Scenario based logistic capacity assessment for disaster preparedness

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Abstract. Disasters that occur in various locations will definitely have impacts on infrastructure damage such as roads, bridges, markets, shopping centers. The perceived disturbances will eventually disrupt logistics distribution (including food) and other basic needs from the point of entering logistics (logistics center) to evacuation sites (victims). In the case of less severe disasters, disturbances can cause logistical delays from producers to consumers. Finally, this can cause price volatility due to the stocks decrease. This study focuses on areas along the two main routes in Aceh: the East and West routes. The object of this study includes all information related to logistic distribution are producers, collectors, traders, wholesalers, consumers, and shipping companies and related local government agencies. This study applied scenario based on the combination of multiple models and geographical information system to identify the optimal location to aid emergency logistics transportation routes. The results of this study indicate that logistics distribution is still very dependent on land transportation modes such as trucks and containers. Ports and airports have not been used optimally while the progress of railway construction is plodding.

1. Introduction

Indonesia faces a higher level of risks triggered by volcanic and tectonic activities such as the earthquake, eruption and tsunami and also experienced more frequent floods, cyclones and landslides due to climate change. Disasters that occur in various locations will have effects on the damage of infrastructures such as roads, bridges, markets, shopping centers. Therefore, the disturbances will ultimately disrupt the distribution of logistics (including foods) and other basic needs from logistic entry points (logistic center) to evacuation sites (victims). In the case of less severity disaster, the disruption may cause delays of logistic from producers to consumers. Eventually, it may lead to a price increase due to decreasing stocks. Previous studies on the relationship between logistics and disaster have been done, [1][2][3][4] however, only a few studies concerned in scenario-based models. Review on various forms and classification of tackling uncertainty in Humanitarian Logistics for Disaster Management and Optimization models utilized in emergency logistics, which are broken down into three parts: facility location, relief distribution and casualty transportation, and other operations, have been done in the past [5][6]. For example, [7] proposed a model to determine the location of relief distribution centers and the allocation of affected area to relief distribution centers
using a mixed-integer nonlinear programming to minimize the sum of the expected total cost (which includes charges of location, procurement, transportation, holding, and shortage) and the variance of the total cost. Furthermore, an attempt to improve the previous model by adding the satisfaction level variables using a multi-objective robust stochastic programming approach for disaster relief logistics under uncertainty has been done[8].

The vulnerability of a demand point can also be computed by using fault tree analysis and incorporating the study into the optimization model[9]. The locations produced by the proposed model are compared to those provided by the p-center model concerning risk value, coverage distance, and covered population by using several test problems. The model is also applied to a real problem. Another research [10] introduces a disaster preparedness system based on a combination of multi-objective optimization and geographical information systems to aid multi-organisational decision-making. The results highlighted that the number of government organizations deployed to handle the situation was excessive, leading to high cost without achieving the best possible level of satisfaction. The system proposed showed the potential to deliver better performance regarding the cost and level of service than the approach currently employed by the authorities. A more recent method on the inventory allocation optimization using a case study from the Turkish Red Crescent has been conducted using forecasting methods from the earthquake engineering literature and avoids using probabilistic scenarios to represent the uncertainties related to earthquake occurrences[11].

This research intends to examine the impact of the disaster on logistic distribution emphasizing on food security in Aceh Province. The motivation is to observe the development of logistic capacity after great Sumatra earthquake and tsunami in 2004. It is expected that the disaster impacts on logistic distribution network based on several scenarios can be derived comprehensively. The scenes involve the changing in demand and supply of goods, distance and travel time, as well as cost and benefit as a consequence of changes in distribution channels. Finally, this research will derive the perception of stakeholders along the supply chains regarding the changing in the logistics distribution in Aceh Province.

2. Methods

This study focuses on the areas along the two main roads in Aceh: Eastern and Western routes. The survey was conducted in 11 districts and cities, and the data was collected from 27 business centers and traditional markets (Figure 1). In total, 185 respondents were interviewed during August to September 2017. The object of this study covers information related to the logistics distribution of related stakeholders involved in the production, trading, and distribution of edible commodities. The stakeholders along the supply chains addressed in this study were producers, collector, traders, wholesaler, consumers, and shipping companies as well as related local government agencies.
Disaster risk analysis needs to be put in the first step in order to identify hazards, exposures, vulnerability, capacity, risk mitigation that has already been carried out, as well as the impact of the disaster. This risk analysis will be used to develop alternative decision strategies as a preventive measure and mitigation if these risks occur in the future. In this analysis, historical data from governmental bodies will mainly be used to assess the risks. Additionally, respondents’ perceptions of the locations for the future development of regional distribution centers in the study areas, during normal conditions and in the event of a disaster, will also be carried. The rationale of this is that the perceptions of respondents are: (1) expected to describe strategic location that are jointly desired from all the stakeholders involved in market activities including producers, collectors, logistics transport of traders and consumers; (2) expected to clarify the missing information that are not recorded in the local statistical data agencies regarding past exposures and impacts of the disasters as well capacities of local communities.

