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Research article

Humanitarian Logistics Modelling for Flood Disaster Management in Thailand

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Abstract: Nowadays, many areas in Thailand have experienced severe flood disasters that have widespread effects on life, property, society, economy, and the environment. Therefore, this research aims to develop a mathematical model for humanitarian logistics management in Thailand's flood-affected areas. Two models were developed using mixed-integer nonlinear programming: one to minimize the total cost of disaster relief management, and another to maximize the number of rescued disaster victims, with operating costs as a constraint, because in some situations there was a limited budget for helping victims. The two proposed models provided disaster preparedness planning by identifying optimal shelter locations, determining appropriate quantities of relief supplies to procure, and allocating and distributing those supplies efficiently to affected victims.

Keywords: Humanitarian logistics; flood disaster; mixed integer nonlinear programming

1. Introduction

Disaster is a severe disruption of the functioning of a community or society that has widespread effects on life, property, society, the economy, and the environment, beyond the affected community or society's ability to cope with available resources [1]. Disaster may arise from natural or artificial causes. A flood is a disaster caused by inundation, flash flooding, or water from rivers, streams, or waterways, all driven by excessive water volume, and may occur as flooding, flash floods, or related events. It is a natural disaster that lies largely beyond human control [2, 3]. Thailand has experienced numerous flooding incidents during 2011-2013 and 2024, which have had a significant impact on people and property, especially during the rainy season in lowlands, hillsides, and riverbanks. However, disaster management capacity across government agencies and local communities remains insufficient to cope with such events effectively. Cotes and Cantillo [4] reported that a survey of public opinion on the government's flood management between 2011 and 2013 revealed that assistance to flood victims was duplicated and unevenly distributed. Humanitarian logistics is the management of the logistics process for providing disaster relief. The procurement of products and services is a critical and challenging process for humanitarian organizations, accounting for approximately 65 percent of total relief operation costs [5].

Humanitarian logistics plays a crucial role in disaster relief and resource management and can be divided into two types: continuous aid work and disaster relief, whether natural or man-made. Therefore, humanitarian logistics is the process of planning, implementing, and controlling the flow of materials and information from the point of origin to the point of need efficiently and cost-effectively to provide relief to those affected [6,7]. Cotes and Cantillo [4] developed a model of facility location for disaster preparedness, aiming to minimize the total social cost. The amount of relief supplies per type is determined in advance and is available in the disaster-affected area during the initial disaster response phase. The model also focuses on the immediate assistance that should be provided within the first 24 hours, using real data from the Caribbean region of Colombia, which was affected by floods in 2010 and 2011. Bozorgi-Amiri et al. [8] presented a robust multi-objective stochastic model for disaster relief logistics that considers uncertain resource demand, procurement costs, and transportation costs. The model objective is to minimize the total cost and the variation in the maximum shortage in the affected area of the earthquake event in Iran. The results showed that the proposed model can support decision-making on location and resource allocation in earthquake relief. In addition, Rodríguez-Espíndola et al. [9] applied logistics to resource management for disaster relief and appropriate operational planning, combining an optimization model with GIS. A bi-objective optimization model was developed to identify the locations of emergency facilities, the amount of stockpiled resources, and the allocation and distribution of resources, along with the number of actors involved in disaster management operations, using real data from the 2013 flood in Acapulco, Mexico.

Rodríguez-Espíndola et al. [10] reviewed a wide range of literature on the application of mathematical models in humanitarian logistics management, finding that most research covers both logistics and supply chain management, and aims to minimize overall costs. Some research aims to minimize processing times, particularly in the transportation of relief goods and disaster victims [11], while other research focuses on developing multi-objective models and applying heuristics [12]. In addition, some research involves simulations or decision support systems to plan for disaster preparedness [13]. A wide range of mathematical models has been applied to disaster management, including single-objective and multi-objective models with nonlinear programming (NLP) [10, 14-16], integer nonlinear programming (INLP), where decision variables are set to integers and the objective function is nonlinear [17], and mixed-integer nonlinear programming (MINLP) [18]. Models for humanitarian logistics management may include either continuous or integer decision variables to determine the location of shelters, the allocation and distribution of relief supplies, and the allocation of resources. Under disaster conditions, this study addresses two research questions: (1) What is the minimum total cost required for effective disaster management? and (2) How can the number of rescued disaster victims be maximized under budgetary constraints?

Accordingly, this research aims to develop a mathematical model for humanitarian logistics management during flooding in Thailand, supporting disaster preparednessby optimizing facility location decisions and resource allocation. The paper is organized as follows: Section 2 introduces the analytical concepts, materials, and methods; Section 3 describes the MINLP models developed for humanitarian logistics. Section 4 applies the models to a real flood-affected area, with accompanying sensitivity analysis, and Section 5 concludes with the key findings and discussion.

