IMPROVING EVACUATION PLANNING AND SHELTER SITE SELECTION FOR FLOOD DISASTER: A STOCHASTIC APPROACH

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This study aims to propose a stochastic linear mixed-integer mathematical programming model for flood evacuation planning to optimize decision related to shelter site selection under a hierarchical evacuation model. This article not only provides a flood-shelter but also determines hierarchical evacuation concept for flood disaster that balances the preparedness and risk despite the uncertainties of flood events. Moreover, we also consider both distribution of communities and evacuee's behavior. We validate the mathematical model by generating a base case scenario using real data for Chiang Mai province, Thailand. Also, we perform a sensitivity analysis on the parameters of the mentioned mathematical model and discuss our finding. This article will be great significance in helping policy makers consider spatial aspect of the strategic placement of flood-shelters and evacuation planning under uncertainties of flood scenario.

Key Words: *stochastic programming, shelter site selection, evacuation planning, flood disaster*

1. INTRODUCTION

Recently, the world is affected by many disasters such as earthquakes, storms, floods, landslides, etc. Since the 1950s, the number of disasters has increased continually as shown in Fig.1. According to annual disaster statistical review 2014 (The number and trend)[1], the number of people was stricken by natural disaster as 324 persons and the economic system was damaged as approximately US$ 99.2 billion. The international disaster database is proposed that Asia and America are the most affected continues by natural disasters such as Hydrological disaster, geophysical disaster, Meteorological disaster, Climatological disaster.[2] The World Health Organization (WHO) defines a 'disaster' as any occurrence that causes damage, destruction, ecological disruption, loss of human life, human suffering, deterioration of health and health services on a scale sufficient to warrant an extraordinary response from outside the affected community or area[3]. Such events may be including natural disasters and epidemics or man-made disruptions[4]. According to disasters have increased exponentially. Therefore, academicians endeavor to manage for helping at-risk persons to avoid or recover from the effect of the disaster as call "Disaster management". The activity of disaster management consists of four stages: mitigation, preparation, response, and recovery[5] that can separate into two phase: pre-disaster (mitigation and preparation) and post-disaster (response and recovery)

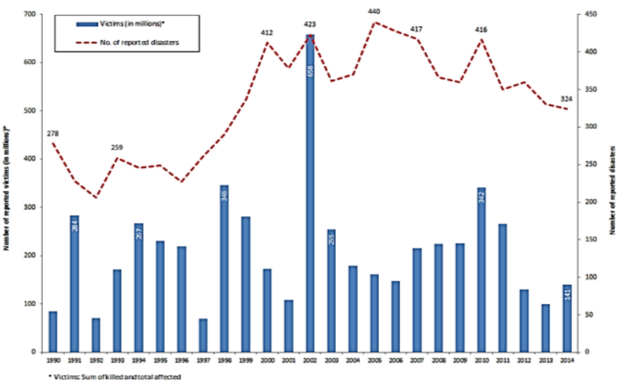

Fig. 1 Trends in occurrence and victims[1]

Flood disaster is largest share in nature disaster occurrence in 2014 (Fig. 2) that have a portion as 47.2%. The number of flood and mass movement of hydrological origin were 153 disasters in 2014 that caused 42.3 million victims or 30% of total disaster victims with economic damaged around US$ 99.2 billion. The biggest flood disaster occurred in China in 2007 and 2011 that more than 100 million people were hit. Furthermore, the most expensive flood occurred in Thailand in 2011, with economic damages estimated to be US$ 42.1 billion.

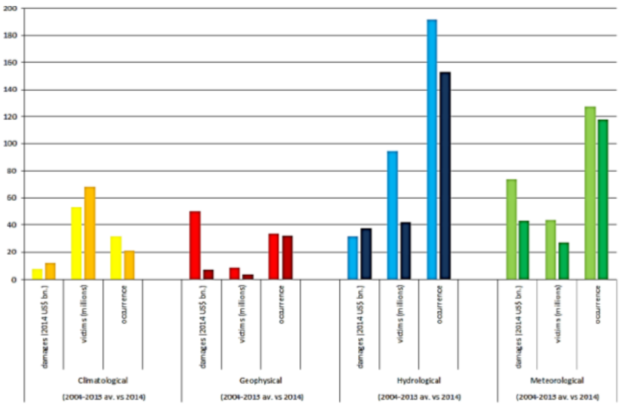

Fig. 2 Natural disaster impacts by disaster sub-group: 2014 versus 2003-2013 annual average[1)]

During flood situation, people in an affected zone have to decide where to evacuate to safety. The shelter is a public safe place provided and organized by the government in order to support people in an affected area. So preparedness design is a major stage to design planning of activities to follow in case a disaster situation. In flood-shelter site selection and flood evacuation planning, there are many major criteria that should consider such as uncertainty of occurrence, evacuee's behavior, and hazard of flood disaster. According to above-mention criteria, we aim to propose novel planning for integrated decision related to flood-shelter site selection and flood evacuation planning under probabilistic scenarios that reflect the uncertainties of flood events and their consequences.

