Evaluation of location and number of aid post for sustainable humanitarian relief using agent based modeling (ABM) and geographic information system (GIS)

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Abstract. One of the crucial phases in disaster management is the response phase or the emergency response phase. It requires a sustainable system and a well-integrated management system. Any errors in the system on this phase will impact on significant increase of the victims number as well as material damage caused. Policies related to the location of aid posts are important decisions. The facts show that there are many failures in the process of providing assistance to the refugees due to lack of preparation and determination of facilities and aid post location. Therefore, this study aims to evaluate the number and location of aid posts on Merapi eruption in 2010. This study uses an integration between Agent Based Modeling (ABM) and Geographic Information System (GIS) about evaluation of the number and location of the aid post using some scenarios. The ABM approach aims to describe the agents behaviour (refugees and volunteers) in the event of a disaster with their respective characteristics. While the spatial data, GIS useful to describe real condition of the Sleman regency road. Based on the simulation result, it shows alternative scenarios that combine DERU UGM post, Maguwoharjo Stadium, Tagana Post and Pakem Main Post has better result in handling and distributing aid to evacuation barrack compared to initial scenario. Alternative scenarios indicates the unmet demands are less than the initial scenario.

Keywords: sustainable, agent based modeling, response phase, geographic information system

1. Introduction

Response phase or emergency response phase is one of the most important phases in disaster management. It requires a sustainable system and a well-integrated management system. Any errors in this short phase will impact on the significant increase of the victims number as well as material damage caused. In addition, it will result in increased casualties and rising refugees that have not been addressed, loss and damage to infrastructure, and emergence of various socio-economic problems, thus making the issue of disaster management more difficult. Determining the location and facilities for the humanitarian relief supply chain in the emergency response phase should be noted in order that aid delivery can be done quickly and appropriately [1]. Determining and selecting the location of
disaster response facilities for the storage of emergency supplies should be managed to ensure the quality of health services provided after occurrence of large scale emergencies such as earthquakes [2].

Emergency operations require precise, accurate, fast and reliable information to facilitate command in making decisions. In the emergency response phase, consideration of the timing of how quickly an information can be received is then disseminated to volunteers [3]. In addition, all actors involved in humanitarian emergencies are entitled to special attention [1, 4]. Several previous studies have integrated Agent Based Modeling (ABM) and GIS in the modeling of multiple disaster case study and determination of the locations and facilities after the disaster. So, ABM will be more complete when integrated with GIS [5].

Spatial data support and geographic visualization data in ABM is one way to make the model capable of being representative of real conditions such as transportation flow, pedestrian path and other geographic data. GIS and ABM can be utilized to explore humanitarian assistance at the individual level after natural disasters, such as earthquakes [6]. The integration of ABM and GIS has been effectively used in optimizing healthcare locations planning for urban population characteristics [7] as well as for building simulation models in the region populations development, the burden and spread of disease, health infrastructure and estimating impact of investment resource decisions related to population health costs and health care systems [8]. Using ABM and GIS explicitly traces agents behavior patterns and helps to understand the resulting processes and effects. ABM and GIS concepts can be used to estimate the number of victims and total global rescue time on real conditions [9].

ABM is a method to study a system consisting of interacting agents and giving rise to the new nature because of interaction. The emerging new nature can’t be summed up simply by uniting all the agent properties [10]. So ABM is a simulation model that represents individual actors or agents in a dynamic social system. On the ABM concept, a system is modelled as a collection of entities that can make their own decisions called agents. While GIS is a computer based tool used to collect, store, manipulate and display spatial reference information used to support decision making in a variety of contexts, including spatial planning and environmental management [11].

One of the disasters that became object of this research is the Merapi eruption in 2010. It resulted in the loss of lives and property. It is the largest compared to similar disasters in the previous five events (in 1994, 1997, 1998, 2001 and 2006). Based on this background, conducted research on the evaluation of location and number of aid posts using agent based modeling (ABM) and GIS for Sleman District Yogyakarta in handling the Merapi Eruption case. The integration of ABM and GIS will show real conditions in a more complex and more representative manner relating to geographical conditions in the field, it will be very helpful in decision making policies related to the number and location of aid posts for aid distribution to refugee barracks.

2. Material and Methods

Modeling formulation and description in this research refers to ODD (overview, design concept and detail) Protocol rules. The conceptual model developed can be seen in Figure 1.

