

A MODELING FRAMEWORK OF HIERARCHICAL EARTHQUAKE RELIEF CENTER LOCATIONS UNDER DEMAND UNCERTAINTY

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ABSTRACT: This paper presents a modeling framework for locating earthquake disaster relief centers, developed through multidimensional and integrated perspectives of transportation engineering and humanitarian logistics planning. The proposed framework consists of three sequential steps: 1) Seismic risk analysis, to evaluate the vulnerability of both road network and area-covering disruptions, using the spaghetti and meatballs method, which is a geographic information system (GIS) based analytical approach enriched with historical earthquake statistics and earthquake fault data; 2) Travel demand analysis, to forecast travel demand, travel behavior, travel pattern, and traffic volume, using the four-step transportation model developed based on field traffic survey data and seismic risk analysis data; and 3) Facility location problem analysis, to locate optimal earthquake disaster relief centers, using the hierarchical location problem model formulated based on a meta-heuristic genetic algorithm (GA) optimization technique. To evaluate model mechanism and performance, a preliminary model was then applied to the simulated geographical area with simulated road network of Chiang Rai Province, Thailand. As a result, two-level hierarchical disaster relief centers in response to earthquakes, taking into account accessibility and functional ability of transportation networks, risk covered/uncovered demand and supply distribution, can be viably determined. In the upper-level, a central disaster relief center is functioned to collect rescue equipment and survival bags from both inside and outside the area and to distribute those to local disaster relief centers in the area. In the lower-level, three local disaster relief centers were optimally located, functioned to receive supplies from the central disaster relief center and then distribute to demand points affected by earthquakes. The resulting model can provide government and related agencies profound information in planning and developing either pre-disaster or post-disaster operations.

Keywords: Humanitarian logistics planning, Spaghetti and Meatballs method, Four-step transportation model, Two-level hierarchical disaster relief centers, Meta-heuristic genetic algorithm

1. INTRODUCTION

Nowadays, world society has been faced to many natural and man-made disasters that cause massive economic and social damage as well as loss of lives every year [1]. For example, a major tsunami affected 12 countries in 2004; massive earthquakes struck Bam, Iran in 2003, Pakistan in 2005, China in 2008, Haiti in 2010, and Chiang Rai, Thailand in 2014, and an extensive flood devastated Pakistan in 2010. The frequency and intensity of natural disasters have also been increasing over the past decades [1]. The natural disasters are often unpredictable [2] such as flood disaster [3, 4], tsunami disaster [5], landslide disaster [6], hurricane evacuation [2], earthquake disaster [7-9], and etc. Thus, planning for response to different natural disasters, including earthquake, has become an important aspect of urban management [10].

Earthquakes often result in severe of the human loss and intensive economic [10]. The powerful vibration of earthquakes caused people homeless because of destruction of houses, whether completely or partially that leaves houses unsafe and non-usable [11]. From the moment of an earthquake's occurrence, relief is necessary to respond to the damages together with all the measures that must be put into action in order to rescue human lives, to maintain property, and to lessen the effects of the disaster [10]. Many research articles obtained from a comprehensive literature survey focus on community and waste recovery at the post-disaster phases [7, 12-13]. Therefore, the locations of earthquake relief centers that used for delivering the relief goods (food, water, medical supplies, etc.) is a key logistical decision for disaster preparedness and response as soon as possible [10].

The suitable site selection of earthquake relief centers is the one of a location-allocation (LA) problem. The general concept of LA is to identify the best distribution of the centers and allocate all parcels to their closest possible relief centers [10]. Moreover, LA is a complex optimization problem because it is grouped to be non-deterministic polynomial (NP) hard problems [14]. Generally, the computational results obtained from exact methods are the best quality when compared with the results obtained from any heuristic algorithm [15]. However, solving any problem in the NP-hard group such as the LA problem, using mathematical or exact methods is very time consuming [10]. Therefore, metaheuristic methods may be the alternative choices to find the optimal or near optimal solutions in a reasonable time [10].

In recent years, many studies have been carried out related to earthquake relief center according to location-allocation problem. The various parameters were considered in the model developments for solving the problems, such as time, cost, distance, demands, uncertainties, and etc [16-27]. The uncertain parameters were used in the analysis based on the unpredictability of earthquake, which include demand supply cost and etc. The objective functions that used in the problems were divided into into three types: 1) Total cost, such as facility cost, transportation cost, shortage cost, loss cost, inventory cost, and operation cost [16-21]; 2) Total time, such as travel time, relief distribution rate, and resource allocation time [22-26], and 3) Total demands [27]. However, most research used total time to determine the locations of earthquake relief center because limitation of initial response after earthquake that should be received within the "golden 72 hours" [28].