2. Materials and Methods

The mathematical models for humanitarian logistics management were developed from two models: Model I aims to minimize the total cost of disaster relief management, and Model II aims to maximize the number of rescued disaster victims. This design concept is not only focused on a single objective but also consistent with the general situation in disaster management, which often has limited budgets. The research procedure is shown in Figure 1. The two proposed models consider constraints on the number of disaster victims and the disaster area, including the habitable disaster-affected area that requires essential relief supplies and the uninhabitable disaster-affected area, where disaster victims must be moved to different temporary shelters. Each shelter can accommodate different numbers of disaster victims. Moreover, the model also considers constraints on the types and capacities of vehicles for transporting disaster victims and relief supplies, as well as on the supply of relief supplies at a given price. The developed mathematical models have an objective function given by Equation (1) and several nonlinear constraints. Therefore, a mixed-integer nonlinear programming (MINLP) approach was used. In Model II, the value of the budget constraints is set from the objective function result of Model I, and sensitivity analysis is performed with various levels of budget, which vary to decrease for each scenario to consider the effect on the value of the objective function, that is, the number of flood victims rescued and receiving relief supplies. Furthermore, the effect on the decision variables, number of relief supplies procured, and number of shelters open, is also considered. This analysis provides insight into operational trade-offs under financial limitations.

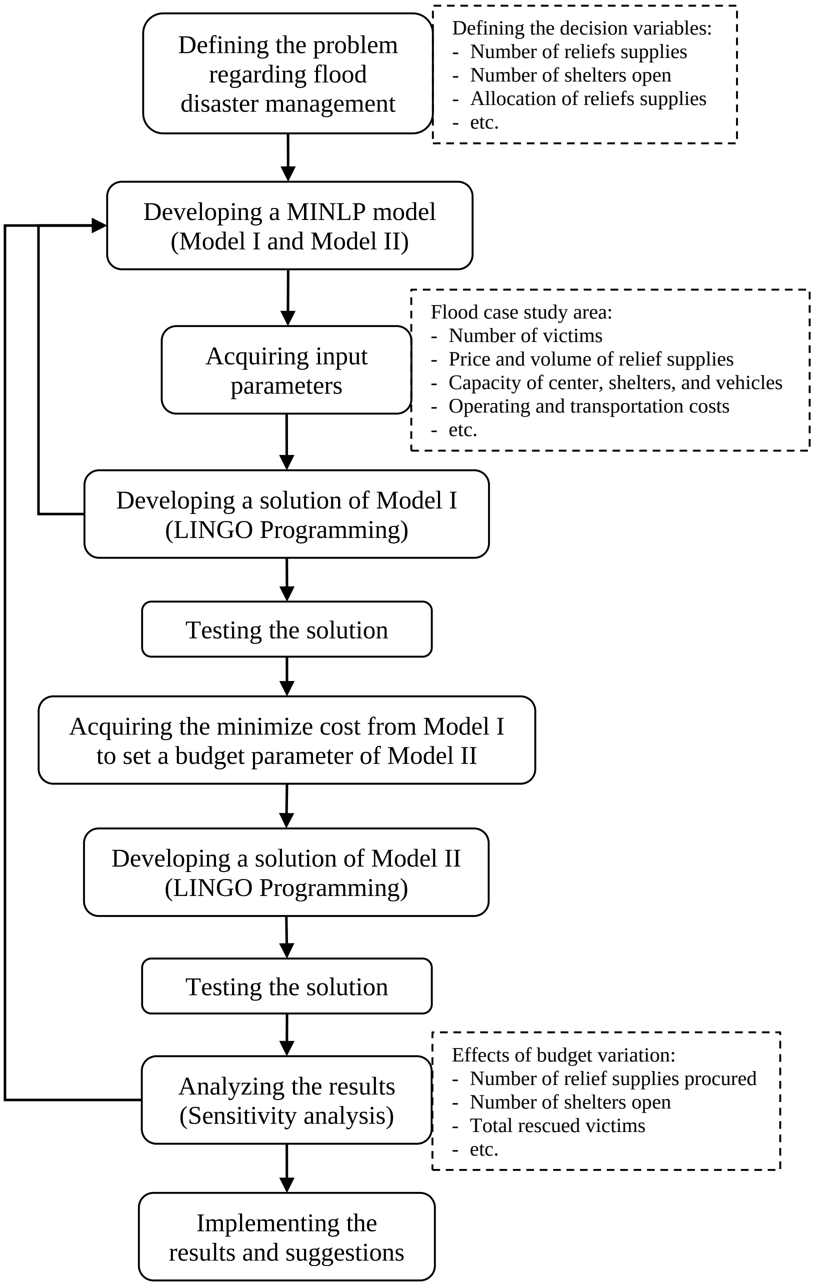

Figure 1. The research procedure.

3. Humanitarian Logistics Models

Two mathematical models for humanitarian logistics management were developed using mixed integer nonlinear programming (MINLP) with the following indexes, decision variables, parameters, and model structure.