The remainder of this article is organized as follows: Section 2 presents a review of related literature. Section 3 shows conceptual model and mathematical model. Section 4 addresses case study. Section 5 shows the computational results. Finally, the conclusion and discussions are presented in section 6.

2. LITERATURE REVIEWS

This section presents an overview of relevant literature. Recent research has also included surveys on effective DM such as Caunhyeet al.[6)], Safeer et al.[7)], and Özdamar and Ertem[8)] and Zheng et al.[9)] There are many paper dealing with sheltering operation and evacuation planning. Goal et al.[10)] proposed flood facility location-allocation in Marikana city by using maximal covering location problems (MCLP) with Lagrange optimization model. This study aimed to optimize the number of shelter by relaxing constraints in order to obtain the optimal demand coverage for every facility location and also considered flood level constraint. Similarly, Wang et al.[11)] proposed an MCLP-based optimization model, precipitation station MCLP, to site precipitation stations. The proposed model considered some special constraints and the associated rainfall monitoring demand which were applied in Jinsha River Basin. Moreover, Chowdhury et al.[12)] proposed multi-objective mathematical programming model and simulation model to quantify objectives and provide decision support for cyclone shelter location in Bangladesh. In related study, Chanta and Sungsawang[13)] proposed bi-objective optimization model to select appropriate temporary shelter sites for flood disaster in Bangkruai, Thailand that to maximize the number of victims that can be covered within a fixed distance and to minimize the total distance of all victims to their closest shelters by selecting epsilon constraint approach to solve the problem. Boonmee et al.[14)] proposed multi-model optimization for selecting shelter site and evacuation planning, four mathematical models were formulated under a dynamic of both constraint and model type. In each model, the objective function is to minimize the total travel distance. Finally, they proposed four models to decision makers for choosing the best one. Furthermore, Kongsomsaksakul et al.[15)] studied optimal shelter location for flood evacuation planning, bi-level programming model was formulated. Addition, bi-level programming model was proposed by Feng and Wen[16)] for managing the emergency vehicle and controlling the private vehicle flows in earthquake disaster. They considered both a multi-community, two-model network flow problem base on the concept of bi-level programming and network optimization theory. Others bi-level programming model was proposed by Liu et al[17)] and Li et al.[18)].

For more realistic, Kulshrestha et al.[19)] presented a robust approach to optimize locations of pubic shelters and their capacities, from a given set of potential sites, under demand uncertainty. This proposed model not only determined the number of shelters and capacities but also considered the route to access to shelters. Salmam and Yucel[20)] proposed a stochastic integer programming model for determining the location of emergency response facilities among a set of potential ones that aims to maximize the expected total demand covered within a predetermined distance parameter, over all possible network realizations.

For integrated decision shelter site selection and evacuation planning, Chen et al.[21] proposed a three-level hierarchical location model to optimize the location of earthquake-shelter by taking into account this temporal variance. This proposed model not only considers changing needs of refugees but also determines financial constraints imposed upon the construction of shelters. The real case in Beijing, China is applied to validate this proposed model. Another multi-step evacuation is proposed by Hu et al.[22] for post-disaster evacuation and temporary resettlement considering panic and panic spread. The proposed mixed-integer linear programming model was constructed for multi-step evacuation and temporary resettlement by minimizing the panic-induced psychological penalty cost, psychological intervention cost, transportation cost, and building shelter cost. Wenchuan Country is selected to test the model.

According to proposed literature review, our article aims to propose novel stochastic linear mixed-integer programming model for optimizing integrated decision related to shelter site selection under a hierarchical evacuation model during flood disaster. This proposed model not only provides a flood-shelter but also considers hierarchical evacuation concept for flood disaster that balances the preparedness and risk despite the uncertainties of flood events under minimization of travel distance. In addition, we also consider the distribution of communities and evacuee's behavior as constraints for our model.

