International Journal on Advanced Science Engineering Information Technology

Vol.9 (2019) No. 5
ISSN: 2088-5334

Designing a Relief Distribution Network under Uncertain Situation: Preparedness in Responding to Disaster

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Abstract*— None can predict a disaster precisely: where, when, and how big a disaster will strike one area. This situation leads to uncertainty in such as required demand and supply availabilities. To an area that has been identified threatening by a natural hazard, a possible disaster scenario may compile. Since time is vital in disaster response operations, developing strategies to speed up emergency response is necessitated. This study is aimed to develop a stochastic model for a location-allocation problem in responding to a forecasted disaster. Our stochastic approach recommends a number and locations of local distribution centers (LDCs) that are required to be set up in the initial stage of the response phase and a number of relief items that will be dispatched to survivors in the affected areas through the proposed relief network. A mixed delivery strategy is applied in a 3-tier of a relief distribution network encompassing warehouses, LDCs, and shelters. This strategy provides the affected people in some of the shelters to receive relief items directly from nearby warehouses, while the remaining shelters will get supplies indirectly through the opened LDCs. Comparing to the indirect strategy that shelters are permitted to receive aid goods only through LDCs, the proposed mixed delivery strategy provides more efficient and effective relief distribution. The probable tsunami in West Sumatra, Indonesia, known as Mentawai Megathrust, is employed to illustrate the developed model. The model will be beneficial for disaster managers to improve the performance of a disaster relief operation.

***Keywords*— disaster preparedness; humanitarian logistics; location-allocation; relief distribution.**

I. INTRODUCTION

Humanitarian logistics is principal in a disaster relief operation. It involves transporting relief goods such as foods, water, medicines, clothing, and shelters to victims in disaster areas to save lives and to alleviate the suffering of vulnerable people. To one area that has been recognized impended by a natural hazard, a possible disaster scenario may evolve. Then, during preparedness period, a relief distribution plan could be set up under the developed scenarios to speed up emergency response. Since time is critical in disaster response operations, it is crucial to develop strategies to speed up emergency response. It will consume much time to develop a plan that is never constructed in advance. In the end, distributing relief items will be postponed.

Designing a relief distribution network plays a significant role to increase the quality of service provided in a response period of a disaster [1, 2]. Our previous study [3] developed a mathematical model for designing the relief network. The model determined locations of LDCs as well as the number of relief items delivered through the proposed relief network in the early response period. The model addressed to the deterministic since all condition is certain. However, none can predict a disaster exactly: where, when, and how big it will occur. This situation leads to uncertainty in such as required demand and supply availabilities.

Some papers focused on stochastic relief distribution models at the strategic level are [4]–[10]. The papers concern about selecting locations of warehouses for storing relief prepositioning stocks conducting in pre-disaster. Moreover, the previous studies only considered one stage delivery where relief items will be directly distributed from the warehouses to affected people in affected areas (a direct delivery strategy). Mostly, warehouses are set up in the capital city or the big city, while a disaster may happen in remote areas. In this situation, applying the right strategy will require more relief vehicles since the vehicles are needed to get back to the warehouse, then it will spend much time. Other papers concerning more stages are [4], and [9]–[14]. They involved a 3-tier of a relief distribution network (warehouses-LDCs-shelters). The LDC has a function as a bridge between the warehouses as a source of supplies and survivors who stay at the shelters. Then, the items will be distributed from the warehouses to LDCs before shipping to recipients. This strategy is called an indirect distribution strategy. Some of the shelters could be located close to the warehouses, so implementing the indirect strategy that requires relief goods to stop in the LDCs before dispatching to the shelters would be inefficient.

This study is a continuation of our previous study [3] by introducing a stochastic approach to design a relief distribution network and determine the number of items shipped through the proposed network. A mixed delivery strategy that integrates a direct and indirect delivery to obtain the timely and effective mobilization of aids supplies is applied. The proposed stochastic model is implemented to a predicted tsunami disaster that would occur shortly in West Sumatra, Indonesia. The current study can contribute to assist a disaster relief manager in conducting a more effective and efficient relief response operation.