A. Model Description

a) Overview

1. Purpose

The model purpose is how to know the best location and right number so that with the assistance capacity that is owned to be able to meet the demand on the barracks evacuation based on the refugees needs that exist during the emergency response.
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Figure 1. Conceptual Model of Location System and Aid Posts Number

2. Entities, state variables, and scales
   a. Entities; involved in this modeling are humanitarian organizations or volunteer category agencies, refugees (victims category agents) and patches. Victims (refugees), are divided into categories of age is children, adolescents, adults, elderly and disability agent. Each refugee by age category has different energy, needs and shifting speed. The refugees are in the region, according to population density of each sub district in Sleman District. Then, initial supply capacity of volunteers is 600 and volunteer energy at the initial stage is 3000.
   b. State variables consisting of volunteer capacity and energy owned by refugees and volunteers.
   c. Scales; are periods of simulation time of emergency response = 60 days, where an agent movement on this model in 1 day = 60 ticks. If 1 day consists of 60 ticks, so 60 days consist of 3600 ticks (60 x 60 ticks).

3. Process overview and scheduling
   Based on the number and location of pre-arranged aid posts, a simulation model was created to determine the direction of agent movement. Refugee agent will move towards the evacuation barracks and stay in barracks. Furthermore, based on the mechanism, the volunteer category agents will move towards the area to provide assistance in accordance with their capacity. More can be seen in Figure 2. The main post location used in the model scenario is as follows:
   a. Initial scenario; Maguwoharjo and UGM Post
   b. Scenario 1 ; UGM, Maguwoharjo and Pakem Post
   c. Scenario 2 ; UGM, Maguwoharjo and TAGANA Post
   d. Scenario 3 ; UGM, Pakem Post and TAGANA Post
   e. Scenario 4 ; UGM, Pakem Post, TAGANA Post and Maguwoharjo stadium

b) Design Concepts
1. Basic principles
   The basic principle of model is the movement of each agent (refugees and volunteers) to evacuation barracks. Agent victims in the evacuation form of Merapi eruption will make movement to the point of evacuation, settling and reporting their needs. The total needs of displaced and moving people in the barracks will be an evacuation barracks demand. Furthermore, volunteers will rush to the evacuation barracks to provide assistance according to their respective capacities. If volunteers have found refuge barracks, their capacity will be distribute to reduce the demand of evacuation barracks use following equation:
a) If initial capacity ($C_t$) > demand ($D_t$):
\[
C_{t+1} = (C_t) - (D_t) \\
D_{t+1} = 0
\]  
(1)

b) If initial capacity ($C_t$) < demand ($D_t$):
\[
D_{t+1} = (D_t) - (C_t) \\
C_{t+1} = 0
\]  
(2)

Figure 2. Model scheme of determining the number and location of aid posts

If volunteer capacity has been exhausted or capacity is equal to 0, they will move towards the volunteer post area. The post areas specified in this study are patched with pycor = 60 on the simulation interface. After that, they will have capacity to return and provide assistance to the next refugee barracks. To ensure that demand moves reasonably and doesn’t decrease drastically, update...
demand is done in accordance with the level of demand increase in the case of Merapi Eruption 2010 using following formulation:

\[ D_{(t+1)}^{update} = D_{(t+1)} + (150 \times (\text{Rate of Demand})) \]  

2. Emergence

Refugees and volunteers move at their own pace and energy. The specified road width is 6 meters. Maximum density of non-skipping paths is 6 people/ m². So the path cannot be skipped if there are about more than 36 people or 40 people per patch on the simulation display. So, the accumulation or agent inhibition who will distribute relief is one of the phenomena that become emergence in this research. The main emergence produced is a graph of the average number of unmet victims' requests. Since the beginning of the incident \( t = 0 \) days (tick = 0) to \( t = 60 \) days (tick = 3600) forward in accordance with the period of emergency response. The average number of unmet requests will increase in the early phase of the disaster. Furthermore, it will decrease until the end of the emergency response period.

3. Interaction

The model includes the interaction between agents and environment that is the path to point of evacuation barracks. The form of interaction between refugees and barracks is to report the number of needs (requirement transfer). While form of voluntary interaction with refugee barracks is the transfer of capacity in distribution form of aid by allocating some agent capacity to fulfill requests for assistance at the evacuation barrack point (corresponding to equation 1 and equation 2).

4. Observation

There are two plots used for observation; the average number of unmet demand and the final stock supply capacity of the supplies until the end of emergency response period. Data from the number of unmet requests are used to measure how much aid effectiveness is being used for each scenario in the quantity model and location of aid posts created.

c) Detail

In this study, the detail section only includes initialization and this model has no input and sub model in its development. At the beginning of the initialization phase, the scenarios are used which consist of the scenario based model, scenario 1, scenario 2, scenario 3 and scenario 4. Furthermore, the number of IDPs in Sleman region is determined with values ranging from 0 to 3000 people. While the volunteers number ranged from 0 to 100 people. Rate of demand is determined on a scale of 0 to 0.1. Then determined value of other parameters namely the amount of initial energy refugees by age category.