Generally, the travel time that related to disaster in past studies were generated by variety of methods, such as shortest path [29], statistical sampling [23], and four-step transportation model under travel demand sampling [30]. The statistical sampling methods were applied in case of uncertain data and not enough statistical data in the study area. While the shortest path method was used to create the travel time under randomized road failure that do not consider travel behavior on road network of the study area.

However, a severe problem that usually occurs after an earthquake is destruction of some parts of the transportation network. Resulting in some roads and links of the city network may not be accessible. This will make it very difficult to dispatch and deliver relief goods from relief

centers to demand points, which affected to transport/travel time directly [28]. Thus, this issue must be considered in the site selection of the earthquake relief center through the seismic risk analysis, which demonstrate the vulnerability of road network and area disruption.

In earthquake engineering, majority of seismic risk analysis (SRA) methodologies are developed on the basis of seismic design decision analysis (SDDA) [31]. The seismic risk analysis methodology considers effects of hazard, damage vulnerability, and economic losses [32], which are the information obtained after the earthquake. Therefore, the statistical sampling methods are used to forecast the initial data for seismic risk analysis in planning and developing either pre-disaster or post-disaster operations.

Therefore, this research proposes a new modeling framework for locating hierarchical earthquake relief centers under demand uncertainty, which differ from the previous studies in two parts: 1) Using historical earthquake statistics for seismic risk analysis, to forecast the affected areas by the earthquake in accordance with the study area; and 2) Using travel demand data after earthquake in four-step transportation models, to forecast travel time in accordance with the travel demands behavior instead of statistical sampling methods.

2. METHODOLOGY

This paper presents a modeling framework for locating earthquake disaster relief centers, developed through multidimensional and integrated perspectives of transportation engineering and humanitarian logistics planning. The proposed framework consists of three sequential steps: 1) Seismic risk analysis; 2) Travel demand analysis; and 3) Facility location problem analysis. Moreover, to evaluate model mechanism and performance, a model was then applied to the simulated geographical area with simulated road network of Chiang Rai Province, Thailand.

However, developing the model required initial data before the analysis, such as historical earthquake statistic data and earthquake fault data, and field traffic survey data. Moreover, developing the models was considered relief goods uncertainty by using a Monte Carlo simulation technique; and then classify into 3 levels of demand (high, medium, low). Thus, the methodological framework guide to achieve the objectives of this research was presented in Fig 1.