II. Material and Method

This section proposes a mathematical model to solve a location-allocation problem. In a location-allocation problem, the optimal locations for setting up facilities such LDCs will be selected among the number of possible sites, and the number of items will be allocated from the located facilities to demand points. The proposed model acknowledges an uncertain situation; then it will be considered as a stochastic model. Our stochastic model has an objective to minimize the total cost encompassing opening cost for setting up LDCs, the transportation cost for transporting relief items through the proposed network, and the penalty cost relating unfair distribution among disaster victims.

A. Mathematical Formulation

In case of a disaster, in the immediate aftermath, a large amount of the relief goods p ($p \in P$) are required to be transported from warehouse i ($i \in I$) to survivors who stay in shelter k ($k \in K$) to mitigate loss and misery. Fig. 1 shows the design of the proposed relief network.

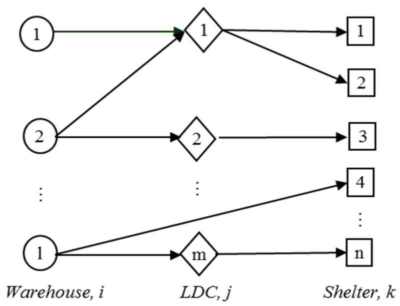

Fig. 1 The proposed relief network design

During the preparedness period, at the planning stage, the demand of relief goods p at shelter k, d_{pks}, is uncertain because it is not yet known if, or where, an event will take place. This uncertainty is significant to the location-allocation model. In some locations, there may be a relatively large probability of victims that require aid supplies throughout the horizon plan.

Uncertainty is defined using a set S of discrete scenarios indexed by $s \in S$, each with a probability of occurrence, α_s. The scenario involves the predicted demand by relief goods and shelter, d_{pks}.

For some situations, the shelters may locate in remote areas and far away from the warehouses. In order to make an efficient and effective relief distribution, it is recommended to open LDCs located between the warehouses and the shelters in the early of response period in a set J, indexed by $j \in J$ with fixed cost f_j. Let Z_{js} be a binary variable equal to 1 if LDC j is opened in scenario s, and 0 otherwise. In scenario s, the LDC j will serve the closest shelter k with an amount X_{pjks} and the transportation cost c_{pjk} while the remains of shelters located nearby the warehouse will be supplied directly from the warehouse with an amount of X_{piks} and the transportation cost c_{pik}.

In this study, it is assumed that each shelter merely receives aid supplies from one of the supply points, either from one of the warehouses or one of the LDCs. Let L_{bks} be a binary variable equal to 1 if shelter k is served by supply point b namely, either one of the warehouses or one of the opened LDCs ($b \in I \cup J$) in scenario s, and 0 otherwise. The formula is as follows:

$$\sum_{b \in I \cup J} L_{bks} = 1 \qquad \forall k \in K, \forall s \in S \qquad (1)$$

If shelter k has been assigned to one of the supply points, either one of the warehouses or one of the LDCs, then the shelter k is not permitted to receive supplies from other points.

The number of aid supplies that will be shipped to each shelter from any supply point in scenario s cannot exceed its required demand. The formula is as follows:

$$X_{pbks} \le L_{bks} d_{pks} \quad \forall p \in P, \forall b \in I \cup J, \forall k \in K, \forall s \in S \qquad (2)$$

In case demand points are assigned to LDC j in scenario s (L_{jks}=1) then LDC j should be opened in scenario s (Z_{js}=1).

$$\sum_{k \in K} L_{jks} \le M Z_{js} \qquad \forall j \in J, \forall s \in S \qquad (3)$$

Thus, no delivery will occur from LDC j unless LDC j is open in scenario s. It is assumed that the capacity of LDC j is unlimited, denoted M as a big positive number since the received items from warehouses will be shipped directly to the affected people.