3. STOCHASTIC LINEAR MIXED-INTEGER PROGRAMMING MODEL

3.1 Conceptual model

From conceptual model as shown in Fig. 3., it can be separated into different levels with higher level impact dominating lower level ones. For floods situation, the water will expand around river following step by step. So we can divide the level following the step of impact level. In this respect, the proposed model is considered a three-level hierarchical evacuation model related to a case study that discusses in section 4. The 1st level is the 1st evacuation period, when the flood warning system alarm for impact level 1, the refugees will be assigned to one of the shelters that is nearest and safety. The 2nd level is the 2nd evacuation period, when flood warning system alarm for impact level 2, refugees will be assigned to one of the shelters and refugees in selected shelters in the 1st level where got effect will be also evacuated to new shelters. For the 3rd level, it is the 3rd evacuation period, when the flood warning system alarm for impact level 3, the refugees will be evacuated to shelters and refugees in selected shelters in 2nd level where got effect will be also assigned to new shelters. According to evacuee's behavior during flood events, some evacuees will evacuate neither before the disaster or after the disaster. So we assume that the refugees can evacuate to shelter whole periods under varying needs of the refugees.

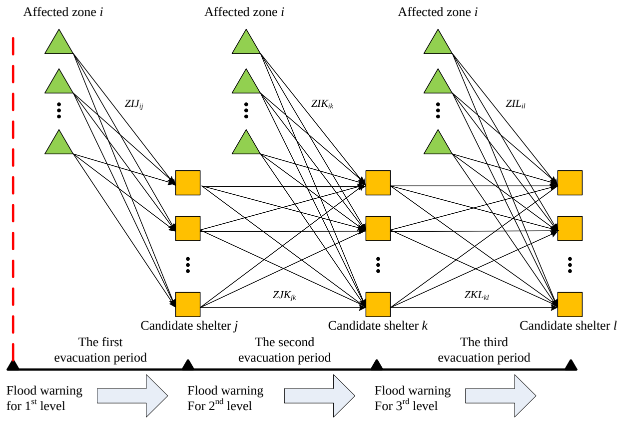

Fig. 3 The conceptual model of a hierarchical location model for shelter site selection and evacuation planning during floods

3.2 Mathematical model

This mathematical model not only determines hierarchical evacuation planning but also considers the assigned population point to flood-shelter, shelter capacity, and uncertain demand following evacuee's behavior. The objective function is to determine total expected population-weighted travel distance. Consequently, the SP model provides the recommended shelter and population assignment in each affected zone to recommended shelter for each evacuation periods. The stochastic linear mixed-integer programming model for optimizing integrated decision related to shelter site selection under a hierarchical evacuation model is formulated as follows:

Indices and index sets

I	Set of affected zones; $i \in I$
J	Set of candidate shelters; $j, k, l \in J$
Ω	Set of evacuation periods; $s \in \Omega$

Parameters

P	Maximum limit of selected shelter
M	A Large positive number
DM_i	Demand in affected zone $i \in I$
Cap_j	Shelter capacity $j \in J$
$Cost_j$	Open cost of shelter $j \in J$
$ProbP_s$	Probability of occurrence of disaster in each period $s \in \Omega$

PrR_j Probability of risk in shelter $j \in J$ that can face disaster

$NPrR_j$ Equal to 1 if $PrR_j \geq 0$, 0 otherwise

$PrDM_{is}$ Probability of demand in affected zone $i \in I$ need to evacuate in period $s \in \Omega$

DIJ_{ij} Distance from affected zone $i \in I$ to candidate shelter $j \in J$

DIK_{ik} Distance from affected zone $i \in I$ to candidate shelter $k \in J$

DIL_{il} Distance from affected zone $i \in I$ to candidate shelter $l \in J$

DJK_{jk} Distance from candidate shelter $j \in J$ to candidate shelter $k \in J$

DKL_{kl} Distance from candidate shelter $k \in J$ to candidate shelter $l \in J$

Decision variables

X_j Binary parameter = 1 if shelter $j \in J$ is selected, 0 otherwise

FP_j Total population of shelter $j \in J$ in 1st evacuation period

SP_k Total population of shelter $k \in J$ in 2nd evacuation period

TP_l Total population of shelter $l \in J$ in 3rd evacuation period

YIJ_{ij} Binary parameter = 1 if affected zone $i \in I$ is assigned to candidate shelter $j \in J$ during 1st evacuation period, 0 otherwise

YIK_{ik} Binary parameter = 1 if affected zone $i \in I$ is assigned to candidate shelter $k \in J$ during 2nd evacuation period, 0 otherwise

YIL_{il} Binary parameter = 1 if affected zone $i \in I$ is assigned to candidate shelter $l \in J$ during 3rd evacuation period, 0 otherwise

