MULTI-PERIOD HUMANITARIAN LOGISTICS MODEL CONSIDERING TEMPORARY DEPOT LOCATION IN FLOOD DISASTER

***Wapee Manopiniwes*[*1*2] *and Takashi Irohara*[*1]**
[*1]*Faculty of Science and Technology, Sophia University*
Chiyoda-ku, 102-8554 Tokyo, Japan wapee.m@cmu.ac.th
[*2]*College of Arts Media and Information Technology, Chiang Mai University*
Muang, 50200 Chiang Mai, Thailand

Introduction

The challenges of humanitarian logistics have number of key aspects that clearly differentiate them from those of the commercial world (Tatham and Christopher, 2014). During emergencies various aid organizations often face significant problems of transporting large amounts of many different commodities including food, clothing, medicine, medical supplies, machinery, and personnel from different points of origin to different destinations in the disaster areas. The transportation of supplies and relief personnel must be done quickly and efficiently to maximize the survival rate of the affected population and minimize the cost of such operations.

Our former study (Manopiniwes and Irohara, 2015) developed a stochastic linear programming for the integrated decision on strategic planning in pre-disaster and post disaster operational stages where a flood is applied as case study. Of all natural disasters, floods possess the greatest variance in cause and degree. Floods are the most common, most expensive, and most frequent of all natural disasters (Kaaland, 2014). As shown in Figure 1, two major phases of emergency management comprise of the stages of preparedness and response in pre and post disaster operations respectively. Preparedness stage is a planning system before disaster occur in order to make a decision on the location of related facilities and relief supplies. The schemes that usually taken into the consideration for this stage are the stock prepositioning, the selection of distribution centers (DC) and evacuation centers as well as the evacuation planning. The response stage is the later process of relief distribution executed right after the disaster happens. The main thrust of the emergency response operations is related to rapid deployment of resources and aid within the first 72 hours or the first three days (Banomyong and Sopadang, 2012). Vehicle routing plan must be efficiently determined to support the rapid movement to deliver relief supplies from selected DC to the demand destinations both in evacuation centers and remaining people in affected area. We have also proposed the transportation plan for this response stage in the second earlier study (Manopiniwes and Irohara, 2015) considering identical single type of vehicle as the land transportation between only DCs and demand points. However, unlike other natural disasters, a massive flood often requires the decision on temporary depot locations over time besides the distribution centers. For the remaining demand in flooded area, boats are needed for delivery because truck is no longer applicable as the land transportation due to the obstacle by water.