Spatial analysis in this study utilizes a Geographic Information System (GIS) method. Through this method will be approached the location of land that is not employed such as shrubs and open area, slope, in an overlay with an official map and supporting infrastructures such as roads, railroads, ports, and airports. Several alternative locations that are feasible and strategic will be able to be recommended according to the approach of social analysis, disaster risk analysis, and respondents’ perceptions.

In the base scenario, businesses are treated as usual without counting the impact of the disasters. Logistics, therefore, are delivered based on standard conditions, following the minimum costs and routes preferences. However, during the disaster scenario, logistics are then delivered based on the nearest affected area regardless the difficulty of the routes and costs burden. Therefore, it is important to identify which routes that will give the optimum benefits and to identify which locations that applicable to be developed as Regional Distribution Centers (RDC). These regional logistic centers will eventually minimize the dependency and time of delivery from the surrounding provinces.
3. Result

The findings show that logistic distributions still rely heavily on land transportation modes such as trucks and containers. Ports and airports have not been utilized optimally whereas the progress of railways construction is stagnant. The geographical features of Aceh and North Sumatra provinces are characterized by mountainous area so that railway connecting the two regions are hard to be developed. In the baseline scenario, the logistics in the eastern areas are transported through the north-east route or known as Medan-Banda Aceh route, while south-west course connecting Medan-Subulussalam- Aceh Barat is used to deliver logistic to western parts of Aceh. In the event of a disaster occurred at these routes, it is certain that there must be adjustments. However, alternative ways are less available. Based on Fig.2, it indicates that the dependency on the two main existing routes put this province in a high level of vulnerability regarding logistics assurance and may trigger food insecurity in the future.

Source: Primary data processed (2017)

Figure 2. Food and logistic distribution in Aceh

3.1. Disaster Risk and Logistics Distribution

On December 26, 2004, Aceh was hit by an earthquake and tsunami which resulted in the loss of hundreds of thousands of lives, damage to physical infrastructure and disturbance in economic activities. Recently, another 6 magnitude earthquake also destroyed Pidie Jaya regency on December 7, 2016. During 2017-2018, approximately 125 events, including floods, cyclones, landslides and earthquakes occurred in several regencies and caused 249,000 people to be evacuated. The disasters that occurred in various regencies had impacts on the damage to infrastructure such as roads and bridges which ultimately disrupted the smooth distribution of goods from producers to consumers in the Aceh region. Aceh also has hundreds of bridges with various specifications as illustrated in Table 7.6. Moreover, access to the distribution of goods in Aceh is only supported by 2 (two) main routes, namely the east and west edges. That is, damage to the infrastructure will lead to smooth access to the distribution of logistics goods in the Aceh region.
This research explores the extent to which disasters disrupt the activities of the respondent's economic activities. One question, for example, is: "To what extent does the following disaster disrupt your economic activities?". If the answer given by the respondent (e.g., producer) is "Never" means that the producer has never been disturbed by the disaster during the production activity. If the answer given is "Rarely-Never" means that some respondents feel annoyed with rare intensity so that they are never disturbed at all. In general, the results of this study conclude that disasters caused by disasters on economic activities of perpetrators are very minor (rarely to never). Spatially, only two regencies which concern the disruption of economic activities due to disasters as shown by yellow signs in Figure 3. Simeulue island is the only regency which may suffer serious food insecurity due to high dependency on neighbour areas. These results are relatively different from expectations because Aceh is one of the areas vulnerable to disaster. Therefore, further analysis and caution are needed in interpreting the results of this study.

3.2. Perceptions of Respondents on RDC locations

The choice of location for an appropriate infrastructure regarding technical, socio-economic and environmental will have a positive impact on the acceleration of development for the region and the surrounding area as well as one of efficient disaster mitigation. Conversely, the selection of locations that are not technically appropriate will increase the risk of incompatibility between the carrying capacity of the land and its use. From an economic aspect, the selection of inappropriate locations will increase the risk of loss and non-use of the infrastructure facilities. Therefore, it is necessary to develop indicators that can represent the range of the right location.