ZIJ_{ij} Number of people evacuates from affected zone $i \in I$ to shelter $j \in J$ during 1st evacuation period

ZIK_{ik} Number of people evacuates from affected zone $i \in I$ to shelter $k \in J$ during 2nd evacuation period

ZIL_{il} Number of people evacuates from affected zone $i \in I$ to shelter $l \in J$ during 3rd evacuation period

ZJK_{jk} Number of people evacuates from affected shelter $j \in J$ to candidate shelter $k \in J$ during 2nd evacuation period

ZKL_{kl} Number of people evacuates from affected shelter $k \in J$ to candidate shelter $l \in J$ during 3rd evacuation period

Objective function

This objective function is multiple values between population-weighted travel distance and the probability of occurrence of a disaster in each period with respect to disaster scenario that consists of three-term. The first term is total expected population-weighted travel distance in 1st evacuation period. The second term is total expected population-weighted travel distance in 2nd evacuation period which composes of both refugees from affected zones and shelters that locate in impact level 1. The third term is total expected population-weighted travel distance in 3rd evacuation period which consists of refugees from affected zones and refugees from shelters where is located in impact level 2. It can be formulated as Equation (1)

$$
\begin{aligned}
&Min\ Z1 = E_{\Omega}[Q(X,S)] \\
&E_{\Omega}[Q(X,S)] = \\
&ProbP_1 * \left[\sum_{i\in I}\sum_{j\in J} DIJ_{ij} * ZIJ_{ij}\right] + \\
&ProbP_2 * \left[\sum_{i\in I}\sum_{k\in J} DIK_{ik} * ZIK_{ik} + \sum_{j\in J}\sum_{k\in J} DJK_{jk} * ZJK_{jk}\right] + \\
&ProbP_3 * \left[\sum_{i\in I}\sum_{l\in J} DIL_{il} * ZIL_{il} + \sum_{k\in J}\sum_{l\in J} DKL_{kl} * ZKL_{kl}\right]
\end{aligned} \tag{1}
$$

Constraints

$$\sum_{j\in J} X_j \leq P \qquad \forall i \tag{2}$$

$$FP_j + SP_k + TP_l \geq X_j \qquad \forall j \in J, k \in J, l \in J \tag{3}$$

$$FP_j = \sum_{i\in I} ZIJ_{ij} \qquad \forall j \in J \tag{4}$$

$$SP_k = \sum_{i\in I} ZIK_{ik} + \sum_{j\in J} ZJK_{jk} \qquad \forall k \in J \tag{5}$$

$$TP_l = \sum_{i\in I} ZIL_{il} + \sum_{k\in J} ZKL_{kl} \qquad \forall l \in J \tag{6}$$

$$FP_j + SP_k + TP_l \leq Cap_j * X_j \qquad \forall j \in J, k \in J, l \in J \tag{7}$$

$$\sum_{j\in J} ZIJ_{ij} = DM_i * PrDM_{i,1} \qquad \forall i \in I \tag{8}$$

$$\sum_{k\in J} ZIJ_{ik} = DM_i * PrDM_{i,2} \qquad \forall i \in I \tag{9}$$

$$\sum_{l\in J} ZIJ_{il} = DM_i * PrDM_{i,3} \qquad \forall i \in I \tag{10}$$

$$FP_j * NPrR_j = \sum_{k\in J} ZJK_{jk} \qquad \forall j \in J \tag{11}$$

$$SP_k * NPrR_k = \sum_{l\in J} ZKL_{kl} \qquad \forall k \in J \tag{12}$$

$$ZIJ_{ij} \leq M * YIJ_{ij} \qquad \forall i \in I, j \in J \tag{13}$$

$$ZIK_{ik} \leq M * YIK_{ik} \qquad \forall i \in I, k \in J \tag{14}$$

$$ZIL_{il} \leq M * YIL_{il} \qquad \forall i \in I, l \in J \tag{15}$$

$$\sum_{j\in J} \mathrm{YIJ}_{ij} \leq 1 \qquad \forall i \in I \tag{16}$$

$$\sum_{k\in J} \mathrm{YIK}_{ik} \leq 1 \qquad \forall i \in I \tag{17}$$

$$\sum_{l\in J} \mathrm{YIL}_{il} \leq 1 \qquad \forall i \in I \tag{18}$$

$$ZIJ_{ij}, ZIK_{ik}, ZIL_{il}, ZJK_{jk}, ZKL_{kl}, FP_j, SP_k, TP_l \geq 0 \qquad \forall i \in I, j \in J, k \in J, l \in J \tag{19}$$

$$X_j,\ YIJ_{ij},\ YIK_{ik},\ YIL_{il},\ YJK_{jk},\ YKL_{kl} \in \{0,1\} \qquad \forall i \in I, j \in J, k \in J, l \in J \tag{20}$$