Indexes:

i	Relief distribution center
j	Shelter
k	Habitable disaster-affected area
o	Uninhabitable disaster-affected area
m	Vehicle type for transporting reliefs
n	Vehicle type for transporting disaster victims

Decision variables:

Y_j	Opening the shelter j
H_i	Number of relief supplies to be purchased and stored at the distribution center i (bags)
XK_{ik}	Habitable disaster-affected area k that receives relief supplies from the distribution center i
XJ_{ij}	Shelters j that receive relief supplies from the distribution center i
Z_k	Number of victims in habitable disaster-affected area k that receive relief supplies (people)
Z_j	Number of victims in the shelter j that receive relief supplies (people)
NOJ_{ojn}	Number of victims in the uninhabitable disaster-affected area o who were transported to the shelter j by vehicle type n (people)
NJ_{ijm}	Number of relief supplies transported from the distribution center i to the shelter j by vehicle type m (bags)
NK_{ikm}	Number of relief supplies transported from the distribution center i to habitable disaster-affected area k by vehicle type m (bags)

Parameters:

CX_i	Operating cost of relief distribution center i (baht)
CY_j	Operating cost of shelter j (baht)
Pr	Price of relief supplies (baht per bag)
CTM_m	Transportation cost of relief supplies by vehicle type m (baht per kilometer)
CTN_n	Transportation cost of victims by vehicle type n (baht per kilometer)
NE	Number of victims per unit of relief supplies (people)
P_k	Number of victims in habitable disaster-affected area k (people)
P_o	Number of victims in uninhabitable disaster-affected area o (people)
VOL	Volume per bag of relief supplies (m^3)
α	Weight per bag of relief supplies (kg)
$CAPX_i$	Capacity of relief distribution center i (m^3)
$CAPY_j$	Capacity of shelter j (people)
$CAPM_m$	Capacity of the vehicle type m used for transporting relief supplies (kg)
$CAPN_n$	Capacity of the vehicle type n used for transporting disaster victims (people)
DXK_{ik}	Distance from relief distribution center i to habitable disaster-affected area k (km)
DXY_{ij}	Distance from relief distribution center i to shelter j (kilometers)
DOJ_{oj}	Distance from uninhabitable disaster-affected area o to shelter j (km)
M	The positive large number

3.1 Model I

The objective of the model is to minimize the overall cost of disaster relief management, as shown in Equation (1), which includes the cost of relief goods, the cost of operating relief distribution centers, the cost of operating shelters, the cost of transporting disaster victims, and the cost of transporting relief supplies.

$$\begin{aligned} \textit{Minimize Total Cost} \; &= \sum_{i=1}^{I} PrH_i + \sum_{i=1}^{I} CX_i + \sum_{j=1}^{J} CY_j Y_j + \sum_{o=1}^{O}\sum_{j=1}^{J}\sum_{n=1}^{N} \frac{CTN_n DOJ_{oj} NOJ_{ojn}}{CAPN_n} \\ &+ \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{m=1}^{M} \frac{CTM_m DXY_{ij}(\alpha NJ_{ijm})}{CAPM_m} + \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{m=1}^{M} \frac{CTM_m DXK_{ik}(\alpha NK_{ikm})}{CAPM_m} \end{aligned} \tag{1}$$

Subject to

$$\sum_{i=1}^{I} XK_{ik} = 1 \qquad ;\forall k \tag{2}$$

$$\sum_{j=1}^{J} Y_j \geq 1 \tag{3}$$

$$\sum_{i=1}^{I} XJ_{ij} = Y_j \qquad ;\forall j \tag{4}$$

$$H_i VOL \leq CAPX_i \qquad ;\forall i \tag{5}$$

$$\sum_{i=1}^{I} H_i \geq \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{m=1}^{M} NJ_{ijm} XJ_{ij} + \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{m=1}^{M} NK_{ikm} \tag{6}$$

$$\sum_{i=1}^{I}\sum_{m=1}^{M} NJ_{ijm} XJ_{ij} \leq M(Y_j) \qquad ;\forall j \tag{7}$$

$$\sum_{j=1}^{J}\sum_{n=1}^{N} NOJ_{ojn} Y_j = P_o \qquad ;\forall o \tag{8}$$

$$\sum_{o=1}^{O}\sum_{n=1}^{N} NOJ_{ojn} \leq CAPY_j(Y_j) \qquad ;\forall j \tag{9}$$

$$\sum_{i=1}^{I}\sum_{m=1}^{M} NJ_{ijm} XJ_{ij} \geq \frac{\sum_{o=1}^{O}\sum_{n=1}^{N} NOJ_{ojn} Y_j}{NE} \qquad ;\forall j \tag{10}$$

$$\sum_{o=1}^{O}\sum_{n=1}^{N} NOJ_{ojn} Y_j \geq Z_j \qquad ;\forall j \tag{11}$$

