segment is called "connected". And when two or more segments do not meet on the same node, segments called "not connected". P (G, k) is expressed as the number of subsets of A containing k in the segments is not connected. P (G, k) is called "class number k is not connected". Figure 2 shows the type of road network (called Gi) and Figure 3 gives an example 2 segment is not connected in Gi.

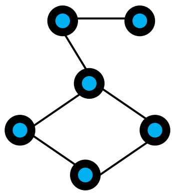


Figure 2. Connected road network $G_{i,}$ (*Ikhsan et al. et al.*, 2010)

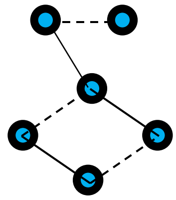


Figure 3. Non-connected road network $G_{i,}$ (*Ikhsan et al. et al.*, 2010)

P (G, k) is the sum of all combinations of a possible road network structure with different types of non-connected (k). If k = 0 (uninterrupted road network), then the combination of road network that formed only one, namely the road network itself. For k = 1, the non-connected segment is one, then the combination of the occurrence of a single broken link is equal to number of links in the network. For k = 2, the non-connected segment is two, where the non-adjacent segments are not sharing the same node, then the number of possible combinations as shown on the figure in Table 1. Similarly to k = 3, the non-connected segment is three segments and occurs on different sides without sharing the same node, as shown in the figure in Table 1. The small number on the figure in Table 1 shows the number of combinations that occur, where the same value indicates the combination of broken links, especially for k = 2 and k = 3. The combination of broken links are not sharing same node.

Road network graph and robustness

Correlation between TI and the robustness of road network can be described in Figure 4, where the number of nodes (n) and link (l) are 6 and 8 respectively, for both network A and B. Both graphs have different structure. Network A has a radial structure, all links are connected to the node (centered d), but the node c and e very easily isolated, since the vertices are only connected by a single road. While the network B, the structure is a combination of radial and circular. Each node has more than one connection link, it makes the possibility of isolation becomes smaller than the network A. Therefore, the network B can be considered more robust against the threat of a disaster, this network is called "network disperse". Based on the equation 2, value of TI for network A is 9 and B is 37, this proves that the value of TI disperse networks is greater than centralized network. Therefore, TI can be used as a quantitative index of disperse/concentrated of road network.

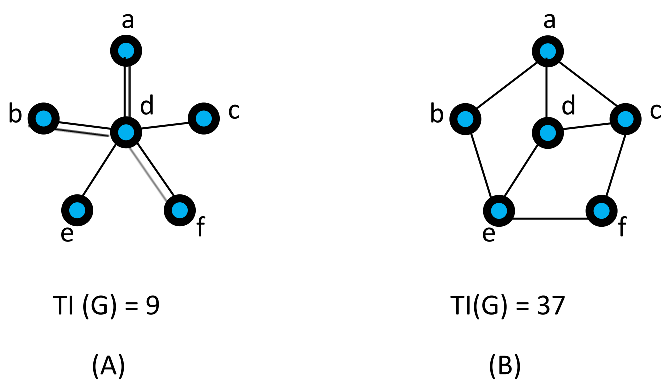


Figure 4. Concentrated network (A) and disperse network (B) (Sakakibara *et al.*, 2004)

3.2 Network Performance

Two good review of literatures done by Konstantinidou *et al*. (2014) and Faturechi and Miller-Hooks (2014), on a number of related literature to transportation and disaster. Based on review result, there is no study that employed Topological Index with road network performance. This study will use a cost function described by Tavasszy (1996), which formulates the general costs of a commodity is a function of the time value of commodities (products), travel time, distance, vehicle operating costs and others expenses.

General cost function:

$$c_{ij}^{q} = \alpha_q \cdot T_{ij} + y_{ij} \cdot \rho_{ij} + c_{ij} \tag{3}$$

where:

c_{ij}^{q} = general cost on link ij for product q
α_q = time value for product q
T_{ij} = travel time on link ij for product q
y_{ij} = distance of link ij
ρ_{ij} = vihecle operational cost (VOC) on link ij
c_{ij} = others expenses on link ij