Equation (2) - (3) states that the total number of selected shelters cannot exceed the maximum limit of selected shelter Equation (4) states that the total number of population in 1st evacuation periods. Equation (5) states the total number of population in the 2rd evacuation periods that compose of both refugees from affected zones and shelters that locate in impact level 1. Equation (6) states the total number of population in 3rd evacuation period which consists of refugees from affected zones and refugees from shelters where is located in impact level 2. Equation (7) states that the total number of refugees that are covered by shelter j should not exceed the its capacity. Equation (8) – (10) ensure that the number of refugees evacuates to shelter in each evacuation period should be equal to the expected evacuation requirements following the evacuee's behavior. Equation (11) states that the number of refugee departure to each shelter j should be equal to the number of refugees come into each shelter j. Equation (12) ensures that the number of refugee departure to each shelter k should be equal to the number of refugees come into each shelter k. Note that $NPrP_j$ present assignment balance, the binary variable of this assignment is set to 1, if the shelter locates in the affected area, the refugees have to evacuate to the new shelter when it's hit. Otherwise, if the shelter doesn't locate in the affected area, the refugees have not to evacuate to the new one. Equation (13) - (15) state that the binary variable of the assignment is set to 1, when the number of refugees in each zone or each shelter is assigned to each shelter. Not that M is a large positive number. Equation (16) – (18) ensure that each zone can be assigned to only one shelter. Equation (19) and (20) describe non-negativity and binary conditions of the decision variable.

4. CASE STUDY

This section presents a case study in Chiang Mai province in northern Thailand to validate our proposed model. Chiang Mai Province usually occurs flood disaster in May-October rainy reason which is dominated by masses of moist air moving from the Indian Ocean, and tropical depressions moving westward from the South China Sea.

Chiang Mai province develops a flood warning system for Ping river which can predict the real-time situation. This system uses two gauging station, P.67 located at Ban Mae-tae in Sansai district and P.1 in downtown Chiang Mai, in which the water takes about seven hours for traveling to P.1 station. The Natural Disaster Research Unit of Civil Engineering Department of Chiang Mai University (CENDRU)[23] has surveyed and collect floods data in Chiang Mai for a long time ago. The Chiang Mai flood hazard map is produced based on historical data from Station P.1 and P.67 since 2006 as shown in Fig 4, the risk area is divided into seven levels.

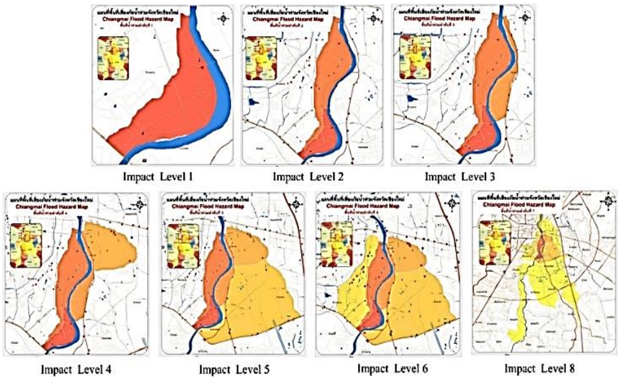

Fig. 4 Seven impact level of the Chiang Mai flood hazard map.[23]

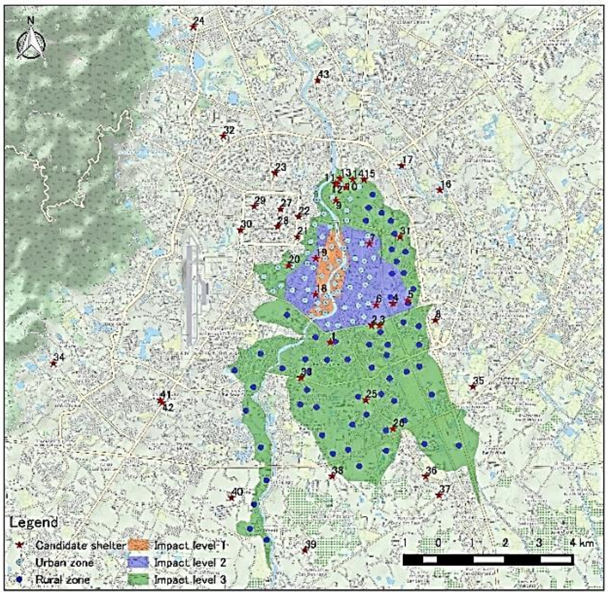

Fig. 5 Geographical location of three impact level areas, candidate shelter, and affected communities in Chiang Mai, Thailand

