MULTI-MODEL OPTIMIZATION FOR SHELTER-SITE SELECTION: A CASE STUDY IN BANTA MUNICIPALITY, THAILAND

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Due to the world is stricken by disasters, people got effect both loss of human life and loss of assets. Therefore, urban planning is important for evacuation planning and shelter selection. The objective of this study aims to propose multi-model optimization for selecting shelter-site and evacuation planning, four mathematical models are formulated under a dynamic of both constraint and model type. In each model, the objective function is to minimize the total travel distance. Finally, an appropriate model is chosen in order to apply to a real case. A numerical example with a real case study of a Banta municipality, Chiang Rai province in Thailand is given to demonstrate the application of the proposed models.

Key Words: *optimization, multi-model, facility location, shelter-site selection, case study*

1. INTRODUCTION

Now, the world is affected by many disasters. Since the 1950s, the number of disasters has increased continually. Base on annual disaster statistical review 2014[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 proposes that Asia and America are the most affected continues by natural disasters such as earthquakes, storms, floods, landslides, etc.[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)]. Due 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)].

During a disaster 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. Modeling, optimization, decision making and simulation are the major approach to overcome these challenges[6)]. However, one model or one plan cannot respond all situations. For supporting disaster relief operation, several models or plans are the best choice for planning selection including shelter site selection and evacuation planning.

This study, we propose multi-model planning for selecting shelters and evacuation planning. The mathematical optimization technique is proposed to create planning that is formulated under a dynamic of both constraint and model type. Finally, an appropriated and realistic plan is selected by organization or government (Decision maker).

The remainder of this study is organized as follows. Section 2 present a review of related literature. Section 3 address proposed models. A case study is given in section 4. Section 5 show that the computational results. Finally, the conclusion and future research are present in section 6.

2. LITERATURE REVIEWS

Facility location problems and assignment problems are the base for shelter site selection and evacuation planning. Facility location problems can divide into four main parts that consist of minisum facility location problems, covering problems, minimax facility location problems and obnoxious facility location problems. In this study, we focus on minisum facility location problems that select or locate as P facilities, the total transport distance (including transport time or transport cost) between the demand points and selected facilities are defined as minimized.

There are some related papers discussing shelter-site location and evacuation operations. Chata and Sungsawang[7)] proposed bi-objective optimization model to find appropriate locations of temporary shelters that to maximize the number of victims that can be covered within a fixed distance and also to minimize the total distance of all victims to their closest shelters. Gold et al[8)] presented flood facility location-allocation in Marikana city by using maximal covering location problem (MCLP) with Lagrange optimization model. This study attempted to select shelter by considering flood level constraint. Anping[9)] proposed two mathematical models that are variations of the maximum set covering problem for selecting the shelter site location after a disaster. Li and Jin[10)] considered the stochastic nature of hurricanes and proposed this randomness by generating different scenarios and respective occurrence probabilities. Moreover, Dalal et al.[11)] also presented problem same as Li and Jin[10)] by using a clustering approach. In addition, Kilci et al.[12)] proposed a Mixed Integer Linear Programming for selecting the location of the temporary shelter. Not only assigning each district to the closest open shelter area, providing the capacity of shelter areas, controlling the minimum utilization and pair-wise utilization difference of open shelter areas, and also making sure that each open shelter area has the main road connection and a health institution within a limited distance.

Furthermore, Kongsomsaksakul et al.[13)] studied optimal shelter location for flood evacuation planning, bi-level programming model was formulated. Another bi-level programming model was proposed by Feng and Wen[14)] 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. The shelter location and evacuation planning were studied with traffic management by Bayram et al.[15)] The proposed model is Mix Integer Non-Linear Programming (MINLP) that optimally locates shelters and assigns evacuees to the nearest shelter sites by assigning them to shortest paths, shortest and nearest with a given degree of tolerance.

All of the reviewed papers proposed only one model or one plan for evacuation planning. Some situations, one model cannot apply to reality case. Therefore, we aim to propose several model planning for the choice of appropriate evacuation planning which can apply to real world case study in Thailand.