$$\sum_{p \in P} \sum_{k \in K} X_{pjks} \le M Z_{js} \qquad \forall j \in J, \forall s \in S \qquad (4)$$

Contrast to the shelter, the selected LDCs are allowed to be supplied by at least one of the warehouses. The total amount of items transported from any warehouse to the opened LDCs in scenario s is the same as the total amount of items transported from those LDCs to any shelter in scenario s.

$$\sum_{i \in I} X_{pijs} = \sum_{k \in K} X_{pjks} \qquad \forall p \in P, \forall j \in J, \forall s \in S \qquad (5)$$

Generally, the amount of stocks prepositioned at warehouses is limited since it is expensive. The total amount of items that will be delivered from the warehouses to all destination point a ($a \in J \cup K$), either the LDCs or the shelters, is less or equal to its available supplies. We denote g_{pi} as the amount of relief item *p* prepositioned at warehouse *i*, and β_{is} as a probability of warehouse *i* will damage in scenario *s*.

$$\sum_{a \in J \cup K} X_{pias} \leq g_{pi}\beta_{is} \qquad \forall p \in P, \forall i \in I, \forall s \in S \qquad (6)$$

A shortage demand of item *p* will be charged by shortage cost h_p. In case of unfair distribution - unequal allocation of supplies among the shelters - each type of item distributed unfairly will be penalized by unfairness cost r_p. This cost is related to the value of human life and the social cost then the value increases with the standard of living [18]. Accordingly, it is hard to measure but it requires to be defined. The level of dissatisfaction of shelter *k* for relief item *p* in scenario s, U_{pks}

$$U_{pks} = \frac{d_{pks} - \sum_{b \in I \cup J} X_{pbks}}{d_{pks}} \qquad \forall p \in P, \forall k \in K, \forall s \in S \qquad (7)$$

Uneven distribution of relief item *p* over the shelters in scenario s, E_{ps}

$$E_{ps} \geq \left| U_{pvs} - U_{pws} \right| \qquad \forall p \in P, \forall s \in S, \forall (v,w) \in K, v \neq w \qquad (8)$$

Finally, non-negative constraints are defined by

$$X_{pias} \geq 0 \qquad \forall p \in P, \forall i \in I, \forall a \in J \cup K, \forall s \in S \qquad (9)$$

$$X_{pjks} \geq 0 \qquad \forall p \in P, \forall j \in J, \forall k \in K, \forall s \in S \qquad (10)$$

Though saving disaster victims ideally should be conducted at any cost, but DROs are usually restricted by budget. Therefore, the objective of the model is to minimize the total logistics cost, which encompasses four types of cost. First is the total cost for opening the LDCs; calculated by multiplying the number of opened LDCs with the cost required to open each LDC. Second is the overall distribution cost; determined by multiplying the amount of item delivered from one point to another with the transportation cost between the points. The third is the total shortage cost; obtained by multiplying the amount of shortage demand with the shortage cost. Fourth is the total unfair distribution cost; calculated by multiplying the unfairness cost with the maximum differences of relief allocation among the shelters.

$$\text{Minimize} \quad \sum_{s \in S} \alpha_s \left\langle \begin{aligned} &\sum_{j \in J} f_j Z_{js} + \\ &\sum_{p \in P} \left\{ \begin{aligned} &\left(\sum_{i \in I} \sum_{a \in J \cup K} X_{pias} c_{pia} + \sum_{j \in J} \sum_{k \in K} X_{pjks} c_{pjk} \right) + \\ &h_p \left[\sum_{k \in K} \left(d_{pks} - \sum_{b \in I \cup J} X_{pbks} \right) \right] + r_p E_{ps} \end{aligned} \right\} \end{aligned} \right\rangle \qquad (11)$$

III. Results and Discussion

A. Data Sets

The future disaster known as Mentawai Megathrust in Sumatra, Indonesia, is used to illustrate the proposed model. According to geological and biological record, [19] found that the Sumatran megathrust sectors have been frozen over than 200 years since the last powerful 9.0 magnitude earthquake that triggered a tsunami in 1833. He predicted that these sectors are ready to release their energy within the next few decades and cause a giant earthquake that triggers a tsunami. In case the event takes place, it will affect the seven coastal cities in West Sumatra, including Agam, Mentawai, Padang, Padang Pariaman, Pariaman, Pasaman Barat, and Pesisir Selatan. The event will influence more than one million people, and the estimated losses are at least the same as the 2004 Indian Tsunami.

