Effect of Merapi Disaster Evacuation on Road Network Performance in Yogyakarta Special Region

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Abstract: The eruption of Mount Merapi, located in Sleman Regency, Yogyakarta Special Region, in the past inflicted heavy casualties. Evacuation of refugees to safe places was a must in order to minimize casualties. In order to identify the extent of changes in road network performance due to disaster evacuation, evacuation modelling is required to optimize the handling in the future. This study was conducted with the help of SATURN version 11.3.12W. This model also involved 140 centroid, 449 buffer node, and 589 segments. The rise and pull as travel inputs included daily OD matrix and simulation of refugees covering 50%, 60%, 70%, 80%, 90% and 100% of the total directly affected population in ring 1. The results of the study showed that there was an increase in the flow and travel times of road network existing in Sleman Regency, either ring 2, ring 3 or the road network outside the rings. There was a decrease in performance in ring 1 because all road networks were only used by refugees in one direction from home to ring 2 in order to keep away from the disaster source. The coverage of evacuation movement did not affect the movement existing in the areas of Yogyakarta City, Bantul Regency, Kulon Progo Regency and Gunung Kidul Regency. Furthermore, it was necessary to carry out an evacuation simulation in ring 2 and ring 3 in order to expand the coverage of the affected area and the extent of the effect of performance changes in the existing road networks.

Keywords: Model, Evacuation, SATURN, Flow, Travel times.

1. Introduction

Mount Merapi, located in Yogyakarta Special Region, is one of the 129 active volcanoes in Indonesia, has erupted more than 80 times and the last eruption in 2010 claimed more than 400 lives [1][2]. Among of the effective solutions for reducing casualties are moving the population permanently (relocation or resettlement) or temporary (evacuation) and enhancing knowledge of the population about natural disasters [3][4].

High population on the side of the mountain and directly adjacent to Yogyakarta city makes the people highly vulnerable to the threat of disaster [5]. An optimum evacuation plan in a state of emergency is an attempt to reduce the number of fatalities. Optimizing the performance of road network for evacuation routes is a critically important part due to high flow of traffic on the road network when the refugees move in panic [6]. Evacuation planning is required to ensure the safety of refugees by involving safe evacuation route network and shelters [7]. Designing an optimum evacuation route is a method to ease the congestion during evacuation [8-10].

Previous studies have introduced a correlation between optimum evacuation plan and levels of adherence to traffic management [11]. An extensive analysis of the phenomenon of changes in the performance of road network during a disaster can be performed using a macroscopic evacuation transport modelling [12]. This paper aims to identify the extent of changes in road network performance due to evacuation of Mount Merapi disaster on the directly affected area.

2. Literature Review

Transport modelling for evacuation can be made using demand model and supply model. The method of network loading by means of user equilibrium (UE) is a method that can be applied from the demand side. The UE is able to analyze flows and travel times of the road network even in a state of emergency, which has resulted in a conclusion that the measurement of evacuation performance is greatly dependent on the structure of road network and the number of vehicles existing in the emergency planning zone [10][13]. UE assignment in emergency evacuation modeling can also optimize route selection and travel times to reduce delay during an evacuation [7]. Several studies
applied emergency evacuation in supply model such as disaster as the cause of disconnection of some networks as a basic model for optimizing travel times and searching indices of the changes in terms of toughness and susceptibility of road networks [14-16]. Disconnected road network can be caused by disruption during disasters such as networks submerged by flood, fires and other disruptions. Modeling for evacuation can also be made by identifying critical networks. Several methods to analyze critical networks include, among other, taking congestion or ratio between road flow and capacity into consideration [17][18].