B. Implementation on NetLogo 5.2.0

Based on the system characteristics, subsequent translation of these characteristics in the programming language (coding) in accordance with those available on the software used. ABM software used in this research is NetLogo 5.2.0 in accordance with the predefined ODD Protocol rule. Sleman area maps that have been converted to maps with raster and txt format, will be inputs in the program. While the predefined parameters are best managed in the initialization stage so that resulting output reflects the real conditions. In interface display, will appear a map of the Sleman district complete with a highway that can be passed by the refugees and volunteers. This street is the path used by the refugees to refugee barracks and volunteers in distributing aid to the refugee barracks.

C. Verification and Validation

1) Verification

Verification is done by using structure code walk through method by asking expert opinion about coding program which made to have been working as it should and giving input to coding program to show and work according to the specified work scheme.
2) Calibration
Calibration of ABM model aims to repair and document the accuracy of parameter values of the model made. Calibration performed on this model is to test the validity of the model and resulting output based on different parameter values in the tools behaviour space on Netlogo. Parameter values close to real conditions are determined based on the smallest maximum error value and Mean Absolute Error (MAE) value is the smallest of all simulations performed. The final calibration result can be seen in Table 1.

| Parameter         | Value            |
|-------------------|------------------|
| Number of Victims | 2717 (scale 1: 10) |
| Number of Volunteers | 90 (scale 1: 10) |
| Rate of Demand    | 0.05             |
| Energy of Children| 450              |
| Energy of Teenager| 500              |
| Energy of Adults  | 700              |
| Energy of Elderly | 400              |
| Energy of Disabilities | 400          |

3) Validation (model calibration and face validation)
In the model calibration, validation is done by comparing the final output of the final stock of the simulated aid capacity to the total ending stocks of the aid under actual conditions. Therefore, some statistical tests were performed in knowing the significant relationship between the simulation results and the actual conditions. In this case, the t-paired sample test is used to determine the relationship of final stock data on actual supply of supply and ending stocks of simulated aid supplies. Before the test t-paired sample test, first tested the classical assumption that the data must be distributed normally and have a homogeneous variant. The result of normality tests of data using the Shapiro-Wilk test with SPSS 16 software aid shows final stock data on actual aid supply and total ending stock of simulated
aid supply has Shapiro-Wilk value greater than $\alpha = 0.05$. Based on these results, it can be seen that there is not enough evidence to reject $H_0$, so that the data used is normally distributed at a 0.05 significance level. While the homogeneity test results, obtained statistical test results with a significance value of 0.483. The significance value of 0.483 is greater than $\alpha = 0.05$. Based on these results it can be concluded that the variance of ending stocks data of actual aid supply and total ending stock of simulated aid supply is homogeneous.

Table 2. The results of t-paired sample test

| Paired Differences | Mean | Std. Deviation | Std. Error Mean | 95% Confidence interval of the difference | t | df | Sig. (2-tailed) |
|--------------------|------|----------------|----------------|------------------------------------------|---|----|----------------|
| Actual- Simulations| 4.89E+03 | 44972.3 | 7295.463 | -9892.76 - 19671.3 | 0.67 | 37 | 0.507 |

Based on table 2, it can be seen that $t$-value = 0.67 is smaller than $t$-table = 2.2069 and significance value of 2-tailed is 0.507 greater than $\alpha = 0.05$, so it can be concluded there is not enough evidence to reject $H_0$. These results indicate that there is no significant difference between the total ending stocks of the actual aid supply to the final stock end of the Netlogo simulation aid supply. In the face validation stage, the simulation model created is analysed by the expert to find out whether the model has been systematically arranged, the model is made according to the framework, and the simulation output is correct and describes the real condition.

3. Results and Discussion

Conceptually, the initial scenario movement model, scenario 1, scenario 2, scenario 3 and scenario 4 are the same. What distinguishes between each scenario is the number of main posts and the number of volunteers of each post. The number of volunteers for each main volunteer post is divided in accordance with the number of main posts. The initial scenario for the simulation model in this study shows that the main volunteer post is centered at Universitas Gadjah Mada (UGM) and Maguwoharjo Stadium. Volunteers gathered at these two main posts and then channeled the previously acquired assistance to the point of evacuation barracks.