Surprisingly, the forecasted disaster has gained attention not only from the government of Indonesia but also from the foreign country. There were 3,700 people from 17 countries and international organizations participated in "the 2014 Mentawai Megathrust Disaster Relief Exercise" hosted by the government of Indonesia National Disaster Management Agency (Badan Nasional Penanggulangan Bencana, BNPB) [20]. The event which took place in Padang, West Sumatra, Indonesia used the issue of Mentawai megathrust to strengthen collaboration and partnership in disaster response among the candidate donors.

The West Sumatra's contingency plan for a tsunami disaster has been developed under a scenario that is the 8.8 SR of a forecasted earthquake centered on Siberut Island, in the group of the Mentawai island, at a depth of 30 km would occur on Monday at 10.00 AM (Fig. 2) [21].

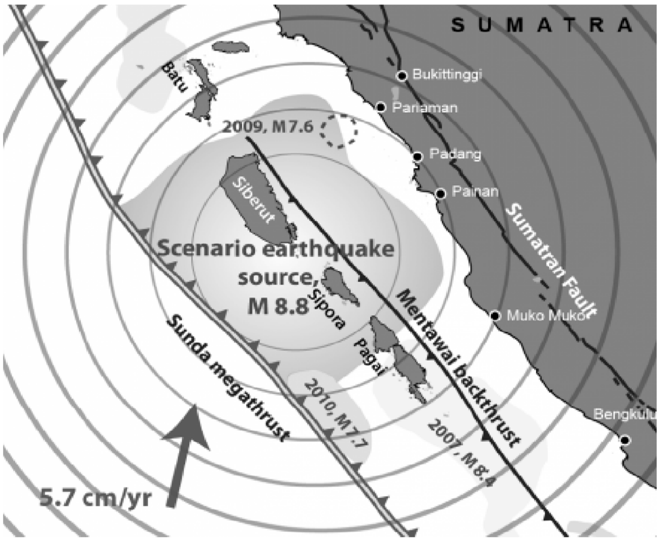

Fig. 2 The probable scenario of an earthquake in West Sumatra, Indonesia

Since it is forecasting, any other situation still possibly occurs. One of the scenarios is that the epicenter of the assumed disaster would shift to the north along 50-200 km of the fragment, such in [22] and occur during the weekend (non-working hour). Respect to the impact of the disaster and population densities around the red zones, in any times of the day, the demand for relief supplies would be different from the first assumed scenario provided in the contingency plan.

In this study, the first assumed scenario is elaborated to anticipate the possibilities of other scenarios happening. Three periods of time between Monday and Friday (work-day) are applied: four hours (6 AM - 8 AM and 4 PM – 6 PM) defined as a rush hour (R), eight hours (8 AM – 4 PM) categorized as a working hour (W), and the remaining time as a non-working hour (N). Saturday and Sunday are dealt with a non-working hour (N). Therefore, there are 20 rush hours, 40 working hours, and 108 non-working hours in a week. Moreover, the relative probabilities of the epicenter of the earthquake shifting a little to the north, to the south, and fixed according to the prior predicted earthquake are assumed respectively 0.15, 0.25, and 0.6 which are obtained by assessing the seismic gap map of Sumatra [19]. Table 1 shows the probabilities of the nine scenarios which are found by multiplying the proportion of each period by the shifting probabilities. For example, for 0.02 of the probability of scenario that the epicenter will shift to the north and the predicted earthquake will occur during the rush hour, it comes from by dividing 20 hours of rush hour by 168 hours of available hours in a week then it is multiplied by 0.15 of shifting probability of earthquake epicenter to the north.