3.3 The New Proposed Model

Continuous Network Design Problem (CNDP) described before is generally based on cost minimization function Tavasszy (1996) for the lower level and maximum function Topological Index by Sakakibara *et al*. (2004) on the upper level. CNDP is constructed in bi-level where each level would influence each other. When a road segment is set up for construction (new development, reconstruction or maintenance) which is results in a larger TI value than before, it will further minimize the performance of the network (lower level), and the budget as a constraint will respond to resulting decision in form of sufficiency/availability of costs to construction (new development, reconstruction, or maintenance) of roads. When the available budget is not sufficient for the construction process it will affect the upper level, i.e. change the policy that has been made before. This can be done by replacing the road that will be carried out to construction process, which will certainly affect the value of TI. So there is a tradeoff between the robustness of the road network and the cost of construction development, as revealed by (Pokharel, 2012). CNDP model with uncapacity road network can written in the formula min-max optimization problem based on equation (2) and equation (3), as follows:

Upper Level:

$$\max \mathrm{TI} = \sum_{k=0}^{m} P(G_1 + G_2, k)$$

Subject to:

$w_g = 0 \text{ or } 1,\ \forall(g) \in A$
TI after > TI before

Lower Level:

$$\min \sum_{q \in Q} \sum_{(i,j) \in A} c_{ij}^{q}$$

Subject to:

$$\sum_{g \epsilon G_2} b_g \cdot x_g \cdot w_g \leq B$$

$$T_{ij} < 48 \text{ hours}$$

where:

G1	=	existing link in graph G1
G2	=	additional link to G1
A	=	link
k	=	class of nonadjacent link
m	=	n/2 (n even) atau (n – 1)/2 (n odd)
n	=	node
b_g	=	road cost maintenance on link g
x_g	=	distance of link g
w_g	=	additional link g (value = 1 if there is additional link; and 0 otherwise)
T_{ij}	=	travel time from i to j

4. PRELIMINARY APPLICATION FOR ACEH CASE

Preliminary survey calculation is manually performed as a validation of the model. Given the structure of the existing graph is shown in Figure 5-I, with number of nodes and links are respectively 6. The amount of general cost for each link is the appropriate number listed between the nodes, which is shown in Figure 5. The calculation is done with two scenarios, namely: scenario I, the addition link connecting nodes B-D (Figure 5-II) and the addition of link connecting nodes A-F is scenario II (Figure 5-III).

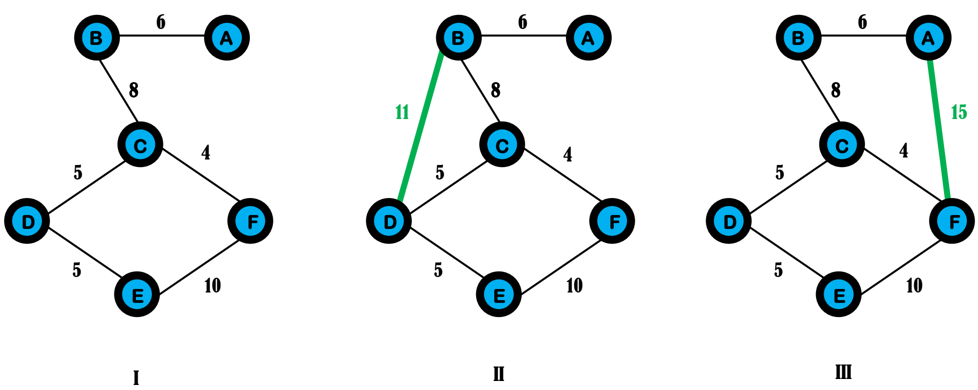


Figure 5. Existing graph (I), graph with adding link on nodes B-D (II), and graph with adding link on nodes A-F (III).