3. PROPOSED MODELS

The mathematical models are proposed for shelter-site selection. The objective in each model is to minimize travel distance between demand zones to candidate shelter. All mathematical models are formulated under a dynamic of both constraint and model type. To formulated mathematical models, the assumption is considered as follows; the demand zone is assigned to the location in one route only due to protecting bafflement. Four mathematical models are proposed for this study that presents as follows:

(1) MODEL I

This model is a deterministic model, the input parameters are constant and certainty. This model determines both distance, demand zone and capacity of shelter. The model is a Mixed Integer Linear Programming (MILP) that present as follows:

Index

I	Set of demand zone i
J	Set of candidate shelter j

Parameter

d_{ij}	Distance between demand zone i and candidate shelter j
c_j	Capacity of candidate shelter j
h_i	Population in zone i
R	Distance limit
M	The large number

Decision variable

x_j 1 = if candidate shelter *j* is selected, 0 = otherwise

y_{ij} 1 = if demand zone *i* is assigned to candidate shelter *j*, 0 = otherwise

z_{ij} The number of demand zone *i* is assigned to candidate shelter *j*

Objective

Min $$\sum_i \sum_j d_{ij} * y_{ij} \quad (1)$$

Subject to

$$\sum_j x_j \leq P \quad (2)$$

$$y_{ij} \leq x_j \quad \forall i, j \quad (3)$$

$$d_{ij} * y_{ij} \leq R \quad \forall i, j \quad (4)$$

$$\sum_i z_{ij} \leq c_j * x_j \quad \forall j \quad (5)$$

$$\sum_j z_{ij} = h_i \quad \forall i \quad (6)$$

$$z_{ij} \leq M * y_{ij} \quad \forall i, j \quad (7)$$

$$\sum_j y_{ij} = 1 \quad \forall i \quad (8)$$

$$x_j, y_{ij} \in \{1, 0\} \quad \forall i, j \quad (9)$$

$$z_{ij} \geq 0 \quad \forall i, j \quad (10)$$

Equation (1) is showed objective function that to minimizes travel distance between demand zone to candidate shelter. Equation (2) ensures that the number of shelters does not exceed *P* locations. Equation (3) states that demand zone is only assigned to the selected location. Equation (4) states that the limitation of distance between demand zone and shelter. Equation (5) allows assignment only to the sites at which shelter have been located and not exceed the capacity of each shelter. Equation (6) states that the number of demand in zone *i* is assigned to selected shelter. Equation (7) - (8) ensure that demand zone *i* is assigned to the location in one route only and equation (10) - (11) enforce integrality restriction.

(2) MODEL II

This section, we propose a Mixed Integer Nonlinear Programming (MINLP). The Model I is developed to a stochastic model. Chance constrained model is used to apply in this model for uncertain distance as shown in equation 11.

$$P\left\{\sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij} * y_{ij} \leq b\right\} \geq \alpha \quad (11)$$

Equation (11) is added to the deterministic model. b is defined as maximum acceptable total distance. α is defined as a confidence level. In this case study we use confidence level as 90% (α = 1.285)

(3) MODEL III

In this model, the robust model that Yu and Li[16] reformulated from Mulvey and Ruszczynski[17], is used to apply for shelter-site selection. This model is proposed several situations by using probability principle for defining the possible situation. The model is a Mixed Integer Linear Programming (MILP) that propose as follows:

Index (addition)

S Set of scenario *s*

Parameter (addition)

h_{is} Population of zone i in scenario *s*

p_s Probability in scenario *s*

λ Variability weight

ω Weighting penalty **(**risk-aversion weight)

Decision variable (addition)

θ_s Non-negative deviation variable per scenario

δ_{is} Under-fulfillment of demand zone *i* in scenario *s*

Objective

$$\text{Min} \quad \sum_s p_s * TD + \lambda * \sum_s p_s * \left[\left(TD - \sum_s p_s * TD\right) + 2\theta_s\right] + \sum_s \omega * \sum_i \sum_s p_s * \delta_{is} \quad (12)$$

Subject to

(2) - (5), (7) - (10)

$$\sum_j z_{ij} + \delta_{is} - h_{is} >= 0 \quad \forall i, s \quad (13)$$

$$\sum_i \sum_j d_{ij} * y_{ij} = TD \quad (14)$$

$$TD - \sum_s p_s * TD + \theta_s \quad \forall s \quad (15)$$

$$\theta_s, \delta_{is} \geq 0 \quad \forall i, s \quad (16)$$

The first and second terms of objective function in equation (12) are mean and variance of the total distance, and aim to measure solution robustness. The third term in equation (12) measures the model's robustness to the infeasibility of the control constraint. Equation (13) is a control constraint, the number of demand at zone *i* in each situation is assigned to selected shelter and also determines the under-fulfilled of demand in each zone. Equation (14) is to minimize total travel distance between demand zones to candidate shelters. Equation (15) is the auxiliary equation. Lastly, the integrality restriction is presented in equation (16).