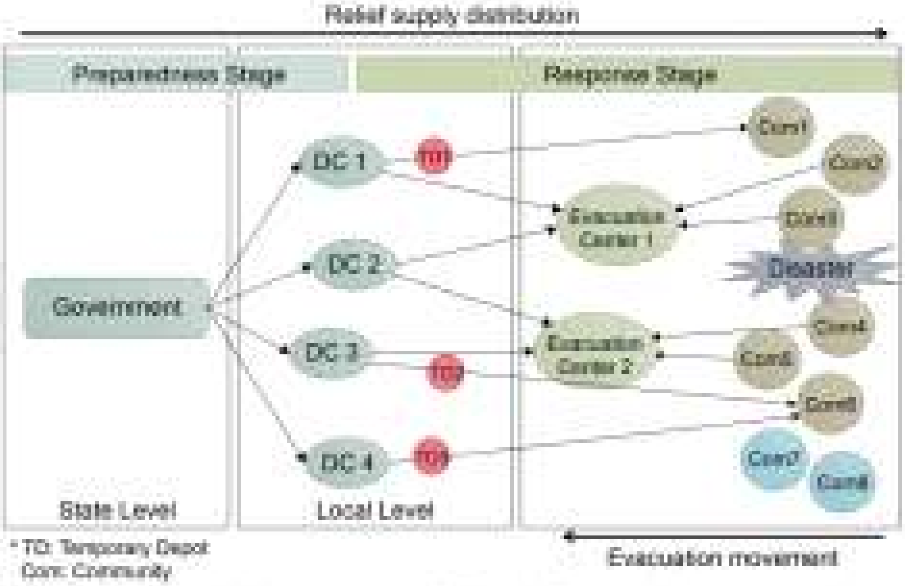


Figure 1: Supply chain management for flood disaster with temporary depots

For this reason, the temporary depots must be taken into the consideration in the relief supply chain where the flood boundary will be considered as the candidate location for. These depots are not mainly for the storage function but for transferring the relief supplies from one carrier type to another carrier type as shown in Figure 2. The most challenge is pertaining to dynamic characteristic as flood size can be changeable overtime period during the disaster. Thus, the location of temporary depots should be determined following to this alteration in order to more closely mimic the realistic behaviour of a disaster.

Figure 2: Flow of relief supplies in flood disaster

Literature review

The literature on strategic planning for logistics problems in humanitarian relief is rather rare but increasingly investigated in the Operations Research (OR) society. The studies generally consider in different components of the problem such as the location of emergency services, dispatching of multiple commodities, uncertainty in the supply and demand or traveling costs, etc. This section includes a review of relief supply chain optimization by Manopiniwes and Irohara (2014).

One of the first studies proposed by Knott (1987) considered the last mile delivery of food items from a distribution center to a number of camps assuming a single mode of transportation making direct deliveries to camp. A linear programming model is developed to determine the number of trips to each camp to satisfy demand while minimizing the transportation cost or maximizing the amount of food delivered. Barbarosoglu et al. (2004) focus on tactical and operational scheduling of helicopter activities in a disaster relief operation. They decompose the problem hierarchically into two sub problems where tactical decisions are made at the top level, and the operational routing and loading decisions are made in the second level. MIP models are formulated for tactical and operational problems, which are solved by an iterative coordination heuristic. Balcik and colleagues (2008) proposed a vehicle-based last mile distribution system, in which a local distribution center stores and distributes emergency relief supplies to a number of demand locations. They conducted a mixed integer programming model that determines delivery schedules for vehicles and equitably allocates resources, based on supply, vehicle capacity, and delivery time restrictions, with the objectives of minimizing transportation costs and maximizing benefits to aid recipients. Recently, Irohara et al. (2013) proposed a tri-level programming model for this integrated category. The top level addressed facility location and inventory decisions; the second level represents damage caused by the disaster, while the third level determines response and recovery decisions. Another recent paper by Ransikarbum and Mason (2014) presents a multiple-objective programming model for the response and recovery phase in post-disaster operations. The network optimization model is developed for making strategic decisions in supply distribution and network restoration in humanitarian logistics operations.

From the literature, the study of humanitarian logistics has attracted a lot of attention in recent years, however, a number of research considering with multi-period problem is limited. Özdamar et al. (2004) develops linear and integer multi-period multi-commodity network flows to coordinate logistics support for relief operations. Model outputs consist of dispatch orders for vehicles waiting at different locations in the area. Hongleri and Nan (2013) proposes the Bayesian sequential decision-making model of multi-period emergency supply distribution based on continuous observation and updated features of disaster information for solving the multi-relief point selection problem in the emergency relief. However, as far as we know, a multi-period problem has not yet been dealt with the selection of temporary depots for supplies transfer between different carrier types has never been found to treat in this area, especially in the aftermath of a flood disaster. A unique and special of flood character is about the dynamic capabilities. Floods may not hit as so urgently as earthquake or other natural disasters but present the unstable size and impact over time instead. In particular, in the case of flooding, where the most common transport channels are trucks in unaffected areas and boats in affected areas. Therefore, it is vital to treat this behaviour of flood problem as a multi-period approach as proposed in this article.