According to the classification of the impact level by CENDRU. To apply to our conceptual model, if we determine with respected to seven impact level, it is too much for evacuation in each level. So we assume that the seven impact levels are classified to three impact level, it implies that we have three evacuation periods the following probability as 0.73, 0.25, and 0.02, respectively[24]. In this study, we consider 123 communities and 43 candidates shelter that shown in Fig. 5. Unlike other evacuation, the evacuee's behavior during flood disaster is uncertainty, in which someone would like to evacuate after they hear alarm immediately, but someone would like to evacuate when the disaster strike. Hence, evacuee's behavior in each evacuation periods should be determined. The probability of evacuee's behavior is assumed to follow a uniform distribution between 0 and 1. Finally, the maximum limit of selected shelter is assumed as 25 shelters.

5. COMPUTATIONAL RESULT

We solved the model using the Gurobi Optimizer Ver. 6.0.0 mathematical programming solution software. All experiments were run on a personal computer with an Intel (R) Core (TM) i7-6700 CPU (3.40GHz) and 16 GB of RAM.

5.1 Result

Fig. 6 shows the geographic distribution under hierarchical evacuation planning as well as selected shelter of different impact level. The total expected population-weighted travel distance is 8,349,950. Among the 43 candidate shelters, 25 were identified as shelters that operate at their capacity to serve the communities during flood disaster occurrence. In first evacuation period, shelter 18 and 19 are selected. The second evacuation period consists of shelter 1-3, 8, 9, 20-22, 28, and 31. For third evacuation period, there are shelter 8, 16, 17, 23, 24, 27, 28, 30, 32, 34-38, and 40. An essential aspect of evacuation planning is its applicability for testing the proposed response operations. The distribution of shelters and distribution of communities should be examined with clearly defined operational details. This model also presents the distribution of evacuees from a community or a shelter to their assigned destination in three evacuation period that shown in Fig. 6.

5.2 Sensitivity analysis

In this section, we present a sensitivity analysis to show how the parameters affect the results with respect to changing input parameters. The total number of selected shelter constraint is the major constraint that impinging on both shelter site selection and evacuation planning. The total number of shelter constraint was varied from 32 shelters to 10 shelters, in increments of 1, to represent the different total number of shelter with aspect to an objective function which shown in Fig. 7