The results of the study on the eastern route of the Aceh region showed that as many as 21 percents of the total respondents stated that the location suitable for the existence of the RDC was a factor of proximity to the site of the primary market in the area. The second factor is that the position of the RDC should be on edge / near the national crossing of Medan-Banda Aceh. Meanwhile, the element of proximity to loading and unloading terminals and near the border of the area is the next consideration. The results related to respondents' perception of the location of the RDC in Aceh province are presented in Figure 3.

| Source: Primary data processed (2017) |
|--------------------------------------|
| Figure 3. Respondents’ perception on the RDC location |

The results of the perception study on the western route show a slight difference with the east route. On the west line, the central aspect that is important to be considered in the selection of the RDC
location is the proximity to the loading and unloading terminal which is 18 percent. Next is the factor of the vicinity of the parent market and is close to the border of the region, which is equal to 17 percent and 12 percent. Whereas the proximity factor to the west-west Medan-Banda Aceh crossing is only around 8 percent.

Based on the two graphs above, it can be concluded that most of the stakeholders related to the distribution network of staple food indicate that the exact and appropriate location criteria for the existence of the RDC are: (1) the location with the primary market in the region; (2) The area is located near / around the freight terminal; (3) the place is at least located in the vicinity of the Medan-Banda Aceh national road, and (4) the situation is at the border of the area. The results of this perception study also show that business and economic motives (costs and benefits) are far more influential than environmental factors such as disaster factors (floods, landslides, earthquake faults). This is relatively surprising because Aceh is a disaster-prone area and several cases show that there is a positive correlation between infrastructure damage due to disasters and delays in supply. Business players’ awareness toward risks may influence this phenomenon. After the 2004 tsunami in Aceh, the risk awareness level has not been put into behaviour as well as structural actions.

3.3. Western Route vs Eastern Routes RDC Scenario
The combined results of spatial data analysis with an analysis of the study of logistics distribution channels and the support of adequate facilities and infrastructure to be used as regional distribution centers in western region (see Fig 4) are at point D (city of Meulaboh) and E (city of Blang Pidie). Factors supporting the election of point D (city of Meulaboh) as an alternative location include: (1) Meulaboh is one of the reference cities to monitor the rate of inflation. Even at some time, the rate of increase in the town of Meulaboh had several times exceeded the average inflation rate in the province of Aceh; (2) Total population and readiness of supporting infrastructure such as markets, shops, warehouses, roads, loading and unloading terminals, ports are available.

However, the primary inhibiting factor in the selection of Meulaboh was the supply line. According to the results of interviews with logistic transportation actors, the supply of staple goods (non-rice) is almost 80 percent still using the eastern route. The east route has many advantages such as transportation players are many (availability of helps due to accidence), safe, wide roads and convenience, and less ascend. Another reason is fewer informal levies than using the westbound lane. So, even though the west route has a shortage regarding time (more extended travel), the costs incurred by transportation actors can be more economical (or not much different) compared to the use of westbound lanes. Some of the impacts are: (1) the possibility that the RDC in Meulaboh will depend on the RDC in Regional I at point A (potentially at Banda Aceh city or Aceh Besar regency) so that its existence is less than optimal; (2) the presence of the RDC will be less optimal in the south-west lane in other words the community in the south-west path does not touch the RDC function as the carrying capacity of food security and price protection for consumers. Therefore, if the RDC will later be built in Meulaboh, it is necessary to pay attention to the impact.

The second possible location for the RDC to be built in Region III is at point E (Blang Pidie City). Several supporting factors for the selection of Blang Pidie are: (1) this area becomes the final destination for trucks/modes of transportation from Medan / North Sumatra via Sidikalang-Subulussalam. Therefore, the function of Blang Pidie is similar to the city of Banda Aceh, which is the last stop of the logistic transportation mode via the east route. The impact, transportation, and logistic distribution activities will accelerate economic development along the path that it passes (Aceh Selatan to Subulussalam city); (2) The location of Blang Pidie is midway to regional III. This position is strategic because it has good access and connectivity with the surrounding area (Aceh Selatan-Nagan Raya and Aceh Barat). Some other supporting infrastructures including markets, shops, open space, warehousing, loading terminals, roads with sufficient access and width as well as ports are available.
The combined results of spatial data analysis with an analysis of the study of logistics distribution channels and the support of adequate facilities and infrastructure to be used as regional distribution centers II are at point B (Aceh Utara regency) and at point C (Bireuen regency). These two locations are chosen because they meet several indicators such as the availability of adequate facilities including Krueng Geukuh Port, Malikussaleh airport, industrial development planning areas, as well as low level of historical risk affected regions. The locations are also near the new line of Aceh Utara to Bener Meriah regency intersection which makes travel distance closer and faster, connecting these regencies to Bener Meriah or Aceh Tengah, which are the vegetables producing centers in Aceh, which takes ranges is from 1.5 to 2 hours to travel. The use of the route to the Aceh Utara - Bener Meriah intersection is far more preferable regarding duration and cost than using the Bireuen-Takengon crossing which takes up to 5 hours from Aceh Utara regency. To sum up, the proposed RDC location based on the scenarios is presented in Figure 4.