Problem formulation

We developed a multi-period mixed-integer programming model that focuses on the response stage of a disaster management system. To formulate this problem, it is preferable to utilize solutions from earlier stages of preparedness and initial response in our previous study (Manopiniwes and Irohara, 2015). Therefore, in this study, we expand the use of multi-period approach to describe the location-routing problem considering multimodal transportation in order to more closely mimic the realistic behaviour of a disaster.

Notations:

N set of all nodes in the network $i, j \in N$

M set of transportation modes $m, m' \in M$

T Time horizon of response operations

DC set of permanent distributi on centers

TD set of temporary depots

DP set of demand points

Parameters:

s_{it} amount of relief supplies in node i at time t

d_{it} amount of demand in node i at time t

α_t maximum number of temporary depots at time t

$Scap_{it}$ storage capacity for the facility in node i at time t

$Lcap_{it}^{m}$ loading capacity for the facility in node i for mode m at time t

$Ucap_{it}^{m}$ unloading capacity for the facility in node i for mode m at time t

$VPcap_{it}^{m}$ maximum number of mode m vehicles that can be parked (carried over) at the facility in node i from time t to time $t+1$

$VRcap_{it}^{m}$ maximum number of mode m vehicles that can be received at the facility in node i at time t

$VScap_{it}^{m}$ maximum number of mode m vehicles that can be sent out at the facility in node i at time t

cap^{m} loading capacity of vehicles of mode m

t_{ij}^{m} travel time from node i to node j for vehicl es of mode m

$k^{mm'}$ time required to transfer commoditie s from mode m to mode m'

Decision variables:

Z_{it} : $\begin{cases} =1, \text{if a temporary depot is located on node } i \text{ at time } t, \\ =0 \text{ otherwise;} \end{cases}$

X_{ijt}^{m} amount of relief supplies shipped from node i to node j by mode m at time t

XO_{it} amount of relief supplies in node i which is carried over from time t to $t+1$

$XT_{it}^{mm'}$ amount of relief supplies in node i which is transferred from mode m to mode m' at time t

Y_{ijt}^{m} amount of vehicles of mode m travel from node i to node j at time t

YO_{it}^{m} amount of vehicles of mode m in node i which is carried over from time t to $t+1$

U_{it} amount of unsatisfie d demand in node i at time t

Based on the above definitions, we developed the following MIP formulation:

$$\text{Minimize } \sum_{i}\sum_{t} U_{it} \tag{1}$$

The objective function in equation (1) minimizes the total amount of unsatisfied demand over all periods and demand points.

$$\sum_{j} X_{ji(t-t_{ji}^{m})}^{m} + XO_{i(t-1)} = \sum_{j} X_{ijt}^{m} + XO_{it} \qquad \forall i \in DC, \forall m \in M, \forall t \in T \tag{2}$$

Constraint (2) refers to supply nodes, the sum of the flows entering each node should be equal to the sum of the flows that leave the same node; in comparison to the commodities that might be already in the system coming from another node or has been at the same node from a previous time period.

$$\sum_{j} X_{ji(t-t_{ji}^{m})}^{m} + \sum_{m'} XT_{i(t-k^{m'm})}^{m'm} + XO_{i(t-1)} = \sum_{j} X_{ijt}^{m} + \sum_{m'} XT_{it}^{mm'} + XO_{it} \qquad \forall i \in TD, \forall m \in M, \forall t \in T \tag{3}$$

Constraint (3) requires that for transfer nodes, commodities being carried over in node i from time period t to t+1 do not include those commodities that are being transferred to another mode in node i at time period t. The amount of transferred commodities is captured in the variable $XT_{it}^{mm'}$.

$$\sum_{m}\sum_{j} X_{ji(t-t_{ji}^{m})}^{m} + U_{it} = d_{it} + U_{i(t-1)} \qquad \forall i \in DP, \forall t \in T \tag{4}$$

Equation (4) shows that the total flow entering each demand node plus the unsatisfied demand is equal to the exogenous demand at that node plus any unsatisfied demand from the previous time period.