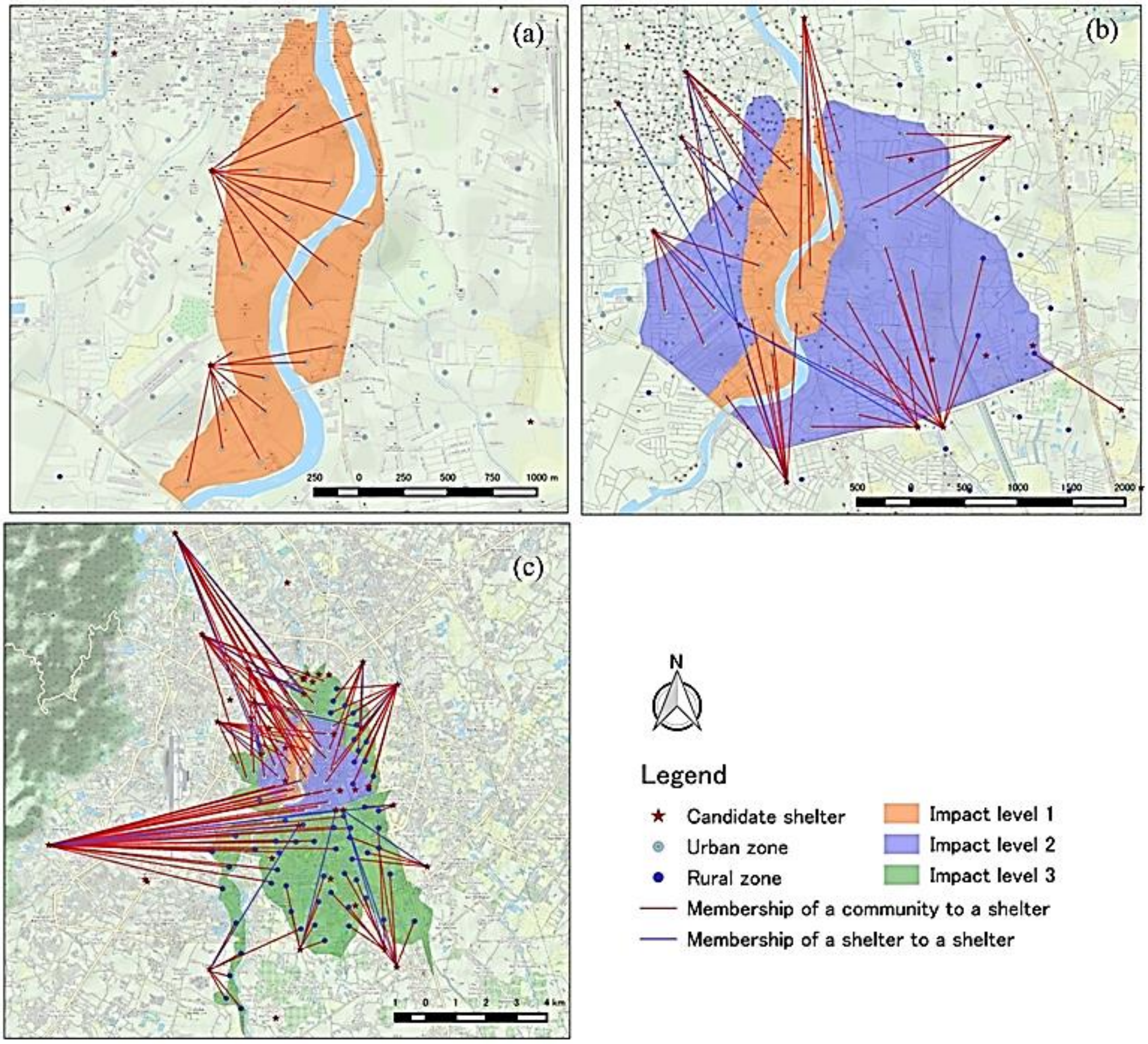

Fig. 6 The scheme of flood-shelter location and evacuation planning (a) The first evacuation planning; (b) The second evacuation planning; (c) The third evacuation planning

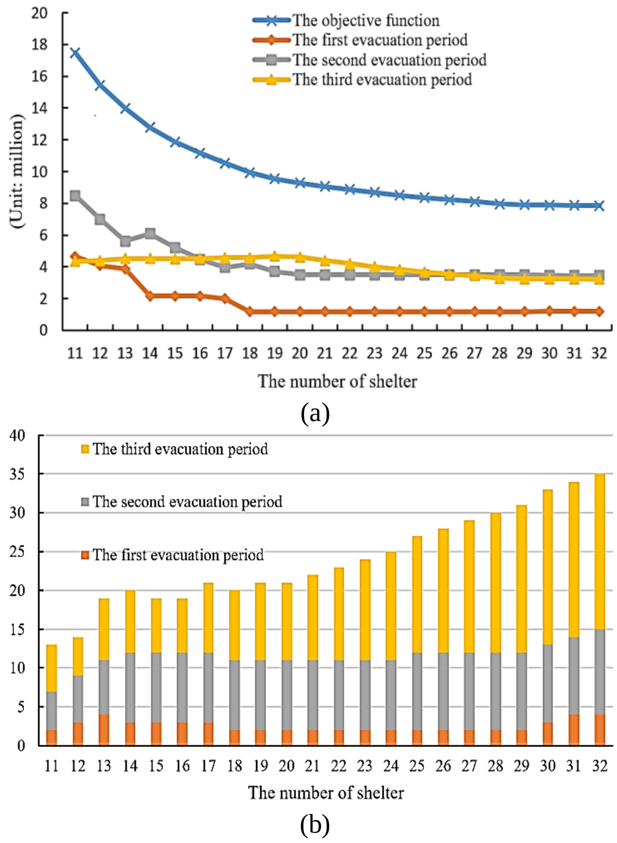

Fig. 7 (a) The derived total expected population-weighted travel distance and (b) the derived the total number of selected shelter in each evacuation period under the different total number of selected shelter.