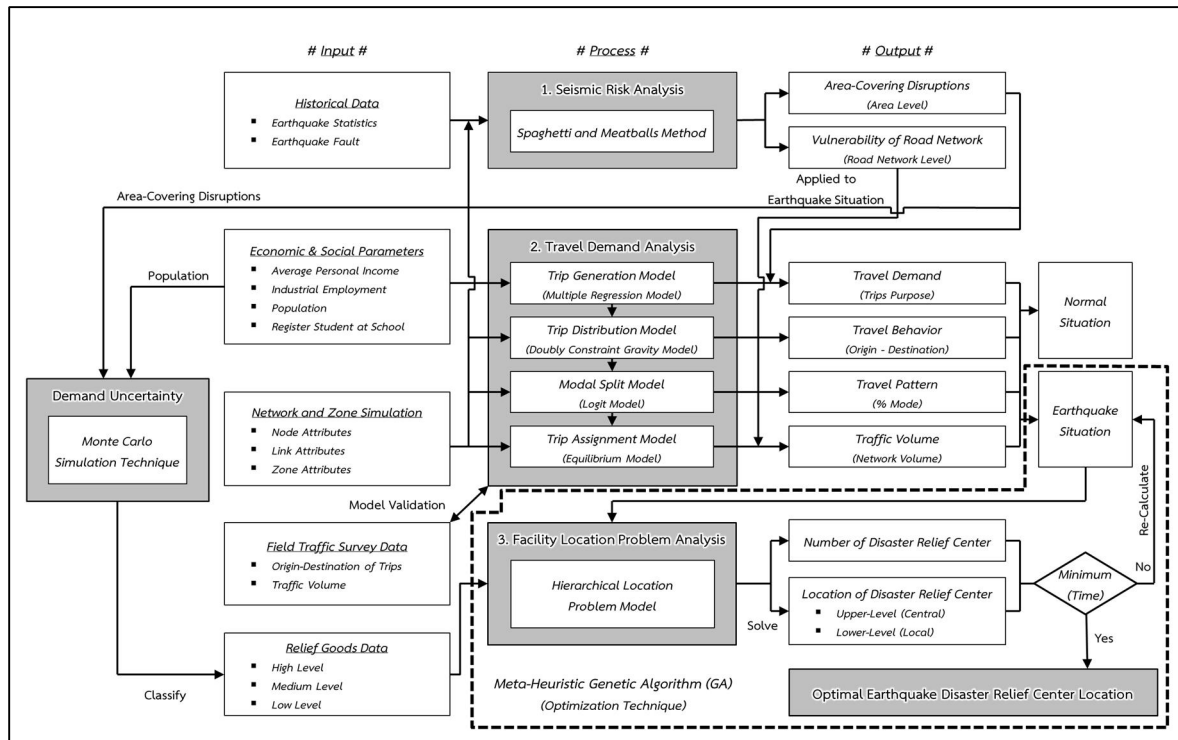


Fig 1. Methodological framework of developing the earthquake disaster relief center location choice models

2.1 Seismic Risk Analysis

Seismic risk analysis aims to evaluate the vulnerability of both road network and area-covering disruptions, using the spaghetti and meatballs method, which is a geographic information system (GIS) based analytical approach enriched with historical earthquake statistics and earthquake fault data. The Process of spaghetti and meatballs method was performed by Whirlpool; a geometric processor originally designed for polygon overlay [33-34], which was used to calculate the number of overlapping polygons.

There are three steps to develop as following:

- 1) Identify the center of the historical earthquake and the earthquake fault data on the simulated geographical area and the simulated road network
- 2) Identify the area affected by each historical earthquake by using the relationship between magnitude and distance affected [35].
- 3) Evaluate the vulnerability of both road network and area-covering disruptions by using the spaghetti and meatballs method under the hypothesis that "the most overlapping area is the highest seismic risk in the study area"

2.2 Travel Demand Analysis

Travel demand analysis aims to forecast travel demand, travel behavior, travel pattern, and traffic volume of the study area, both normal situation and earthquake situation, using the four-step transportation model developed [36-38] based on field traffic survey data and seismic risk analysis data. The scenarios of travel demand analysis are as follows:

- Without Earthquake (at day time)
- After earthquake (1 hour at day time)
- After earthquake (1 day at day time)

The developed models require the calibration to consistent with local traffic conditions of the study area, according to acceptable criteria of UTPS highway network development guide [39]. There are four sub-models to develop as following:

2.2.1 Trip generation model

The trip generation model in this research consists of two sub-models: 1) Trip production model; and 2) Trip attraction model, which is the developed model according to multiple linear regression analysis by finding the relationship between the travel demands, obtained from the field traffic surveys, and socioeconomic characteristics in the area [36, 40], such as average

personal income, industrial employment, population, register student at school, and etc. Moreover, the model also considered the reduction of travel demand after earthquake, which used simulating the travel demand decision of people in the area, according to the principles of binary logistic regression analysis, as shown in Eq. (1) and (2). However, the trip generation models is the sum of all trips purpose in the study area, which consists: the home-based work trips (HBW), the home-based school trips (HBS), the home-based other trips (HBO), and the non-home-based trips (NHB).

$$P_{i(Purpose)} = \left[C_P + \sum_{j=1}^n (a_j X_{j(i)}) \right] \cdot \left[\frac{I}{I + e^{-\left[D_P + \sum_{k=1}^m (g_k Z_{k(i)}) \right]}} \right] \quad (1)$$

$$A_{i(Purpose)} = \left[C_A + \sum_{j=1}^n (b_j X_{j(i)}) \right] \cdot \left[\frac{I}{I + e^{-\left[D_A + \sum_{k=1}^m (h_k Z_{k(i)}) \right]}} \right] \quad (2)$$

Where, e = Irrational number ≈ 2.7182818
 $X_{1(i)}, \dots, X_{n(i)}$ = Socioeconomic variables of zone i
 $a_1, \dots, a_n$ = Coefficients of trips production
 $b_1, \dots, b_n$ = Coefficients of trips attraction
 $Z_{1(i)}, \dots, Z_{m(i)}$ = Earthquake variables of zone i ,
 such as magnitude earthquake
 scale, risk level of area-covering
 disruptions, and etc.
 $g_1, \dots, g_m$ = Logistic regression coefficients of
 trips production
 $h_1, \dots, h_m$ = Logistic regression coefficients of
 trips attraction
 C_P, C_A, D_P, D_A = Constant