$$\sum_{i=1}^{I}\sum_{m=1}^{M} NK_{ikm} \geq \frac{Z_k}{NE} \qquad ;\forall k \qquad (12)$$

$$\sum_{j=1}^{J} Z_j Y_j = \sum_{o=1}^{O} P_o \qquad (13)$$

$$Z_k = P_k \qquad ;\forall k \qquad (14)$$

$$Y_j \in \{0,1\} \qquad ;\forall j \qquad (15)$$

$$XK_{ik} \in \{0,1\} \qquad ;\forall i, \forall k \qquad (16)$$

$$XJ_{ij} \in \{0,1\} \qquad ;\forall i, \forall j \qquad (17)$$

$$H_i \geq 0 \text{ and integer} \qquad ;\forall i \qquad (18)$$

$$Z_k \geq 0 \text{ and integer} \qquad ;\forall k \qquad (19)$$

$$Z_j \geq 0 \text{ and integer} \qquad ;\forall j \qquad (20)$$

$$NOJ_{ojn} \geq 0 \text{ and integer} \qquad ;\forall o, \forall j, \forall n \qquad (21)$$

$$NJ_{ijm} \geq 0 \text{ and integer} \qquad ;\forall i, \forall j, \forall m \qquad (22)$$

$$NK_{ikm} \geq 0 \text{ and integer} \qquad ;\forall i, \forall k, \forall m \qquad (23)$$

The constraint, as Equation (2) shows, is that the habitable disaster-affected area does not receive relief supplies from duplicate distribution centers. Shelters are opened to accommodate the number of victims affected by uninhabitable areas, as shown in Equation (3). Equation (4) shows that relief supplies are transported from distribution centers to open shelters. The number of relief supplies to be purchased must not exceed the storage capacity of each relief distribution center, and the total number of relief supplies to be purchased must be able to meet the relief needs of both the habitable disaster-affected areas and the needs of the shelters, as shown in Equation (5) and Equation (6), respectively. Sufficient relief supplies will be transported to the open shelters as in Equation (7). All victims in the uninhabitable disaster-affected area will be moved to open shelters, and the number of victims that move to the opened shelter must not exceed that shelter's capacity, as shown in Equation (8) and Equation (9), respectively. The constraint, as shown in Equation (10), is that the number of relief supplies transported to the opened shelter must be sufficient to meet the shelter's relief needs. This corresponds to Equation (11), which shows that the number of victims in the uninhabitable disaster-affected areas who have been moved to the opened shelters must receive relief supplies. Equation (12) shows that the number of relief supplies transported to habitable disaster-affected areas must be sufficient to meet that area's relief needs. Moreover, all victims in the uninhabitable disaster-affected areas must have been moved to open shelters and must have received relief supplies. All victims in each habitable disaster-affected area must receive relief supplies, as shown in Equation (13) and Equation (14), respectively. In addition, Equations (14)-(17) show the binary variables, and Equations (18)-(23) show the non-negative integer variables.

3.2 Model II

The objective of the model is to maximize the number of rescued disaster victims under a specified budget constraint, as shown in Equation (24), which refers to the number of disaster victims who receive relief supplies, including both those in habitable disaster-affected areas and those in shelters who have been moved from the uninhabitable disaster-affected areas.

$$Maxmize\ Rescued\ Victims = \sum_{k=1}^{K} Z_k + \sum_{j=1}^{J} Z_j \tag{24}$$

Subject to

Equation (2)-(13), Equation (15)-(23), Equation (25) and Equation (26)

$$\left(\begin{array}{l} \sum_{i=1}^{I} PrH_i + \sum_{i=1}^{I} CX_i + \sum_{j=1}^{J} CY_j Y_j + \sum_{o=1}^{O}\sum_{j=1}^{J}\sum_{n=1}^{N} \dfrac{CTN_n DOJ_{oj} NOJ_{ojn}}{CAPN_n} \\ + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{m=1}^{M} \dfrac{CTM_m DXY_{ij} (\alpha NJ_{ijm})}{CAPM_m} + \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{m=1}^{M} \dfrac{CTM_m DXK_{ik} (\alpha NK_{ikm})}{CAPM_m} \end{array} \right) \le Budget \tag{25}$$

$$Z_k \le P_k \qquad ;\forall k \tag{26}$$

In addition, the total cost of disaster relief management is set as a constraint, as in Equation (25). The total cost must not exceed the available budget, which includes the cost of relief supplies, operating relief distribution centers, operating shelters, transporting disaster victims, and transporting relief supplies. Due to limited budgets, appropriate decisions must be made to help victims as much as possible. Moreover, the constraint of Equation (14) is adjusted to Equation (26) to relax the constraint in such a limited budget. Not all victims in each habitable disaster-affected area can receive relief supplies, but all victims in uninhabitable disaster-affected areas must have been moved to open shelters and must receive relief supplies. Other conditions remain the same as in Model I.