TABLE I
PROBABILITIES OF SCENARIOS

Scenario	**Shift to the north (SN)**		
	R	**W**	**N**
Probability	0.02	0.03	0.1
Scenario	**Shift to the south (SS)**		
	R	**W**	**N**
Probability	0.03	0.06	0.16
Scenario	**Fixed (F)**		
	R	**W**	**N**
Probability	0.07	0.14	0.39

Table 2 presents the estimated number of survivors for each scenario calculated based on the population density and percentage of safe people provided in the contingency plan [21]. We consider the fact that there are more people in the red zone of tsunami during the working hour than the non-working hour since the center of business and government activities are close to the coast such as in Padang City. In case the event takes place in the working period, the estimated number of safe people would be less than in the non-working period. In the situation where the center of the earthquake shifts to the north, the cities in the southern part of West Sumatra will get less influence than in the north one thus the number of survivors such in P. Selatan will be increased. In this study, all the affected cities, excluding Mentawai are taken into consideration since that region consists of islands situating apart from others.

Three warehouses, ten locations of potential LDCs, and 34 shelters are considered in the proposed relief distribution network for distributing three kinds of relief items, as shown in Fig. 3.

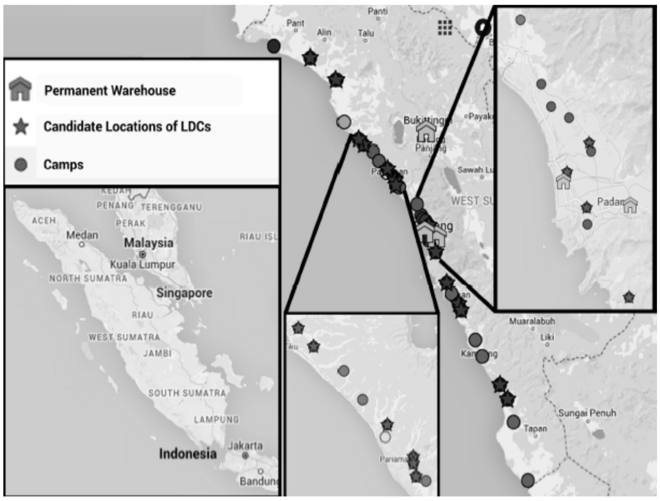

Fig. 3 Locations of Warehouses, potential LDCs, and Shelters

The number of relief stocks at the warehouses are assumed the same as in [3], as presented in Table 3. The shortage costs per package of relief aids are set at 3, 2, and 5 USD for rice, noodle, and preserved food, while the cost of unfairness for each item is assumed to be 1,000-time the shortage cost of the item. The cost of setting up an LDC is 500 USD.

Two types of the truck are used to transport relief goods. The 6-wheel truck of 4 tons will be assigned to ship relief goods to LDCs with transportation cost of USD 0.35 per kilometer, while the 4-wheel truck of 1.5 tons is utilized to transport the supplies to shelters with a transportation cost of USD 0.5 per kilometer. The vehicle speed is assumed 30 km/h. The distance between the two locations is obtained from Google Maps.

TABLE II
NUMBER OF ESTIMATED SURVIVORS IN THE PREDICTED DISASTER

Cities	**Shift to the north**		
	R	**W**	**N**
P. Selatan	154,331	143,688	164,975
Padang	417,361	388,687	430,104
P. Pariaman	13,053	14,296	11,809
Pariaman	36,883	35,465	38,302
Agam	15,256	16,709	13,804
P. Barat	50,282	55,071	45,494
Cities	**Shift to the south**		
	R	**W**	**N**
P. Selatan	131,980	129,851	134,109
Padang	420,547	395,059	433,290
P. Pariaman	16,906	18,149	16,160
Pariaman	43,125	41,990	44,260
Agam	19,615	21,214	18,162
P. Barat	69,916	70,874	69,437
Cities	**Fix in the center**		