$$\sum_j Y^m_{ji(t-t_{jim})} + YO^m_{i(t-1)} = \sum_j Y^m_{ijt} + YO^m_{it} \qquad \forall i \in N, \forall m \in M, \forall t \in T$$

(5)

Equation (5) represents the conservation of flow for the vehicles. At any node i and time period t, total number of available vehicles of mode m is equal to the number of vehicles of mode m that left node j for node i at time $t\text{-}t_{jim}$, plus the number of vehicles that were carried over from the previous time period.

$$cap^m Y^m_{ijt} = X^m_{ijt} \qquad \forall i, j \in N, \forall m \in M, \forall t \in T$$

(6)

Constraint (6) makes sure that commodities are not sent out of a node unless a number of vehicles with enough capacity are available at that node to carry those commodities.

$$\sum_j X^m_{ijt} \le Lcap^m_{it} Z_{it} \qquad \forall i \in TD, \forall m \in M, \forall t \in T$$

(7)

$$\sum_j X^m_{ji(t-t_{jim})} \le Ucap^m_{it} Z_{it} \qquad \forall i \in TD, \forall m \in M, \forall t \in T$$

(8)

$$\sum_m \sum_j X^m_{ji(t-t_{jim})} + XO_{i(t-1)} \le Scap_{it} Z_{it} \qquad \forall i \in TD, \forall t \in T$$

(9)

Constraints (7)-(9) are the maximum capacity for loading, unloading, and storage of commodities at temporary depots.

$$\sum_j Y^m_{ijt} \le VScap^m_{it} Z_{it} \qquad \forall i \in TD, \forall m \in M, \forall t \in T$$

(10)

$$\sum_j Y^m_{ji(t-t_{jim})} \le VRcap^m_{it} Z_{it} \qquad \forall i \in TD, \forall m \in M, \forall t \in T$$

(11)

$$\sum_j Y^m_{ji(t-t_{jim})} + YO_{i(t-1)} \le VPcap^m_{it} Z_{it} \qquad \forall i \in TD, \forall m \in M, \forall t \in T$$

(12)

Constraints (10), (11), and (12) require the maximum number of vehicles that are sent, received, and parked at each depot to be less than the relevant capacities.

$$\sum_i Z_{it} \le \alpha_t \qquad \forall i \in TD, \forall t \in T$$

(13)

Constraint (13) oblige the maximum number of each temporary depot to be limited by the maximum allowable numbers of facilities during the chosen time periods.

Test case description: Flood hazard map

This section presents a case study, in which we demonstrate our approach to the preparation and response to a flood disaster in Chiang Mai province in northern Thailand, where large floods usually occur late in the May–October rainy season that is dominated by masses of moist air moving northeast from the Indian Ocean and associated with tropical depressions moving westward from the South China Sea (Wood and Ziegler, 2008). Chiang Mai has a long history of flooding, since 1966 due to its bowl-like shape.