4. Case Study and Results

The developed MINLP models were applied to flooding scenarios in Kantharawichai District, Maha Sarakham Province, Thailand. The study area is a water collection point between two reservoirs, which experienced flooding approximately 500 times: 269 floods, 209 overflows, and 22 flash floods during 2012-2020 [19, 20] and consists of 10 sub-districts, 183 villages, and a total population of 82,764. Based on historical disaster records, 180 villages (k1-k180, with 82,194 victims) were classified as habitable disaster-affected areas, while 3 villages (o1-o3, with 570 victims) were classified as uninhabitable and requiring evacuation, as shown in Figure 2. The model parameters are shown in Table 1. The application of the developed MINLP model to the disaster area has the following important assumptions or limitations:

1. There are two centers for distributing relief supplies, namely the Provincial Disaster Prevention and Mitigation Office (i1) and the District Office (i2).

2. There are 19 alternative shelters (j1-j19), which are the locations of various government agencies such as schools and temples.

3. The transportation of disaster victims and relief supplies will be used only by trucks.

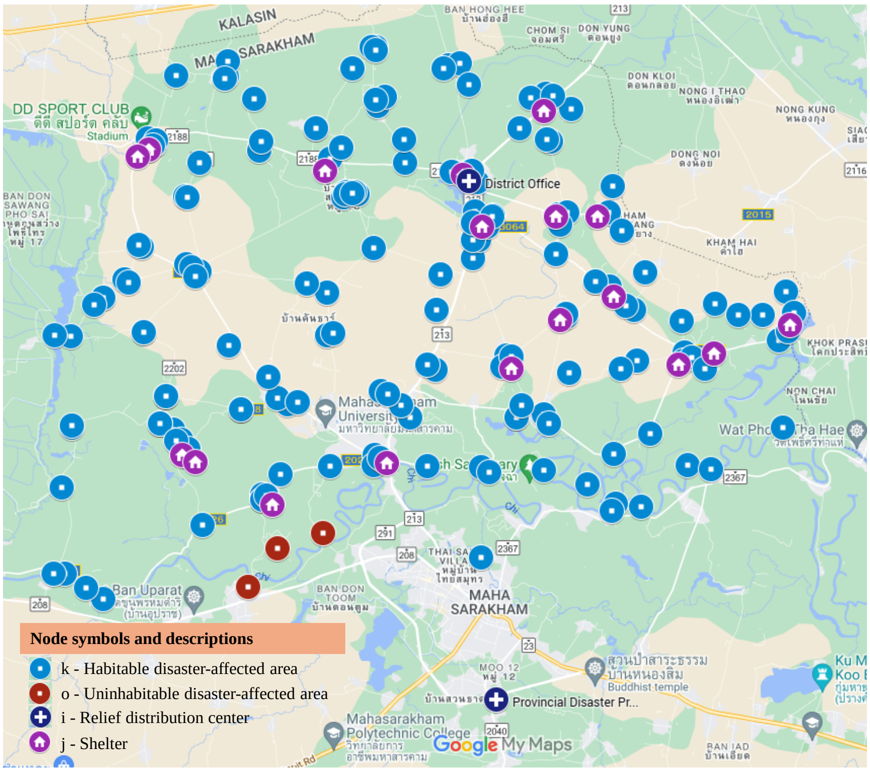

Figure 2. Case study map of flood disaster-affected area in Kantharawichai District, Maha Sarakham Province, Thailand.

Table 1. Model parameter values under flood disaster scenarios in the case study area.

Parameters	Values	Unit	Source
Operating cost of relief distribution centers	25,000-30,000	baht	Department of Disaster Prevention and Mitigation [19, 20]
Operating cost of shelters	28,000-80,000	baht	
Capacity of the relief distribution center	400-500	m^3	
Capacity of shelter	500-1,000	people	
Price of relief supplies	500	baht per bag	
Volume per bag of relief supplies	0.02	m^3	
Number of victims per unit of relief supplies	2	people	
Weight per bag of relief supplies	3	kg	
Capacity of vehicles for transporting relief supplies	1,000-10,000	kg	
The capacity of the vehicle for transporting disaster victims	6-12	people	
Number of victims in the habitable disaster-affected area	97-9,325	people	Department of Provincial Administration [21]
Number of victims in the uninhabitable disaster-affected area	164-216	people	
Transportation cost of relief supplies	11-22.5	baht per km	GIZTIX Co., Ltd. [22]
Transportation cost of victims	11-22.5	baht per km	
Distance from the relief distribution center to the habitable disaster-affected area	0.5-36.3	km	Google maps
Distance from the relief distribution center to the shelter	0.41-30	km	
Distance from the uninhabitable disaster-affected area to the shelter	5-28	km	

4.1 Results of Model I

The developed Model I was processed using LINGO 13.0 by an AMD Ryzen 7 processor (2.00 GHz) with 16.0 GB of RAM. Under the problem size of 1,804 variables and 464 equations constraints, with a computation time of approximately one second, as shown in Figure 3. The optimal solution yielded a minimum total disaster management cost of 20.941 million baht, enabling the provision of relief supplies to all 82,764 victims.