	R	W	N
P. Selatan	149,009	138,366	159,653
Padang	414,175	382,315	426,918
P. Pariaman	13,674	14,917	12,431
Pariaman	42,558	39,721	43,693
Agam	15,983	17,436	14,530
P. Barat	52,677	57,465	47,888

TABLE III
THE AMOUNT OF RELIEF STOCKS AT WAREHOUSES IN THE PREDICTED DISASTER IN WEST SUMATRA (PACKAGE)

Relief Goods	Warehouse 1	Warehouse 2	Warehouse 3
Rice	3,132,810	22,662,633	8,766,263
Instant Noodle	2,343,379	162,632	1,184,032
Preserved food	1,964,760	325,270	2,251,160

B. *Computational Results*

The results are obtained using optimization software LINGO 17.0 on a PC with Intel® Core™ i7-4790 3.6 GHz processor, and 4.00 GB RAM. There are 17,818 variables involved in the problem. It is found that between 7 and 9 LDCs require to be set up after the tsunami disaster strikes West Sumatra. Table 4 shows the number of LDCs involved in each scenario.

In any disaster scenario, it is recommended to open LDC J3, J4, J5, J6, J7, J8, and J9 (Table 4) whereas LDC J1 and LDC J2 are only opened in three scenarios: 3, 6, and 8. In addition to those three scenarios, LDC J1 is also opened in scenario 7. When more survivors stay at distant shelters, it will insist more LDCs established around the shelters since the additional transportation charge for conducting direct shipping from the warehouses to the victims at the shelters is more than applying the indirect one. As a result, more supplies will be distributed to the disaster victims in two stages: from the warehouses to the opened LDCs then from the LDCs to shelters.

TABLE IV
NUMBER OF OPENED LDCS AFTER A PREDICTED DISASTER OCCUR

#	Scenario	Opened LDC	# of Opened LDCs
1	SN – R	J3, J4, J5, J6, J7, J8, J9	7
2	SN – W	J3, J4, J5, J6, J7, J8, J9	7
3	SN – N	J1, J2, J3, J4, J5, J6, J7, J8, J9	9
4	SS – R	J3, J4, J5, J6, J7, J8, J9	7
5	SS – W	J3, J4, J5, J6, J7, J8, J9	7
6	SS – N	J1, J2, J3, J4, J5, J6, J7, J8, J9	9
7	F – R	J1, J3, J4, J5, J6, J7, J8, J9	8
8	F – W	J1, J2, J3, J4, J5, J6, J7, J8, J9	9
9	F – N	J3, J4, J5, J6, J7, J8, J9	7

Table 5 explains how the refugees at shelters receive aid goods during the emergency period for all scenarios. Thirteen shelters (K1, K4, K5, K7, K8, K9, K14, K17, K26, K31, K32, K33, and K34) will be served directly from the warehouses. These 13 shelters are located close to the warehouses, so it will be more efficient to ship relief items directly from the warehouse than through LDCs while 12 other shelters (K11, K12, K13, K15, K19, K20, K21, K22, K23, K25, K28, and K29) will receive supplies via the opened LDCs. In this situation, the presence of LDCs is beneficial to reduce total transportation cost for transporting relief goods from the warehouses to beneficiaries. For some scenarios, the remains of shelters (K2, K3, K6, K10, K16, K18, K24, K27, and K30) will be supplied directly from warehouses while for the other scenarios, these nine shelters will utilize the LDCs to obtain the aid goods. In this situation, there is a trade-off between extra transportation cost that occurs by implementing the direct delivery strategy and the total cost for setting up LDCs and applying the indirect strategy. When the number of supplies required by shelters increases as an impact of the scenario and performing the direct delivery will cause bigger extra transportation cost than extra cost for opening LDCs and distributing aid goods via the LDCs, it will be better to apply the indirect one. Otherwise, the direct delivery is more suitable if the total additional cost for transportation plus opening LDCs is bigger than the additional transportation cost for dispatching the goods from the warehouse to the affected people directly. Hence, the number of estimated safe people required for aids and the distance between the shelters and the warehouses determine how the recipients will get aid supplies.