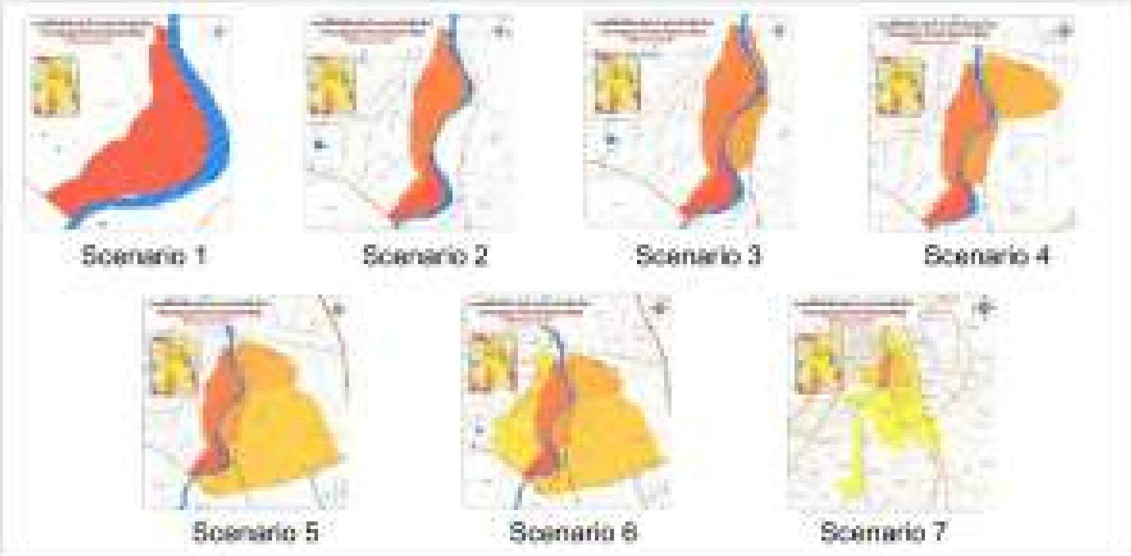


Figure 3. Seven scenarios of impact shown on the Chiang Mai flood hazard map. (CENDRU, 2015)

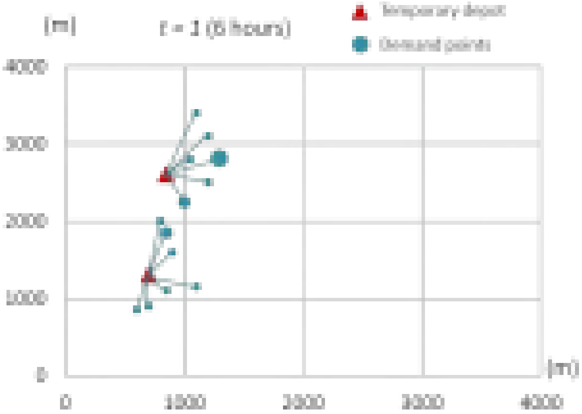
Chiang Mai implemented a flood warning system for the Ping River in downtown of city. This system makes real-time predictions of the flood level by using a gauging station named station P.67 that is located at Ban Mae-tae in Sansai district, 32 kilometres north of Station P.1, which is in downtown Chiang Mai. When there is heavy rainfall, it usually takes about seven hours for the water to travel from Station P.67 to Station P.1. through the Ping River. Thus, it is possible to estimate the impact on the downtown area by measuring the level of the Ping River at Station P.67 in advance. In this study, we generate various possible scenarios in which there would be a need for relief supplies; these are based on the Chiang Mai flood hazard map produced by the Natural Disasters Research Unit of the Civil Engineering Department of Chiang Mai University (CENDRU, 2015). The flood hazard map shows the flooding risk of each area, based on the historical data from Stations P.1 and P.67; the risk is divided into seven scenarios along the Ping River, as shown in Figure 3.

Computational results

The computational results and analysis of the proposed model behaviour are presented. The optimal solutions were obtained using Gurobi optimizer version 5.6.2 mathematical programming solution software. All experiments were run on a personal computer with an Intel (R) Core (TM) i7-3770 CPU (3.40 GHz) and 16.0 GB of RAM. All test problems were computed in less than ten minutes.

In this section, we present illustrative examples in order to demonstrate how the proposed models can be used to optimize the temporary depot locations for each time period. As it is certainly agreed that the first three days or 72 hours is most critically important for the response stage of emergency management system. Therefore, the example results in this study refer to the solution according to this information as the first 72 hours delivery plan right after the city has been attacked by floods. Considering time scale is important that can affect the performance of time-scale networks dramatically. The problem size may increase hugely with shorter time steps due to the number of time scales in the planning horizon while longer time steps keep the problem at a reasonable size. In this study, hours is appropriate than minutes according to those activities needed in floods response stage. Both delivery flow and transfer nodes requires at least couple hours but less than six hours to complete. Thus, each six hours is appropriate for treating in this problem.