Travel distribution is an essential aspect of the transport and travel simulation process. Although distribution and loading are often discussed separately, but human behavior makes these three stages related to one another. Regarding to travel distribution, it is necessary to know two things about the end of the travel, namely connected together, without determining the actual route and sometimes without reference to travel mode, with a travel matrix between origin and destination known [19]. The Furness method generates flow from the first equilibrium zone and pull into a balanced zone, as expressed in equation 1.

\[
t'_{ij} = t_{ij} \times \frac{p_i}{p_i} \\
t''_{ij} = t'_{ij} \times \frac{A_j}{\sum \text{pull of travel to } j \text{ in the first iteration}} \\
t'''_{ij} = t''_{ij} \times \frac{p_{ij}}{\sum \text{travel generated from } i \text{ in the second iteration}}
\]

Transport modeling eventually requires regression analysis to analyze changes in road network performance burdened by the evacuation process including flow and travel times as dependent variables and the number of refugees in the affected area as an independent variable, as expressed as equation 2.

\[
Y = b_0 + b_1 x X_1 + b_2 x X_2 + b_3 x X_3 + \cdots + b_n x X_n
\]

Where,

- \(b_0\) = intercept term or constant (results of regression analysis)
- \(X_1, X_2, X_3\) = independent variable.

3. Methodology

Data required in this research were origin-destination (OD), road network, validation data and general overview of evacuation route. Daily OD matrices and disaster evacuation were made by modifying data taken from the 2012 Regional Transport Level (Tatrawil) of the Province of Yogyakarta Special Region predicted in 2016 as a base year model. The development of road network was constructed from the Decree of the Minister of Public Works and Housing No. 248/KPTS/M/2015, Decree of Governor of Yogyakarta Special Region No. 118/KEP/2016, Decree of Sleman Regent Number 105/Kep.KDH/A/ 2013, Regional Regulation of Yogyakarta City No. 2 of 2010, and then summarized into a network map using ArcGIS program. Meanwhile, the validation employed data of traffic counting results that referred to National IRMS data of Province of Yogyakarta Special conducted by the National Roads Planning and Development Agency (P2JN). Moreover, the simulation required data from studies of the making of evacuation route in disaster prone areas of Sleman Regency issued by the Regional Disaster Management Board (BPBD) of Yogyakarta Special Region in 2014.

With the help of SATURN version 11.3.12W, this model involved 140 centroid, 449 buffer nodes, and 589 segments. The rise and pull inputs of the travel during evacuation were obtained from the modification of daily OD matrices and the number of directly affected people in ring 1 with variations of 50%, 60%, 70%, 80%, 90% and 100% of refugees. Road network performance observed was total flow and travel times in ring 1, ring 2, ring 3, Sleman (outside the ring), Yogyakarta, Bantul, Kulon Progo and Gunung Kidul.
4. Results and Discussion

4.1. Results

In the traffic modeling, understanding of network characteristics is very important to build a model that can represent the actual state of the network. In order to run the model in the SATURN program, two types of data were first input, namely origin-destination matrices (ODM) and road network. The output of road network model is shown in Figure 1.

![Figure 1. Output model of SATURN](image)

In addition to the output of network image, the results obtained from the SATURN program were the traffic flow in PCU/hour and travel cost or time in second. Prior to the model simulation, validation was done by comparing the model results with the traffic counting in the field. After the model was considered similar, the simulation process was done to analyze the road network based on the evacuation movement in ring 1. The variations of refugee movement started with 0%, or daily travel, while 50%, 60%, 70%, 80%, 90% and 100 % were loading simulation of the number of people evacuating. The results of analysis indicating the changes of road network performance are shown in Table 1 and Table 2.

**Table 1. Total flow of road network**

<table>
<thead>
<tr>
<th>Refugee (%)</th>
<th>Ring 1 (PCU/hour)</th>
<th>Ring 2 (PCU/hour)</th>
<th>Ring 3 (PCU/hour)</th>
<th>Sleman (Outside the ring)</th>
<th>Yogyakarta City</th>
<th>Bantul</th>
<th>Kulon Progo</th>
<th>Gunung Kidul</th>
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<tbody>
<tr>
<td>0</td>
<td>3236</td>
<td>64184</td>
<td>504959</td>
<td>130289</td>
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<td>93003</td>
<td>107096</td>
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<td>2989</td>
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<td>128563</td>
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<td>91841</td>
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<td>128616</td>
<td>216363</td>
<td>91597</td>
<td>105527</td>
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</tr>
</tbody>
</table>