![Figure 4. RDCs proposed location](image)

Source: Field assessment (2017)

4. Conclusion

Especially for rice, demand needs can still be met by local rice production in Aceh. However, other commodities much rely on supply from other provinces (North Sumatra). The eastern route is more preferred by the land transportation players, connecting from Medan (North Sumatra) to Meulaboh (Aceh Barat), while the western route is only favored for the logistics from Medan to the Aceh Barat Daya, or vice versa. This study considers the establishment of a regional logistics center to facilitate the flow of supply and distribution of logistics in both eastern and western parts of Aceh Province in the future, as well as to anticipate the negative impacts related to the disruption of logistics distribution due to the natural disaster. Based on disaster risk analysis, respondents' perceptions and spatial analysis using geographic information systems found potential locations that could be used as RDCs. Aceh Besar regency, which is adjacent to the city of Banda Aceh, is one of the locations that have high
potential as a Provincial Distribution Center. Whereas for the eastern route, Aceh Utara or Bireuen Regencies are the most suitable location due to the support from the existing facilities and infrastructures, whereas Aceh Barat Daya or Aceh Barat is recommended for the west route.

**Keywords:** food security; disaster preparedness; humanitarian logistic; regional distribution center

**References**

[1] Balcik, B., & Beamon, B. M. (2008). Facility location in humanitarian relief. *International Journal of Logistics, 11*(2), 101-121.

[2] Barbarosoğlu, G., & Arda, Y. (2004). A two-stage stochastic programming framework for transportation planning in disaster response. *Journal of the operational research society, 55*(1), 43-53.

[3] Kovács, G., & Spens, K. M. (2007). Humanitarian logistics in disaster relief operations. *International Journal of Physical Distribution & Logistics Management, 37*(2), 99-114.

[4] Lin, Y. H., Batta, R., Rogerson, P. A., Blatt, A., & Flanigan, M. (2011). A logistics model for emergency supply of critical items in the aftermath of a disaster. *Socio-Economic Planning Sciences, 45*(4), 132-145.

[5] Liberatore, F., Pizarro, C., de Blas, C. S., Ortúno, M. T., & Vitoriano, B. (2013). Uncertainty in Humanitarian Logistics for Disaster Management. A Review. In *Atlantis Computational Intelligence Systems*. https://doi.org/10.2991/978-94-91216-74-9_3

[6] Caunhye, A. M., Nie, X., & Pokharel, S. (2012). Optimization models in emergency logistics: A literature review. *Socio-Economic Planning Sciences*. https://doi.org/10.1016/j.seps.2011.04.004

[7] Bozorgi-Amiri, A., Jabalameli, M. S., Alinaghian, M., & Heydari, M. (2012). A modified particle swarm optimization for disaster relief logistics under uncertain environment. *International Journal of Advanced Manufacturing Technology*. https://doi.org/10.1007/s00170-011-3596-8

[8] Bozorgi-Amiri, A., Jabalameli, M. S., & Mirzapour Al-e-Hashem, S. M. J. (2013). A multi-objective robust stochastic programming model for disaster relief logistics under uncertainty. *OR Spectrum*. https://doi.org/10.1007/s00291-011-0268-x

[9] Akgun, I., Gumusbuga, F., & Tansel, B. (2015). Risk based facility location by using fault tree analysis in disaster management. *Omega-International Journal of Management Science*. https://doi.org/10.1016/j.omega.2014.04.003

[10] Rodriguez-Espindola, O., Albores, P., & Brewster, C. (2018). Disaster preparedness in humanitarian logistics: A collaborative approach for resource management in floods. *European Journal of Operational Research*. https://doi.org/10.1016/j.ejor.2017.01.021

[11] Battarra, M., Balcik, B., & Xu, H. (2018). Disaster preparedness using risk-assessment methods from earthquake engineering. *European Journal of Operational Research*. https://doi.org/10.1016/j.ejor.2018.02.014