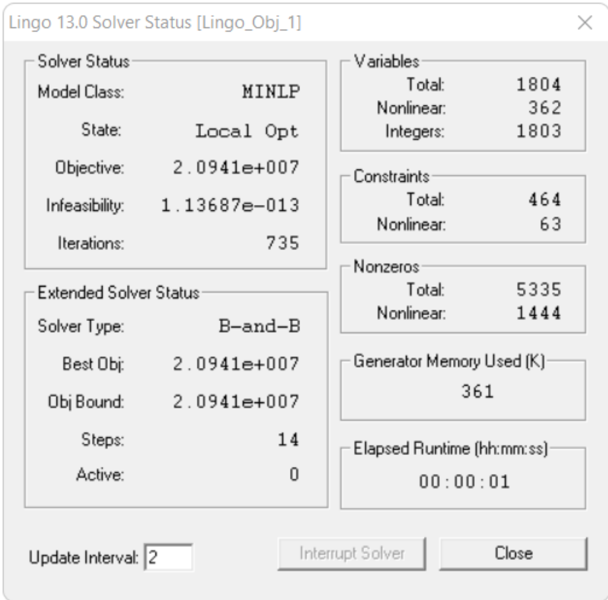

Figure 3. Processing results of Model I.

For the opening of shelters, it was found that three shelters should be opened: 1) Shelter j6, accommodating 164 victims from Village o1; 2) Shelter j11, accommodating 190 victims from Village o2; and 3) Shelter j19, accommodating 216 victims from Village o3. Victims should be transported to shelters by 4-wheel trucks. In addition, the results also found that the relief distribution centers, the Provincial Disaster Prevention and Mitigation Office (i1) and the District Office (i2) should procure 25,000 and 16,428 bags of relief supplies, respectively, totaling 41,428 bags. The i1 and i2 distribution centers distributed relief supplies to the 180 villages that were habitable disaster-affected areas. In comparison, the three villages that were uninhabitable disaster-affected areas received relief goods from the i2 distribution center using 6-wheel and 10-wheel trucks, which had a large capacity to transport relief supplies from the distribution centers to the disaster areas. The results are summarized in Figure 4.

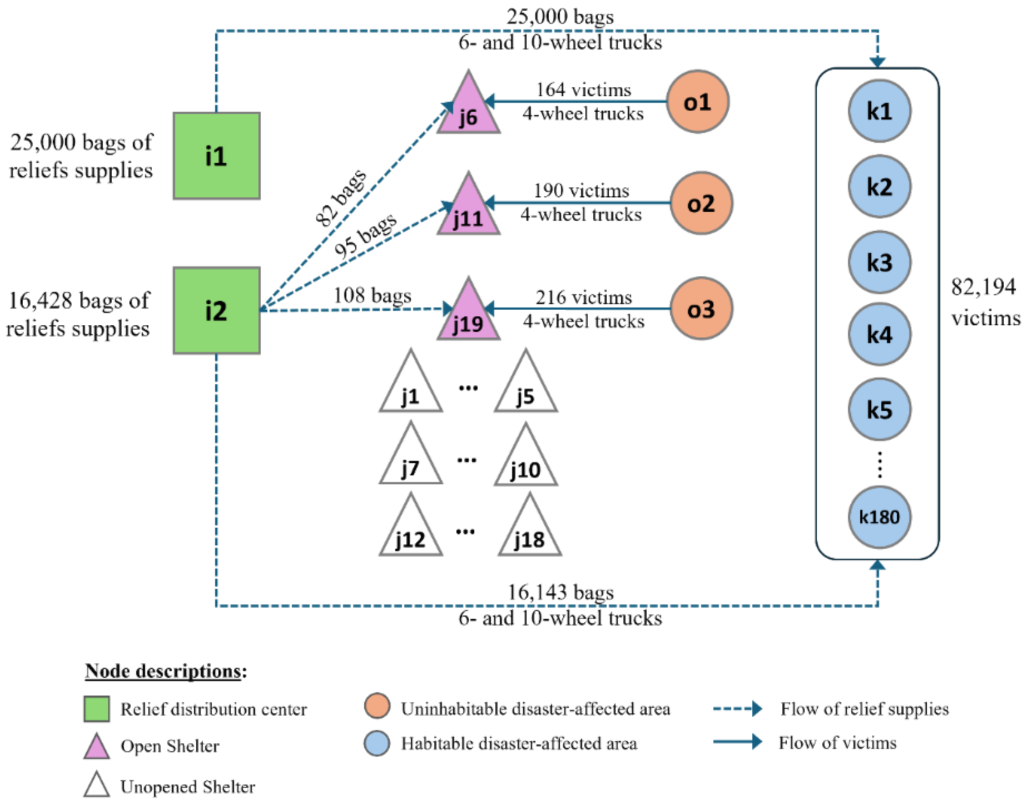

Figure 4. Summary results of Model I.