In the simulation, volunteers (DERU UGM, TNI and POLRI) are prepared to provide post disaster assistance. For each scenario, initial initialization is done according to the parameter values obtained from the calibration result. The initial scenario, then runs with replication 10 times. Furthermore, the initial scenario consisting of 2 main posts previously developed with the addition of 1 or 2 other posts so that the total post is a combination of 3 posts or combination of 4 posts with different locations. 2 choices of post are the Pakem Post and Tagana Post. This is done to determine the speed of aid distribution to the refugee barracks with three and four different posts. In addition, scenario 1 to scenario 4 assumes the number of volunteers is evenly distributed for each post. For the value of each parameter adjusted to the value of the previous calibration parameter results. Each scenario in this study was carried out with replication 10 times.

Table 3. Final Results and Best scenario determination based on the weight of each indicator

| Scenario | Total unmet demand (unit of goods) | Total Final Stock of relief supplies | Refugees in the barracks (10 people) | Final Volunteers Simulation (10 people) | Percentage x Weight |
|----------|-----------------------------------|------------------------------------|-------------------------------------|----------------------------------------|---------------------|
| 1        | Percentage weight                 | 55.51%                             | -2.84%                              | 0.13%                                  | -1.15%              | 0.29                |
| 2        | Percentage                        | -5.39%                             | 0.114%                              | 0.24%                                  | 0.103               | -0.0045             |
The final result of simulation shows scenario 4 has unmet demand, which is smallest compared to other scenario that is equal to 14054 unit with percentage of 68.42% less compared to total unmet demand base scenario. While the total ending value of the final supply of simulated assistance is 429779 units (7.29% more supply is left than the basic scenario) and this scenario shows the number of volunteers who can still operate and channel assistance at the end of the simulation of 89 people or 2.30% greater than the number of final volunteers simulating the basic scenario. Based on these results, scenario 4 is a pretty good scenario in fulfilling the demand for evacuation barracks. In addition, based on the weighting result, the best alternative scenario is scenario 4 which has the greatest weight compared to other scenarios. Scenario 4 covers UGM area, Maguwoharjo stadium, TAGANA post and Main Pakem post with weight of 0.357.

However, all alternative scenarios indicate that the final stock of aid supplies that can still be distributed by volunteers is always greater than the basic scenario. So there is an overcapacity of aid that has not been channeled. In real conditions, this certainly creates a buildup of goods and allows the aid to be damaged. If the main priority is the fulfilment of the needs of the refugees, then the alternative scenario is quite effective in fulfilling the demand. While the excess capacity of the final volunteers and the number of volunteers at the end of the simulation becomes a weakness in modeling alternative scenarios in this model. There are several weaknesses that may occur in the implementation of scenario 1, scenario 2, scenario 3 and scenario 4 in relief distribution activities such as:

a) Application of scenario 1, scenario 3 and scenario 4 can only be done if the Merapi eruption that occurred not classified as explosive. Eruption conditions that are explosive allow the main post area grip cannot be used. This is due to regulation to avoid the area of Mount Merapi or is in a safe area with a radius of 15 km to 20 km.

b) The addition of the location and the number of main posts requires a cost and careful planning. So the cost factor becomes an important issue to consider.

Based on the conditions in the field, the basic scenario also has weaknesses in terms of distribution management of aid that is the number of relief items on the main post that has not been distributed. So the aid sometimes becomes damaged and of course this is very detrimental to disaster management activities. Therefore, good synchronization between all parties involved in humanitarian operations and disaster relief operations is required. The government should establish regulations and policies related to the ease of receiving and distributing aid. Determination of location and number of main aid posts should be further noted such as cost factors, population behaviour, community disaster perspective, speed of distribution and distribution of goods, efficiency of disaster logistics distribution and effectiveness of aid distribution.

4. Conclusion
Based on the research that has been done can be drawn some conclusions are:

a. Scenario 1 Scenario 2, Scenario 3 and 4 scenarios show better results in the handling and distribution of aid to the refugee camps compared to the initial scenario.

b. The period for reaching the balance point between unmet demand and total end-stock of aid capacity shows scenario 1, scenario 2, scenario 3 and scenario 4 faster than the time required to reach the equilibrium point for the underlying scenario or preliminary scenario.
Alternative scenarios (1, 2, 3 and 4) show the final stock capacity of supply at the end of the simulation is greater than the initial scenario. This indicates that scenario 1, scenario 2, scenario 3 and scenario 4 have weaknesses in form of the amount of aid left over and not yet efficient.

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