The illustrative results are displayed following the assumption of dynamic demand. This time, we assume that flood causes demand in a certain amount of scenario 2 at the beginning with 12,971 demand in total and the floods and become as enormous as scenario 5 in the next day with 48,041 demand in total. Figure 4a and 4b display the results of the location selection of temporary depots between the beginning of flood at t=1 and the next 24 hours at t=5 which flood becomes massive for the unlimited capacity case. At the beginning, the certain amount of 13 demand points according to floods in scenario 2 are served by two temporary depots which optimally located in the boundary of flood area in order to receive the relief supplies from the DCs by trucks as land transportation and give a delivery to demand points in affected area by boats. In the next day at t=5, total demand points greatly increase due to the floods in scenario 5. The former 13 demand points in grey colour are completely satisfied within t=5. One of two depots in the earlier stage is moved to a new location to serve those added demand when the other one remains at the same place to serve the new closest demand points. Two more depots are selected to provide the delivery to the rest of demand.



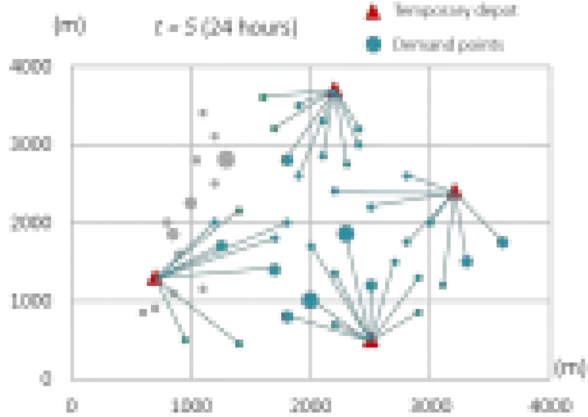
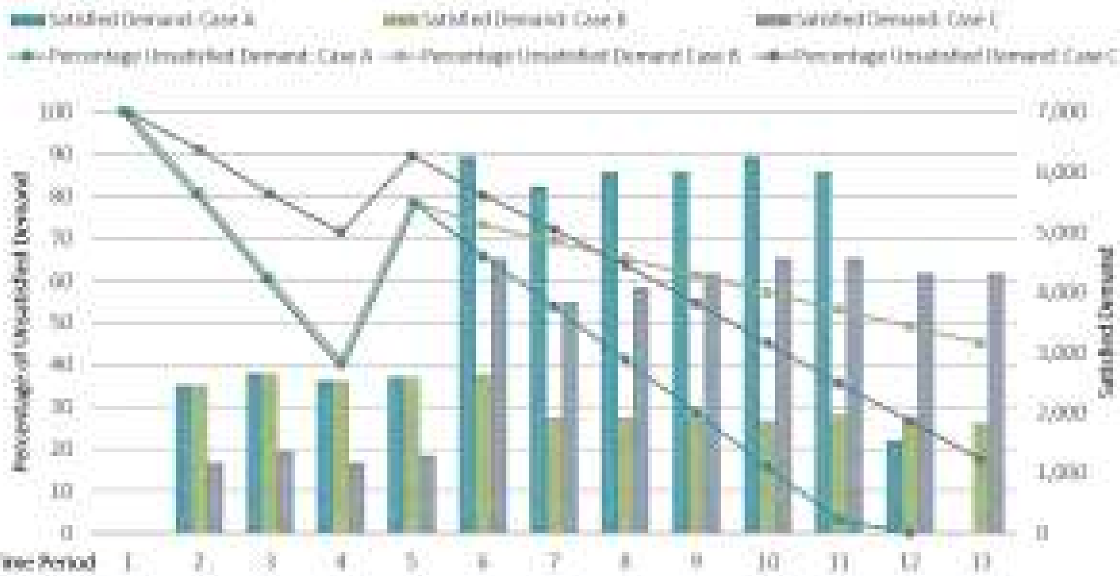