4.2 Results of Model II

Using the minimum cost from Model I as a budget reference, which has the lowest total disaster management cost of 20.941 million baht, it will be able to help all disaster victims and receive relief supplies. Model II was first solved under a 20 million baht budget, which found that 79,203 disaster victims out of a total of 82,764 could be helped, as shown in Figure 5.

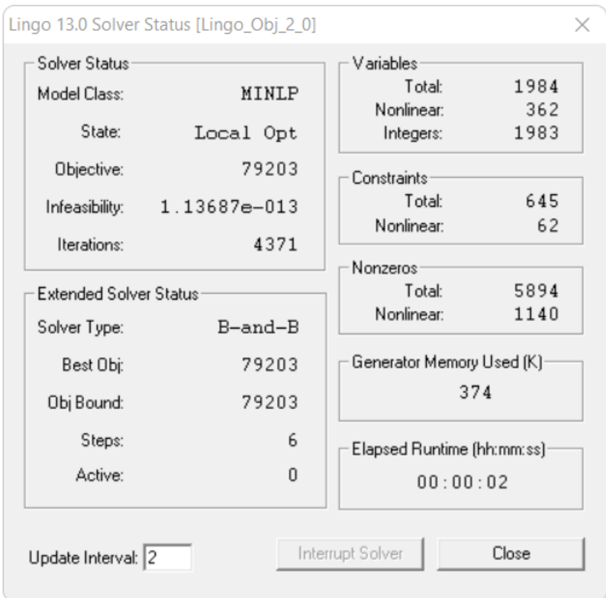

Figure 5. Processing results of Model II with a budget constraint of 20 million baht.

There are 5 villages in the habitable disaster-affected areas that will not be receiving relief supplies: k111, k112, k113, k118, and k120, which are remote villages from the relief distribution center. The result is consistent with the total procurement of relief supplies by the two distribution centers, which was only 39,679 bags. Only one shelter, j18, was opened to accommodate 570 people in the three uninhabitable villages. For transporting disaster victims to shelters, 4-wheel trucks should be used; for transporting relief goods from distribution centers to disaster areas and shelters, 6- and 10-wheel trucks should be used, yielding the same result as Model I. A sensitivity analysis was conducted by reducing the budget by 1 million baht in each scenario (Table 2 and Figures 6-8). As the budget decreased, the number of relief supplies procured declined, and the number of villages not receiving relief increased. However, under the conditions that stipulate all disaster victims in uninhabitable areas must be rescued by moving to appropriate temporary shelters, only one shelter opens, and its location differs in each scenario. The number of victims in habitable disaster-affected areas who did not receive relief supplies has increased, as mentioned above. It was also found that some villages received no relief supplies at all.

Table 2. Summary results of Model I and Model II.

Model	Cost or Budget (Million Baht)	Number of relief supplies procured	Number of shelters open	Number of victims receiving relief supplies			Unrelieved villages
				At shelters	At villages	Total	
Model I	20.941	41,428	3	570	82,194	82,764	-
Model II	20	39,679	1	570	78,633	79,203	5
	19	37,704	1	570	74,764	75,334	11
	18	35,704	1	570	70,768	71,338	21
	17	33,773	1	570	66,910	67,480	30
	16	31,608	1	570	62,645	63,215	38
	15	29,728	1	570	58,821	59,391	39

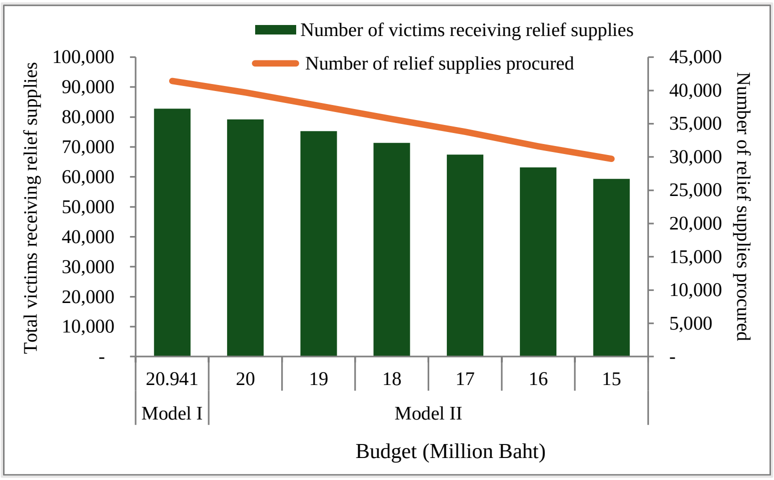

Figure 6. Total victims receiving relief supplies and relief supplies procured when varying the budget.