(4) MODEL IV

This model is formulated from combining between Model II and Model III that analyze both uncertainty distance and several situations. The equation 11 is added to the constraint of Model III under the objective in equation 12. This model is a Mixed Integer Nonlinear Programming (MINLP).

4. CASE STUDY

Landslides and flash flood are a common geological phenomenon in many parts of the world.[18] In 2014, the landslide and flash flood have occurred in many countries such as Nepal, India, and Sri Lanka.[1] Thailand is one country that has occurred this disaster. The landslide and flash flood event which took place in Thailand and also killed a lot of human life. Department of Mineral Resource, Ministry of Natural Resources and Environment in Thailand have been surveyed risk areas in 2012. They found that Chiang Rai province has a risk to occur landslide and flash flood.[19] In this case study, we present Banta municipality in Chiang Rai that has risk areas about more than 50% of the area as shown in Fig 1. The area of Banta municipality is 58.99 square kilometers, the population is 12,866 persons, and consists of 20 villages.

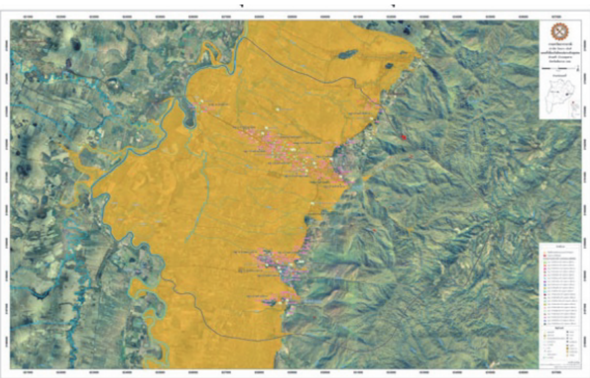

Fig. 1 Risk areas in Banta municipality, Chiang Rai, Thailand.[19]

In this section, we present a simple numerical experiment that using a case study of landslide and flash flood situations in Banta municipality. This case study, there are 20 zones and 13 candidate shelters. The position of villages and candidate shelters are shown as Fig.2. The distance limit in each route is 5 kilometers and the maximum of selected shelter is 10 shelters.

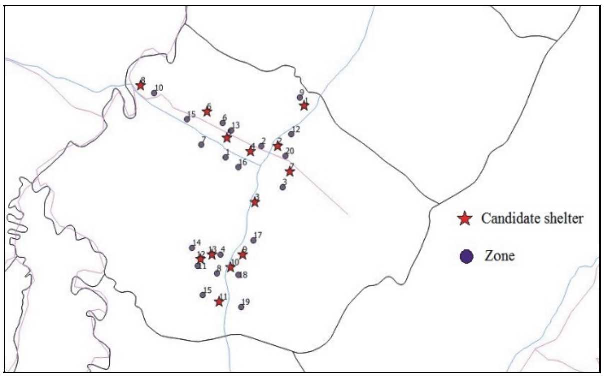

Fig. 2 The position of villages and candidate shelters in Banta municipality

5. RESULT

We code all mathematical models in LINGO 15 on a laptop with Intel Core i7 CPU 2.4 GHz and 4 GB of RAM. The example Lingo model is proposed in Fig 3. From Fig. 3, the model is divided into three main parts. The first part is how to define the used set and set members (variables and parameters). The second part is the proposed mathematical model in the form of Lingo code written. The third part is input data for the case study which Microsoft Excel is applied to input and output data. All runs were solved in less than 2 minutes.

```
model:
      sets:
      zone/1..20/:h;!i;
      location/1..13/:x,Cap;!j;
      link1(zone,location):z,d,y;                    Part 1
endsets
!Constraints;
@for(zone(i):@for(location(j):@BIN(y(i,j))));
@for(location(j):@BIN(x(j)));
@sum(location(j):x(j))<=p;
@for(zone(i):@for(location(j):y(i,j)<=x(j)));
@for(zone(i):@for(location(j):d(i,j)*y(i,j)<=5));
@for(location(j):@sum(zone(i):z(i,j))<=Cap(j)*x(j));
@for(zone(i):@sum(location(j):z(i,j))=h(i));
@for(Zone(i):@for(location(j):z(i,j)<=99999*y(i,j)));
@for(zone(i):@sum(location(j):y(i,j))=1);

!Objective;
min = @sum(zone(i):@sum(location(j):d(i,j)*y(i,j)));   Part 2
data:
      h= @OLE('E:\PHD_Thesis\Lingo\Simple_model\data.xlsx');
      d= @OLE('E:\PHD_Thesis\Lingo\Simple_model\data.xlsx');
      Cap= @OLE('E:\PHD_Thesis\Lingo\Simple_model\data.xlsx');
      p= 10;
      @OLE('E:\PHD_Thesis\Lingo\Simple_model\data.xlsx')=z;
      @OLE('E:\PHD_Thesis\Lingo\Simple_model\data.xlsx')=y;
enddata
end                                                    Part 3
```

Fig. 3 The example Lingo model.