2.2.2 Trip distribution model

The trip distribution model in this research developed the model according to the principles of doubly constrained gravity model, which is the most popular in transportation planning [36]. The gravity model illustrates the interaction between two locations declines with travel time increasing between them, but is positively associated with the amount of activity at each location [40], similar to Newton's gravitational law [36]. The rate of decline of the interaction called the impedance or friction factor, as shown in the Eq. (3).

$$T_{ij} = \alpha_i \cdot \beta_j \cdot P_i \cdot A_j \cdot F(t_{ij}) \quad (3)$$

Where, T_{ij} = Trips between origin i and
 destination j

α_i, β_j = Balancing factors of i and j

P_i = Trips production at i

A_j = Trips attraction at j

$F(t_{ij})$ = Impedance or friction factor
 between i and j

2.2.3 Modal split model

The Modal Split model in this research developed the model according to the principles of logit model, which considered the utility functions of travelers received from each alternative [41]. The mode that considered in the model consisted passengers car, truck. Mathematically, the modal split model takes the form in the Eq. (4).

$$P_n(i) = \frac{e^{U_{in}}}{\sum_{j \in C_m} e^{U_{jn}}} \quad (4)$$

Where, $P_n(i)$ = Probability of individual n
 choosing mode i

U_{in} = Utility function for modes i of
 individual n

C_m = Number of total modes

j = Choice mode j

2.2.4 Trip assignment model

The trip assignment model in this research developed the model according to the principles of user equilibrium method, which is giving the exact solution [36]. The method is developed based on Wardrop's first principle, which states that no driver can unilaterally reduce his/her travel costs by shifting to another route. Moreover, the model also considered vulnerability of road network after earthquake, which affected to reduction of road capacity and delay in travel time [42]. Mathematically, the trip assignment model takes the form in the Eq. (5) and (6).

$$\text{Min} \sum_{a \in A} \int_0^{V_a} t_a(\omega) d\omega \quad (5)$$

$$t_a = t_0 \cdot \left(1 + \alpha \cdot \left(\frac{V_a}{C_a} \right)^\beta \right) \quad (6)$$

Where, t_a = Travel time on link a

t_0 = Travel time on link a
 (at free-flow speed)

V_a = Traffic volume on link a

C_a = Capacity on link a

α, β = Coefficients

A = All set of a

2.3 Facility Location Problem Analysis

Facility location problem analysis aims to locate optimal earthquake disaster relief centers, using the hierarchical location problem model formulated based on a meta-heuristic genetic algorithm (GA) optimization technique. The hierarchical location problem is subset of static facility location problems in type of network facility location problems, which considered a distribution system of multiple hierarchical facilities [43-44]. The model develops a mathematical programming for two-level hierarchical disaster relief centers in response to earthquakes, taking into account accessibility and functional ability of transportation networks, risk covered/uncovered demand and supply distribution, can be viably determined. In the upper-level, the central disaster relief centers (CDRCs) are functioned to collect rescue equipment and survival bags from both inside and outside the area and to distribute those to local disaster relief centers in the area. In the lower-level, the local disaster relief centers (LDRCs) are functioned to receive supplies from the central disaster relief center and then distribute to demand points affected by earthquakes. The hierarchical earthquake disaster relief centers model shown in Eq. (7) to (18):

$$\begin{aligned} \text{Min}(Z) = & \sum_{i=1}^I \sum_{k=1}^K \left[\sum_m \left(w_{ik(m)} \cdot t_{ik(m)}^* \right) \right] \\ & + \sum_{k=1}^K \sum_{l=1}^L \left[\sum_n \left(w_{kl(n)} \cdot t_{kl(n)}^* \right) \cdot X_{kl} \right] \\ & + \sum_{l=1}^L \sum_{j=1}^J \left[\sum_o \left(w_{lj(o)} \cdot t_{lj(o)}^* \right) \cdot Y_{lj} \right] + \left[\sum_{j=1}^J (tr_j \cdot Z_j) \right] \end{aligned} \quad (7)$$

$$\sum_{i=1}^I \left[\sum_m \left(w_{ik(m)} \right) \right] = \sum_{l=1}^L \left[\sum_n \left(w_{kl(n)} \cdot X_{kl} \right) \right], \quad \forall k \in K \quad (8)$$