**Table 2. Total travel times of road network**

<table>
<thead>
<tr>
<th>Refugee (%)</th>
<th>Ring 1 (second)</th>
<th>Ring 2 (second)</th>
<th>Ring 3 (second)</th>
<th>Sleman (Outside the ring)</th>
<th>Yogyakarta City</th>
<th>Bantul</th>
<th>Kulon Progo</th>
<th>Gunung Kidul</th>
</tr>
</thead>
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<td>0</td>
<td>19832</td>
<td>533607</td>
<td>1403447</td>
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<td>1389225</td>
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<tr>
<td>50</td>
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<td>1395381</td>
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</tr>
</tbody>
</table>
The subsequent performance changes were analyzed using linear regression in order to obtain the equation of each variation of the number of refugees evacuating in the areas under observation. In order to obtain the equation, dependent variable was determined which was the total value of network road network and travel times, while independent variable was the percentage of population that evacuated. The graphs of the correlation between the variations of the number of refugees and the flow and travel times of the road network of each area observed are shown in Figures 2 and Figures 3.

**Figure 2.** Graphs of the correlation between total flow of road network and the number of refugees
Figure 3. Graphs of the correlation between the total travel times of road network and the number of refugees

4.2. Discussion

The results of interviews previously conducted with the population in the area directly affected by natural disaster of Mount Merapi indicated that the number of population who would evacuate using vehicles was 91% and the rest would do on foot. Therefore, by using the equation produced previously, this research obtained the total change of travel times and flow from daily condition for each observation area as shown in Figure 4 and Figure 5. As a result, it could analysis the extent of influence resulted from the evacuation process of the population in ring 1 area.
Figure 4. Graph of changes in total travel times of the road network in the observation areas

Figure 5. Graph of changes in total flow of road network in observation areas

Figure 4 and Figure 5 show that the affected areas due to the movement of refugees were ring 2, ring 3 and Sleman Regency located outside the ring. The total flows of road network were 73,319; 198,760; 517,415 pcu/hour respectively, while the total travel times were 625,526; 1,221,685; 3,113,877 seconds from previous 533,607; 1,221,685; 3,113,877 seconds respectively. From such results, it can be seen that the value of travel times on the road network existing in ring 3 decreased although the flow increased, because the capacity of the existing road network was still able to serve the impact of evacuation movement caused by the refugees in ring 1. On the other hand, the value of total flow and travel times of the road networks existing in Yogyakarta City, Bantul Regency, Kulon Progo Regency and Gunung Kidul Regency decreased from the values of daily travel times, indicating that the coverage of evacuation movement did not affect the movement in the areas. On actual condition, this decrease could be more significant due to the fear of the danger of disaster and the prohibition from parties concerned to keep alert and reduce travel activities.

The next phenomenon was the decrease in the total flow and travel times of the road network in ring 1, because during the disaster all road networks in ring 1 tended to be used only by the refugees in one direction to stay away from the source of disaster. It causes the capacity of the road became larger to accommodate the evacuation movement. This phenomenon might be different when the evacuation occurred in the areas of ring 2 and ring 3.

5. Conclusion

Based on the results of the discussion, some conclusions can be drawn as follows:

a. The evacuation taking place in ring 1 increased the values of flow and travel times of the road network existing in Sleman Regency either ring 2, ring 3 or road network outside the ring.

b. Road networks existing in Yogyakarta City, Bantul regency, Kulon Progo regency and Gunung Kidul regency decreased Performance.
c. The decrease in the values of flow and travel times in ring 1 was indicated because the road network was only used by refugees in one direction to keep away from the source of disaster.

d. It is necessary to perform an evacuation simulation in ring 2 and ring 3 in order to observe the extent of the influence of total changes in road network performance.

e. Furthermore, disaster evacuation modeling can also be combined with changes in evacuation road network.

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REFERENCES