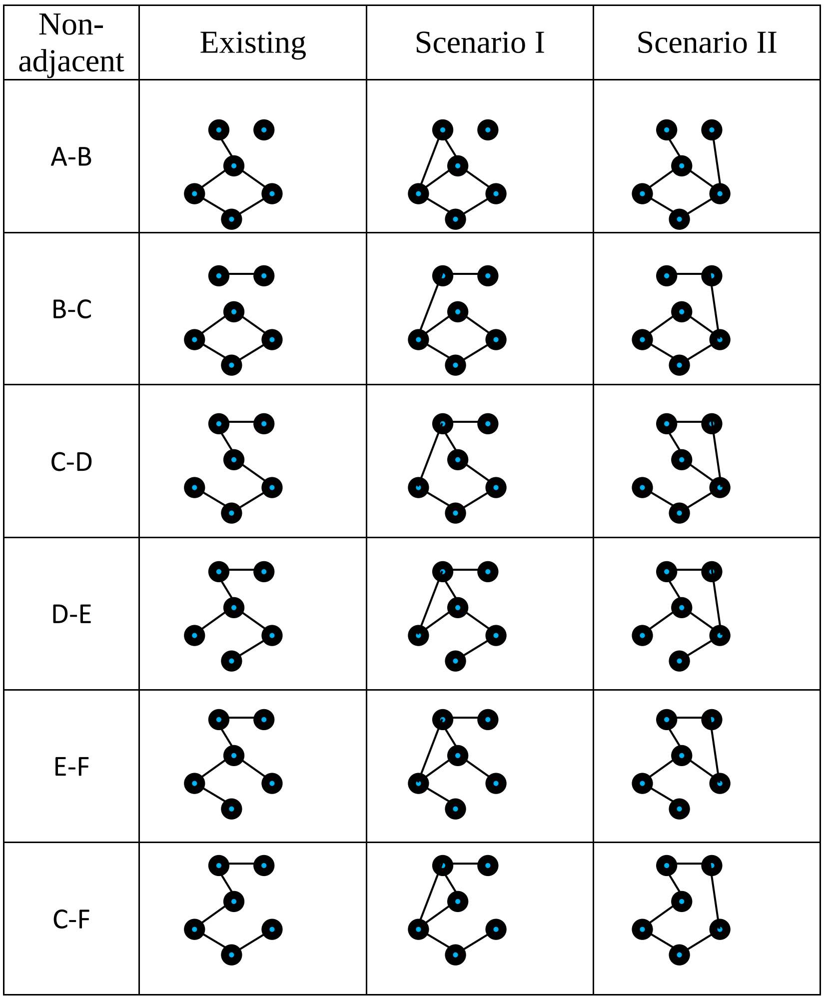


Figure 6. Probability graph after disaster event for k = 1

Total General Costs (TGC) were estimated is calculations for a number of non-adjacent of link (k = 1) or in other words, disastrous events that led to road fails to function just happened on a segment, not disasters that occurring simultaneously in several roads (k > 1). Non-adjacent will be carried out on all segments alternately in the road network (existing graph) and also to scenarios condition that have been set, as shown in Figure 6.

Calculations focused on the value of TI and TGC, while for barriers such as the cost of procurement/maintenance of roads considered to be the same in all segments, so it is not taken into account in this calculation. There are nodes in isolated conditions and cluster of the graph after the disaster, so the general cost on these conditions will be added a number of 500 units that illustrate there is full or partial (cluster) isolation. The results of the model calculations using hypothetical data is shown as follows:

Table 2. Calculation of Topological Index and Total General Cost value at normal conditions

Topological Index			Total General Cost		
Existing	Scenario I	Scenario II	Existing	Scenario I	Scenario II
17	19	22	175	167	173

Table 3. Calculation of Topological Index and Total General Cost value after disaster event

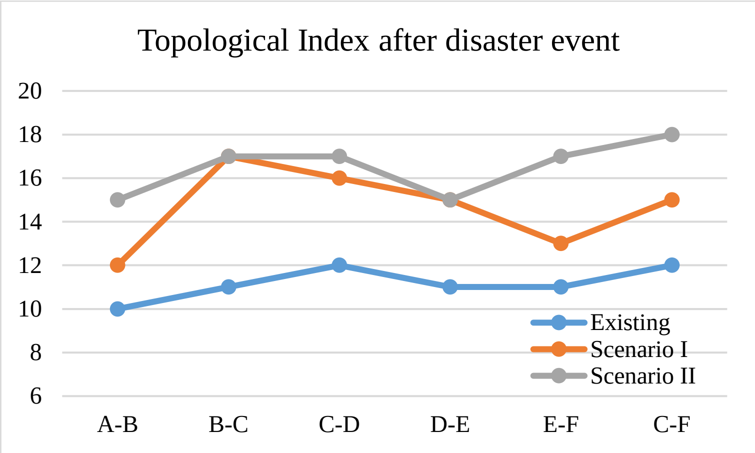
	Topological Index			Total General Cost		
Non-adjacent	Existing	Scenario I	Scenario II	Existing	Scenario I	Scenario II
A-B	10	12	15	675	671	204
B-C	11	17	17	975	199	239
C-D	12	16	17	235	191	226
D-E	11	15	15	201	197	195
E-F	11	13	17	179	171	176
C-F	12	15	18	227	217	194

Table 4. Calculation of difference Total General Cost relative to existing normal condition