Figure 4a: Optimal solutions for location selection of temporary depots at time period 1[st]

Figure 4b: Optimal solutions for location selection of temporary depots at time period 5[th]

The experiments in Figure 5 depict the results of objective function in each time period for three cases. Case A indicates the optimal solutions as same as in Figure 4 while single-period approach have been added to case B and C. Two and four temporary depots are located in period 1 and 5 respectively in case A. In order to show how the solutions perform when using unchanged locations of depots for all time period, we conduct case B and C for this purpose. In case B, only two depots are used from the



Time Period	1	2	3	4	5	6	7	8	9	10	11	12	13
Hours	0	6	12	18	24	30	36	42	48	54	60	66	72
Scenario	2	2	2	2	5	5	5	5	5	5	5	5	5
Total Demand	12,971	12,971	12,971	12,971	48,041	48,041	48,041	48,041	48,041	48,041	48,041	48,041	48,041
Number of opened TD													
Case A	2	2	2	2	4	4	4	4	4	4	4	4	4
Case B	2	2	2	2	2	2	2	2	2	2	2	2	2
Case C	4	4	4	4	4	4	4	4	4	4	4	4	4

Figure 5: Experimental results for each time period between limited and unlimited capacity cases

beginning with unchanged locations as in Figure 4a. Finally, case C refers to the results of using four temporary depots all time periods with the location as in Figure 4b.

Generally, the percentage of unsatisfied demand reduces over time period due to the relief delivery from the temporary depots. In case A, about 40% of demand in scenario 2 remains unsatisfied after 18 hours. However, the percentage of unsatisfied demand is sharply increase to 78.7% due to the assumption of scenario 5 at the next day, then continue decreasing until the last demand is served within 66 hours. Case B shows the same performance with case A in the first day, however, remaining only two depots is unable to satisfy all demand increasing in the second day within 72 hours. This is because both depots locate in the same locations with long distances to the rising demand points. The use of four temporary depots from the beginning to all time period is represented in case C. Poor performance occurs for the first day because only one from four depots is applicable due to the water boundary in scenario 2.

Likewise, every 6 hour in case A, an average of about 2,500 demand are served by two temporary depots in the first day and more demand about 6,000 in average are served due to the increasing number of temporary depots as four in total from the second day. Case C shows the similarity with case A that the total satisfied demand from the second day is greater than the total satisfied demand in the first day because more depots are applicable from the second day due to scenario 5. However, only 1,200 demand in average for each period are satisfied in the first 24 hours and the average satisfied demand increases to 4,300 after 24 hours. It is worse than the situation in case A because the selected depots have to satisfy the remaining demands from the first day in scenario 2. At the end of the third day, there are 8,456 demand still not satisfied. Case B shows the worst one after 24 hours. When floods are more spreading from the second day, the average amount of satisfied demand is lower than the average in the first day because both depots remain in the same locations with long distances to the rising demand points. Only 2,000 demands in average for each period are served from the second day and there are the remaining of 21,763 demand are still unsatisfied at the end of the third day.

Conclusions

This study extended the contribution by presenting a decision model at the operational level that describes the details of supply chain logistics in major emergency management agencies, in response to immediate aftermath of a flood disaster. A unique and special of flood character is about the dynamic capabilities. Floods may not hit as so urgently as earthquake or other natural disasters but present the unstable size and impact over time instead. In particular, in the case of flooding, where the most common transport channels are trucks in unaffected areas and boats in affected areas. Therefore, it is vital to treat this behaviour of flood problem as a multi-period approach as proposed in this article.