After running Lingo software, the result of all formulation is shown in Table 1 and Fig. 4. From

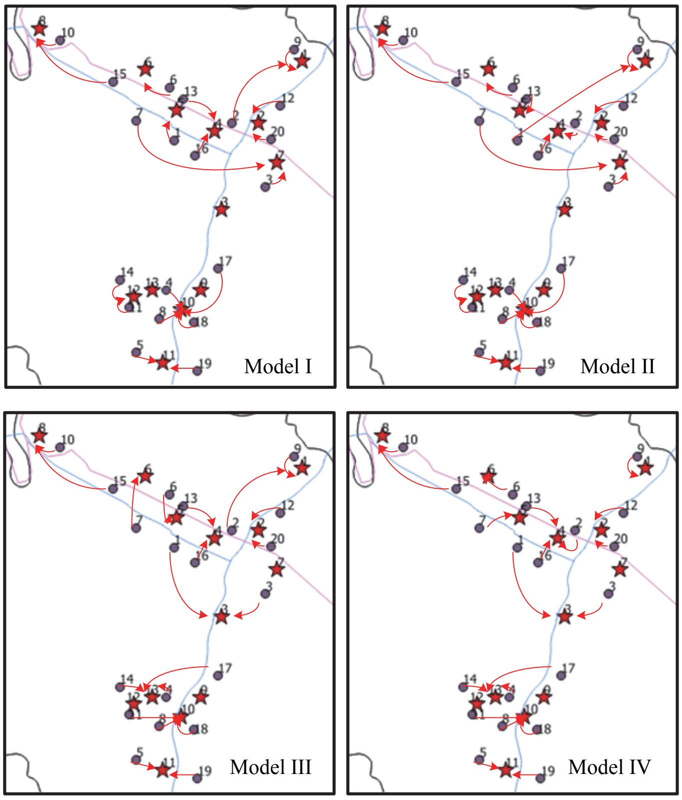

Fig. 4 The result of case study in Banta municipality

Table 1. The result of case study in Banta municipality, Chiang Rai Province, Thailand

Model type:	Model I	Model II	Model III	Model IV
Model class:	MILP	MINLP	MILP	MINLP
Optimal solution:	18.01 kilometer	19.25 kilometer	18.91 kilometer (ω=0.025)	17.91 kilometer (ω=0.025)
Selected shelter:	1,2,4,5,6,7, 8,10,11,12	1,2,4,5,6,7, 8,10,11,12	1,2,3,4,5,6, 8,10,11,13	1,2,3,4,5,6, 8,10,11,13
Zone 1	5	1	3	3
Zone 2	1	4	1	4
Zone 3	7	7	3	3
Zone 4	10	10	13	13
Zone 5	11	11	11	11
Zone 6	6	6	5	6
Zone 7	7	7	6	5
Zone 8	10	10	10	10
Zone 9	1	1	1	1
Zone 10	8	8	8	8
Zone 11	12	12	10	10
Zone 12	2	2	2	2
Zone 13	4	5	4	5
Zone 14	12	12	13	13
Zone 15	8	8	8	8
Zone 16	4	4	4	4
Zone 17	10	10	13	13
Zone 18	10	10	10	10
Zone 19	11	11	11	11
Zone 20	2	2	2	2

Table 2. The result of sensitivity analysis for the number of shelters.