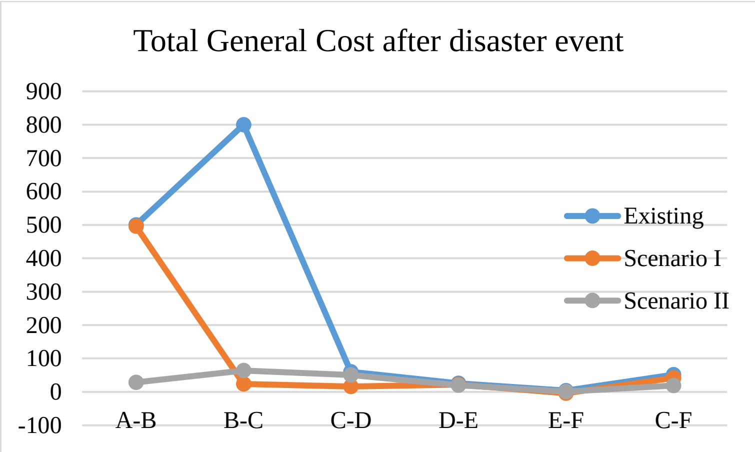
Non-adjacent (with k = 1)	Difference Total General Cost relative to existing normal condition		
	Existing after disaster event	Scenario I after disaster event	Scenario II after disaster event
A-B	500	496	29
B-C	800	24	64
C-D	60	16	51
D-E	26	22	20
E-F	4	-4	1
C-F	52	42	19

Based on the calculation above shows that with the addition of a new link in normal conditions will increase Topological Index to both scenarios (Table 1.). On the contrary, the addition of new roads will reduce the value of Total General Cost for both scenarios (Table 1), which means it will give a positive value for the user. While a location affected by the disaster, where there are roads fail to function then the value of Topological Index will adjust to the structure of road network that still functioning. In Table 2, declining of TI values to all conditions due to roads cut off, even to the existing conditions after the disaster there are two conditions where isolations are occur, full isolation (Figure 6, Existing, non-adjacent A-B) and partial isolation/clustering (Figure 6, Existing, non-adjacent B-C). In the Scenario I occur one full isolated event, namely when link A-B non-adjacent (Figure 6). As for the Scenario II, although the value of TI has decreased but there are no isolated area at all.

Table 3 shows the difference in value of TGC against the existing normal conditions with post-disaster conditions for all scenarios. For both post-disaster conditions, existing and Scenario I, some TGC value are very large compared to other values, its represents the isolation described earlier. As for the post-disaster Scenario II, the value of TGC did not experience a significant margin, which means that in any disaster event there is no isolated node.



Graphic 1. Topological Index values after disaster event



Graphic 2. Total General Cost values after disaster event

Based on the description above, the decision could be made that choosing a scenario II is the best choice because it gives largest value to road network robustness (Graphic 1). Road network robustness contribute to make wider connectivity between nodes so that will give better road network performance, it is seen from the lower difference TGC than the other scenarios (Graphic 2).

5. CONCLUDING REMARKS

The road network is prone to disasters (natural, non-natural, and social) such as earthquakes, tsunamis, floods, failure of technology, and terrorism that could result damage to one or several roads thereby reducing the performance of the road network. Study on road network robustness has been done, even include using approaches from different disciplines and applied to the field of transport, one of which is Topological Index.

Previous researches that use this concept do not consider network performance (eg: travel time, costs, etc.) so cannot give description about the reliability of routes in the network. Reliability information on road network very useful for road users, particularly in an emergency where the needs of movement with the shortest travel time will be needed to evacuate or delivering aid to disaster victims. In this study, Topological Index was employed with network performance (general costs) to transport goods by trucks on the road network which is rare in a regional. Trucks operational are very dependent on the characteristics of the road network (technical and geometric) and routes policy in a regional, where the truck may only flows on permitted routes in a network. Dependencies truck to both of those factors (characteristic of road network and routes policy) are truck vulnerability on network, and if it is associated with the transported goods that requires minimum travel time, it will increase the vulnerability of the modes. With such condition it is necessary to evaluate the robustness of the road network as mitigation.

The measurement of road network robustness using Topological Index is very suitable for developing countries, where the road network is still rare (in progress) and the budget for investment road network is limited. The proposed model has the objective function for road network robustness optimization with some restriction factor (such as budget, characteristics of the road network and travel time). The proposed model also accommodate the objective function of optimal usage of the budget, so can determined priority improvement/construction of road network in accordance a lack of funding.

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