The results of this research show the optimal locations of temporary depots for each time period regarding to the dynamic characteristics of flood. Single-period solution approach is also conducted in the experimental results to compare the performance of our proposed multi-period model. In this study, we found that the multi-period approach produces better solutions than the single-period ones. The proposed model controls the flow of all the relief commodities from the sources through the chain and until they are delivered to the hands of recipients. This model provided the opportunity for a centralized operation plan that can eliminate delays and assign the limited resources in a way that is optimal for the entire system.

Although, there are a number of possible extensions of this model, future research will explore larger and more complex problems. The use of a heuristic method is expected to provide significant opportunities for improvement when problem sizes and complexity become greater. This can be expected to facilitate finding proper and satisfactory solutions to problem processes. Moreover, improvements to vehicle routing and scheduling can be expected to enhance the flow of the relief distribution network.

References

- Balcik, B., Beamon, B., and Smilowitz, K. (2008), "Last mile distribution in humanitarian relief", *Journal of Intelligent Transportation Systems*, Vol.12, No.2, pp. 51-63.
- Banomyong, R. and Sodapang, A. (2012), "Relief supply chain planning: insights from Thailand", Kovács, G. and Spens, K. M., *Relief Supply Chain Management for Disasters: Humanitarian Aid and Emergency Logistics*, IGI Global, Hershey, PA: Business Science Reference, pp. 31-44.
- Barbarosoglu, G., Ozdamar, L., and Cevik, A. (2002), "An interactive approach for hierarchical analysis of helicopter logistics in disaster relief operations", *European Journal of Operational Research*, Vol.140, No.1, pp. 118-133.
- Civil Engineering Chiang Mai University Natural Disasters Research Unit' CENDRU. 2015 "Chiang Mai City Flood Preparedness System", available at: http://cendru.eng.cmu.ac.th/cmflood/map.html (accessed 13 July 2015).
- Irohara, T., Kuo, Y. H., and Leung, J. M. Y. (2013), "From preparedness to recovery: a tri- level programming model for disaster relief planning", D. Pacino et al., *Computational Logistics*, Springer: Heidelberg, pp. 213-228.
- Kaaland, C. (2014), "Natural disasters", Lokey, W., *Emergency Preparedness and Disaster Recovery in School Libraries: Creating a Safe Haven*. ABC-CLIO, California, CA, pp. 12-24.
- Knott, R. (1987), "The logistics of bulk relief supplies," *Disasters*, Vol.11, pp.113–115.
- Liu, N. and Ye, Y. (2014), "Humanitarian logistics planning for natural disaster response with Bayesian information updates", *Journal Of Industrial And Management Optimization*, Vol. 10, No. 3, pp. 665-689.
- Manopiniwes, W., and Irohara, T. (2015), "Relief vehicle transportation plan: thai flooding case study", Cetinkaya ,S. and Ryan, J. K. in Proceedings of the 2015 industrial and systems engineering research conference, Nashville, Tennessee.
- Manopiniwes, W., and Irohara, T. (2015), "Integrated relief supply distribution and evacuation; a stochastic approach", Kachitvichyanukul, V., Sethanan, K. and Golinska-Dawson, P., *Toward Sustainable Operations of Supply Chain and Logistics Systems*, Springer International Publishing Switzerland, pp. 297-308.
- Manopiniwes, W., and Irohara, T. (2014), "A review of relief supply chain optimization", *Industrial Engineering and Management Systems*, Vol.13, No.1, pp.1-14.

- Özdamar, L., Ekinci, E. and Küçükyazici, B. (2004), "Emergency logistics planning in natural disasters", *Annals of Operations Research*, Vol. 129, pp. 217–245.
- Ransikarbum, K. and Mason, S. J. (2014), "Multiple-objective analysis of integrated relief supply and network restoration in humanitarian logistics operations", *International Journal of Production Research*, pp. 1-20.
- Tatham, P. and Christopher, M. (2014), *Humanitarian Logistic: Meeting the Challenge of Preparing For and Responding to Disasters, 2nd Edition*, Kogan Page Publishers, London Philadelphia New Delhi.