The number of shelter		7	8	9	10	11	12	13
Model I	Total distance	28.05	23.8	20.41	18.01	16.31	15.91	15.91
	Selected shelters	1,3,4,5,8, 10,13	1,3,4,5,6, 8,10,13	1,2,4,5,6, 7,8,10,13	1,2,4,5,6, 7,8,10,11 ,12	1,2,3,4,5, 6,7,8,10, 11,12	1,2,3,4,5, 6,7,8,9,1 0,11,12	1,2,3,4,5, 6,7,8,9,10 ,11,12,13
Model II	Total distance	30.02	25.79	21.71	19.25	18	17.6	17.6
	Selected shelters	1,3,4,5,8, 10,13	1,3,4,5,6, 8,10,13	1,2,4,5,6, 7,8,10,13	1,2,4,5,6, 7,8,10,11 ,12	1,2,3,4,5, 6,7,8,10, 11,12	1,2,3,4,5, 6,7,8,9,1 0,11,12	1,2,3,4,5, 6,7,8,9,10 ,11,12,13
Model III	Total distance	25.2	23.8	21.46	18.91	17.76	17.26	17.11
	Selected shelters	1,3,5,6,8, 10,13	1,3,4,5,6, 8,10,13	1,2,3,4,5, 6,8,10,13	1,2,3,4,5, 6,8,10,11 ,13	1,2,3,4,5, 6,7,8,10, 11,13	1,2,3,4,5, 6,7,8,10, 11,12,13	1,2,3,4,5, 6,7,8,9,10 ,11,12,13
Model IV	Total distance	26.6	24.03	20.48	17.91	16.84	16.31	16.28
	Selected shelters	1,3,5,6,8, 10,13	1,2,3,5,6, 8,10,13	1,2,3,4,5, 6,8,10,13	1,2,3,4,5, 6,8,10,11 ,13	1,2,3,4,5, 6,7,8,10, 11,13	1,2,3,4,5, 6,7,8,9,1 0,11,12	1,2,3,4,5, 6,7,8,9,10 ,11,12,13

Table 1 and Fig. 4, the optimal solution of the Model I is 18.01 kilometers that candidate shelters consist of 1, 2, 4, 5, 6, 7, 8, 10, 11 and 12. For the Model II, the optimal solution is 19.25 kilometers, the selected shelters are same as the Model I. For Model III, the optimal solution is 18.91 kilometers. In this solution, there are shelter 1, 2, 3, 4, 5, 6, 8, 10, 11 and 13. Finally, the Model IV, the optimal solution is 17.91 kilometers which there are shelters same as the Model III. The nomination in each model is different. However, nomination in some zone, the result is same, consists of zone 5, 8, 9, 10, 12, 15, 16, 18, 19 and 20. The sensitivity analysis of a number of limited shelters is showed in Fig 5 and Table 2.

From Fig 5, we first run all models by varying the number of limited shelters, in a decrement of 1, to present the different objective function and assignment. The result found that the total distance is increased when the number of limited shelters is reduced. For Model I and Model II at the number of limited shelters as 12 and 13, the total distance is stable as 15.91 and 17.6 kilometers, respectively. However, when the number of selected shelters less than or equal to 10, the total distance is increased continually. The system needs at least 7 shelters for the relief response to be feasible. For Model III and Model VI, the tendency is also increased continually when the number of selected shelters is reduced. The total distance of Model III is higher than Model IV during the number of selected shelters as 9-13 shelters. On the other hand, during the number of selected shelters as 7-8 shelters, the Model IV starts to decrease lower than the Model III.

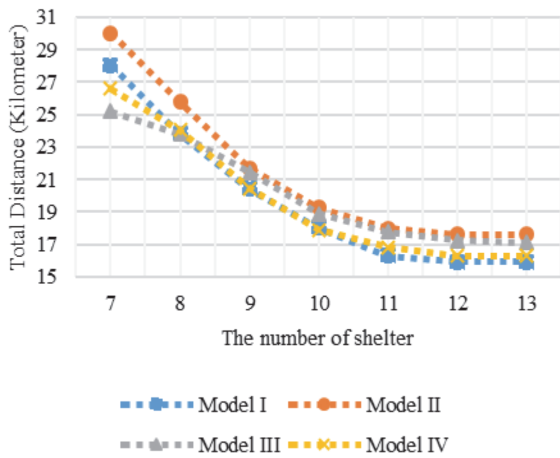

Fig. 5 Sensitivity analysis of the number of shelters

6. CONCLUSIONS

This study proposes choice for selecting shelter and evacuation planning by considering the number of population, capacity and travel distance. Four mathematical models are formulated under dynamics conditions and model types. The objective of each model is to minimize the total travel distance. The proposed model was tested with a real case study in Banta Municipality, Chiang Rai province, Thailand. Finally, an appropriate and realistic plan is proposed to select by organization or government (Decision maker) in Banta Municipality.

Our study is an advantage for decision making. Decision makers can choose an appropriate planning model from several mathematical models that is better than using one model for solving the problem.

For future research, the models should add some conditions and create more realistic. Furthermore, Multiple Criteria Decision Making (MCDM) are proposed to apply in this study for selecting an appropriated planning by considering qualitative factors such as accessibility, safety, availability, sustainability, etc.

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