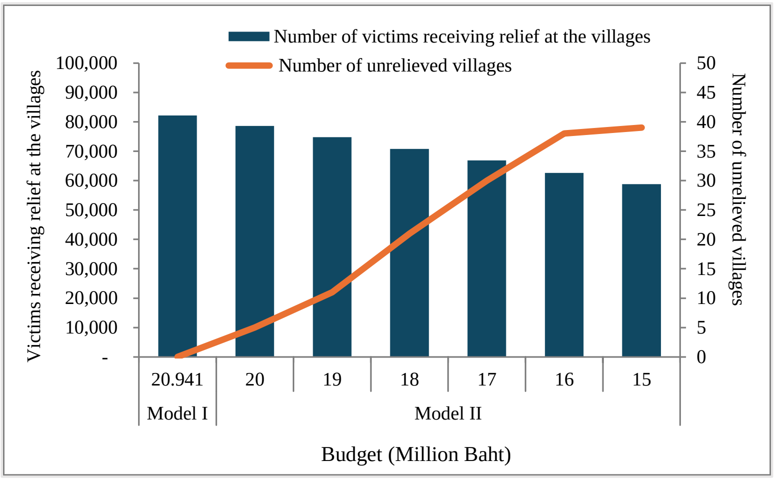

Figure 7. The number of victims receiving relief in villages and in unrelieved villages varies with the budget.

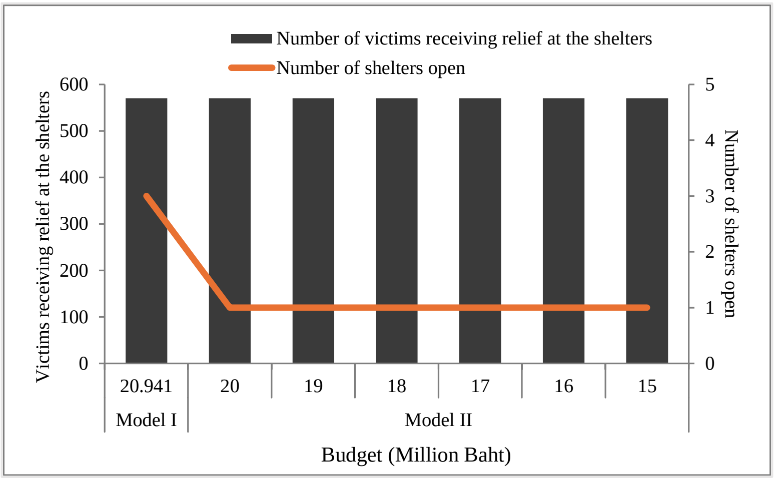

Figure 8. The number of shelters open and the number of victims receiving relief supplies vary with the budget.

To strengthen disaster management under such conditions, flood, fires, or earthquakes [12], several complementary approaches may be considered. First, negotiating lower unit costs of relief supplies with vendors could reduce overall expenditure. Second, adjusting the allocation guideline to allow one relief bag to support two to three individuals instead of one may extend assistance coverage during the initial response phase, particularly during the first two to three days of an event [9, 10]. Additionally, mobilizing monetary donations or in-kind relief supplies, as well as recruiting volunteers to expedite emergency operations, can further enhance response capacity. The proposed models can assist government agencies, humanitarian organizations, and local authorities in preparing effective disaster-response strategies. They can also serve as decision-support tools for shelter planning, supply chain design, and emergency resource allocation. Future research may 1) extend the models to incorporate dynamic decision-making, time-dependent evacuation processes, multi-modal transportation options such as boats, helicopters, or drones during severe flooding [11], and real-time data integration through GIS and advanced analytics. 2) The other metaheuristic methods, Genetic algorithm, Swarm intelligence, etc., can be applied in case of complex problems and take a long time to find the optimal solution. 3) Simulation-based or AI-enhanced approaches could also be explored to increase model adaptability and provide real-time guidance during disaster events. 4) Do comparison; solutions and processing time, with the others using Lingo programming [11].

5. Conclusion

This study developed two MINLP-based models to support humanitarian logistics management in flood disaster settings. The objective of Model I is to minimize the total cost required to fully support all disaster victims, while the objective of Model II is to maximize the number of victims assisted when the available budget is limited. Applied to a real flood-prone district in Thailand, the models provided practical guidance on shelter location, relief-supply procurement, resource allocation, transportation planning, and operational efficiency. The findings indicate that a cost-minimization approach ensures full coverage but may require substantial financial resources, whereas a rescued disaster victims-maximization approach under budget constraints necessitates prioritization and trade-offs. Sensitivity analyses revealed that budget reductions disproportionately affect remote villages in habitable areas, underscoring the need for strategic planning, improved resource mobilization, and targeted support for hard-to-reach communities.

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Conflicts of Interest: The authors declare no conflict of interest.

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