In this study, we also conduct a sensitivity analysis to investigate the impact of transportation costs changing on both the decision variables and objective function. The transportation costs are varied between 50% and 500%.

In a mixed delivery strategy system, the total transportation cost encompasses inbound, outbound, and direct transportation cost. Inbound transportation cost is the transportation cost occurred to transport relief items from warehouses to LDCs. Outbound transportation cost is the transportation cost for transporting relief items from the LDCs to the shelters. Direct cost is defined as the cost that occurs for transporting relief goods from the warehouses to the shelters directly. Fig. 4 describes the effect of the transportation cost in mixed delivery strategy.

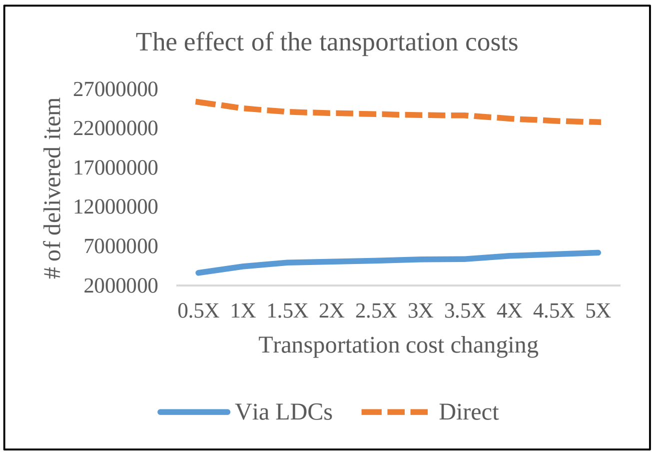

Fig. 4 Effect of transportation cost in a mixed delivery strategy

In case the transportation costs are going up, the total number of items dispatched from warehouses to shelters through LDCs will be going up as well, while the total numbers of items directly delivered to shelters are down (Fig. 4). It means that the total cost for inbound and outbound delivery is increased by the transportation costs. On the other hand, the total direct transportation cost will reduce with the increase of the transportation costs. Therefore, utilizing LDC as a bridge between the warehouses and the shelters is effective to reduce the total transportation cost occurred through the relief distribution network. If the parameters of transportation costs are set at small values, while the LDC opening costs are fixed, more items will be directly distributed from the warehouses to the recipients. It has proven our previous intuition when warehouses are located far from affected people and require more transportation cost, it will be more efficient to employ LDCs between the warehouses and the shelters and applying the indirect delivery strategy for distributing relief items to disaster victims in affected areas. While to the shelters built around the warehouses, a direct delivery provides lower transportation cost than indirect delivery. Therefore, an efficient and effective relief distribution will be achieved.

In this study, we try to accommodate the equity issue in distributing relief supplies to survivors during the response period by giving a penalty cost to unfair distribution. Fig. 5 denotes the effect of fairness cost on relief distribution for all disaster scenarios. If relief distributions are conducted by assuming that no cost will be charged for unfair distribution, the unfairness level will be one. It means that there is at least one shelter gets no supplies, and at least one shelter receives all its demand in any scenario. When allocating relief supplies to all shelters have considered unfairness cost, the uneven distribution among shelters can be reduced. Though the fairness cost still cannot ensure zero unfairness, at least the gap between the shelter which gets more and fewer supplies can be narrowed.