Table 1 shows the result when the model is run multiple time with varying the total number of selected shelter. The table not only presents the statistics of planning result but also shows the total expect population-weighted travel distance and the number of selected shelter in each evacuation period. The result found that when the total number of selected shelter is decreased, the total expected population-weighted travel distance is increased. In the first evacuation period, the expected population-weighted travel distance is constant over time around 1,180,000 during the total number of selected shelter as 18-32. After that, it is increased continually. The total number of selected shelter is selected between 4-2 shelter, almost is selected at 2 shelters during the maximum limit is 18-29 shelters. In the second evacuation period, the expected population-weighted travel distance is higher than the first evacuation period because the new shelters are located farther from affect area and the number of community is also increased. The maximum of the number of shelters in this period requires 11 shelters. The total number of selected shelter in this period is decreased when the total number of selected shelter of the function is decreased. But it is unchanged between the number of shelter as 25-31 shelters and 14-24 shelters that there are 9 and 10 shelters, respectively. The total expected population-weighted travel distance of this period is increased continually as same as the first period. Same as the second evacuation period, the total number of shelter in the third evacuation period is decreased when the total number of selected shelter of the function is decreased. For the total expect population-weighted travel distance of this period is increased during it have shelter at 19-32, but it is a little bit decreased after the total number of shelter is 19 shelters. In this case, the model needs at least 11 shelters for the relief response to be feasible.

Table 1. The result under the different total number of selected shelter.

The maximum limit of shelter	The number of selected shelter			The objective function (Unit: million)	The total expected population-weighted travel distance (Unit: million)		
	Period 1	Period 2	Period 3		Period 1	Period 2	Period 3
10	N/A						
11	2	5	6	17.4817	4.6611	8.4791	4.3415
12	3	6	5	15.4446	4.0714	6.9897	4.3834
13	4	7	8	13.9897	3.8627	5.6114	4.5161
14	3	9	8	12.7832	2.1584	6.0936	4.5310
15	3	9	7	11.8743	2.1584	5.2189	4.4968
16	3	9	7	11.1547	2.1584	4.4718	4.5244
17	3	9	9	10.5306	1.9920	3.9679	4.5705
18	2	9	9	9.94006	1.1804	4.1814	4.5781
19	2	9	10	9.54381	1.1804	3.6981	4.6652
20	2	9	10	9.28308	1.1804	3.4929	4.6097
21	2	9	11	9.06798	1.1804	3.4929	4.3946
22	2	9	12	8.87445	1.1804	3.4929	4.2011
23	2	9	13	8.68376	1.1804	3.4929	4.0104
24	2	9	14	8.50861	1.1804	3.4929	3.8352
25	2	10	15	8.34995	1.1804	3.4972	3.6722
26	2	10	16	8.21626	1.1804	3.4963	3.5394
27	2	10	17	8.11065	1.1804	3.4940	3.4362
28	2	10	18	7.95604	1.1804	3.4959	3.2796
29	2	10	19	7.91435	1.1804	3.4959	3.2379
30	3	10	20	7.89021	1.2031	3.4556	3.2314
31	4	10	20	7.86772	1.1887	3.4432	3.2357
32	4	11	20	7.85070	1.1887	3.4408	3.2210

6. CONCLUSIONS

This study presented a stochastic linear mixed-integer programming mathematical model for flood evacuation planning to optimize decision related to shelter site selection under hierarchical evacuation planning. The proposed mathematical model considers minimum expected population-weighted travel distance as the objective function. This article not only provides a flood-shelter but also determines hierarchical evacuation concept, population assignment, and evacuee's behavior for flood disaster that balances the preparedness and risk despite the uncertainties of flood events. Our proposed model was validated by generating a base case scenario using real data for Chiang Mai province, Thailand. Moreover, we also proposed sensitivity analysis for more guideline under uncertainty decision.

Our results can serve emergency management purposes. The first is to help in preparation stage in the pre-disaster period including spatial distribution of shelter and assignment of affected communities. The second is to aim in response stage in the post-disaster period for reducing suffering, financial loss, and providing evacuation flow and directions at each evacuation periods. The third is to aim in recovery stage in post-disaster period for reverse evacuation in term of distance. Briefly, this article will be great significance in helping policy makers consider both spatial, financial, risk, and performant aspect of the strategic placement of flood-shelters and evacuation planning under uncertainties of flood scenario.

The implementation of proposed mathematical model also has limitations. According to unlike another nature disaster, it cannot be generated to others disaster due to some condition of each nature disaster are different such as shelter type, time condition, etc. However, our mathematical model can apply to any other city in flood situation as well. Although this proposed conceptual model is quite complicated, but it can response to many criteria completely. So the decision maker should decide carefully to apply with a real case.

In future research, the model should consider in road closures or traffic congestion that may affect to an efficient evacuation. Furthermore, this model should consider utilization of shelter, financial cost and risk of open shelter as well.

ACKNOWLEDGMENT: We sincerely thank The Natural Disaster Research Unit of Civil Engineering Department of Chiang Mai University (CENDRU) for supporting the data.

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