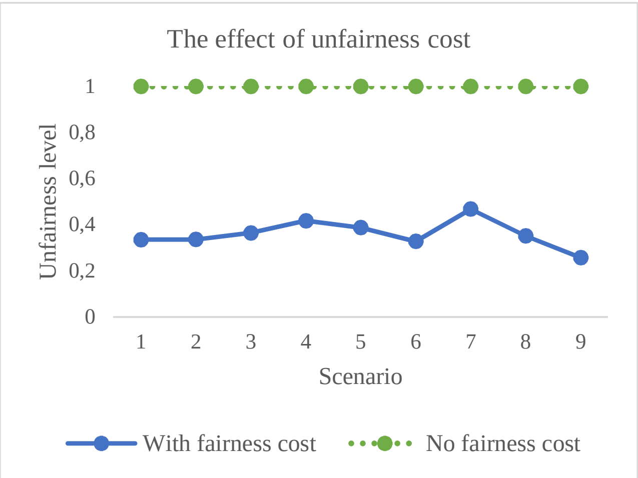

Fig. 5 Effect of unfairness cost on relief distribution

C. Practical Implementation

Usually, to the hazard-prone area, a contingency plan is supposed to be developed. Then probable disaster scenarios have been elaborated. Using the scenarios, a preparedness plan regarding humanitarian logistics plan, including making relief pre-positioning stocks and locating it at the strategic locations during pre-disaster and developing a relief distribution plan for post-disaster operation can be set up. Thus, shortly after a disaster attacks the area, disaster response operations could be conducted. Therefore, this activity is helpful for disaster coordinators to improve disaster relief performance.

Though the developed model is implemented to a probable tsunami disaster in West Sumatra, Indonesia, the model can be adopted to any disaster such as a hurricane, flood, earthquake, and volcanic eruption in any country.

The current study used an optimization software to solve a numerical experiment. The case is how to dispatch three types of relief items through the relief network consisting of three warehouses, ten potential LDCs, and 34 shelters. Applying almost 18,000 variables, the most solution was obtained more than two hours. However, in other cases, the problem size could be bigger, so the optimization software will not be efficient and effective anymore for solving the problem. A heuristic algorithm that also provides a globally optimal solution is recommended to be developed.

IV. Conclusions

This study presented a stochastic model for a location-allocation problem in responding to a disaster. Our stochastic approach recommends the number and locations of LDCs that are required to be set up at the beginning of response phase and a number of relief items that will be dispatched to survivors in the affected areas through the relief network. By implementing a mixed delivery strategy, some of the shelters will receive relief items directly from nearby warehouses, while the remaining shelters will get supplies through the LDCs. Comparing to the indirect strategy that shelters will receive aid goods only through LDCS, the proposed model (a mixed delivery strategy) provides a more efficient and effective relief distribution by considering equity among survivors. Future research focuses on an operational plan applying the response stage of disaster management involving vehicle routing problem.

Nomenclature

Sets

- i index for warehouses.
- j index for potential LDCs.
- k index for shelters.
- p index for relief goods.
- s index for scenario.

Parameters

- α_s probability of scenario.
- β_{is} probability of warehouse damaged.
- f_j opening cost of LDC.
- g_{pi} number of stocks at warehouse.
- d_{pks} number of demand.
- s_{pis} number of stocks at the warehouse.
- M a big positive number.
- h_p shortage cost.
- r_p penalty cost for the unfair distribution.
- c_{pij} transportation cost from the warehouse to LDC.
- c_{pjk} transportation cost from LDC to shelter.
- c_{pik} transportation cost from the warehouse to shelter.

Variables

U_{pks} satisfaction level.

E_{ps} the maximum difference of satisfaction level among shelters.

X_{pijs} number of relief goods delivered from warehouse to LDC.

X_{pjks} number of relief goods delivered from LDC to shelter.

X_{piks} number of relief goods delivered from the warehouse to shelter.

Z_{js} selecting for opening LDC.

L_{jks} shelter served by LDC.

L_{iks} shelter served by the warehouse.

ACKNOWLEDGMENT

We would like to thank the Industrial Engineering Department, Faculty of Engineering, Universitas Andalas for providing us with the research fund. We also would like to thank Local Agency for Disaster Management (BPBD) of West Sumatra Province for their valuable collaboration and support, and to our friends in DRRI Padang for sharing knowledge, discussions, and supporting data.

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