$$\sum_{k=1}^K \left[\sum_n \left(w_{kl(n)} \cdot X_{kl} \right) \right] = \sum_{j=1}^J \left[\sum_o \left(w_{lj(o)} \cdot Y_{lj} \right) \right], \quad \forall l \in L \quad (9)$$

$$\sum_{l=1}^L (Y_{lj}) = I, \quad \forall j \in J \quad (10)$$

$$\sum_{k=1}^K (X_{kl}) = P_1 \quad (11)$$

$$\sum_{l=1}^L (Y_{lj}) = P_2 \quad (12)$$

$$w_{kl} \leq q_k X_k, \quad \forall l \in L \quad (13)$$

$$w_{lj} \leq q_l Y_l, \quad \forall j \in J \quad (14)$$

$$X_k = \begin{cases} 1 & \text{if CDRC is located/opened at node } k, \forall k \in K \\ 0 & \text{otherwise} \end{cases} \quad (15)$$

$$Y_l = \begin{cases} 1 & \text{if LDRC is located/opened at node } l, \forall l \in L \\ 0 & \text{otherwise} \end{cases} \quad (16)$$

$$Z_j = \begin{cases} 1 & \text{if affected area is located/opened at node } j, \forall j \in J \\ 0 & \text{otherwise} \end{cases} \quad (17)$$

$$w_{ik(m)}, w_{kl(n)}, w_{lj(o)}, t_{ik(m)}^*, t_{kl(n)}^*, t_{lj(o)}^*, tr_j \geq 0 \quad (18)$$

Where, I = Set of supply area, $i = 1, \dots, I$

K = Set of CDRC, $k = 1, \dots, K$

L = Set of LDRC, $l = 1, \dots, L$

J = Set of affected area, $j = 1, \dots, J$

P_1 = Number of CDRC

P_2 = Number of LDRC

P_l = Number of CDRC

$w_{ik(m)}$ = Amount of rescue equipment and survival bags from i to k by route m

$w_{kl(n)}$ = Amount of rescue equipment and survival bags from k to l by route n

$w_{lj(o)}$ = Amount of rescue equipment and survival bags from l to j by route o

$t_{ik(m)}^*$ = Travel time on route m from i to k

$t_{kl(n)}^*$ = Travel time on route n from k to l

$t_{lj(o)}^*$ = Travel time on route o from l to j

tr_j = Travel time delay at j

Regarding this problem, two levels are considered for disaster relief centers (upper-level (CDRC) and lower-level (LDRC)) since the problem is hierarchical. Concerning the model, the total demand weighted travel time is minimized, which consists: 1) demand weighted travel time from supply area to CDRC, 2) demand weighted travel time from CDRC to LDRC, 3) demand weighted travel time from LDRC to affected area, and 4) demand weighted travel time delay at affected area, as shown in Eq. (13).

By constraints in Eq. (14) and (15), the total demand of a supply area is equal to the demand transferred from that supply area to a CDRC, and the total demand of a CDRC is equal to the demand transferred from that CDRC to a LDRC. Constraint in Eq. (16), each affected area is received the rescue equipment and survival bags from one LDRC only. Moreover, constraints in Eq. (17) and (18) demonstrate the capacity of disaster relief centers at two levels, and constraints in Eq. (19) and (20). Constraints in Eq. (21) to (24) define binary or sign restrictions on the variables.

3. CASE STUDY

To evaluate model mechanism and performance, a preliminary model was then applied to the simulated geographical area with simulated road network of Chiang Rai Province, Thailand. Developing the network and zone simulation divided structure into 3 layers: 1) Zones layer or boundary 2) Node and centroid layer or point; and 3) Link layer or connector. The zones layer consist the attribute about boundary, area, average personal income, industrial employment, population, and register student at school. The attribute about GIS coordinates (X/Y) included in the node and centroid layer. In the part of the link layer, attribute consist distance, number of lane, traffic volume capacity, and free-flow speed. Moreover, each links are connected to the nodes and centroids of the zone, which is the linkage of trips production and trips attraction between those zones. Moreover, a case study divided the internal and external area into 124 zones and 8 zones, respectively, based on the map of sub-district administrative areas of Thailand for developing the travel demand models. The road network in the study area was developed according to roadway data from Department of Highways and Department of Rural Roads, Thailand, as shown in Fig. 2.

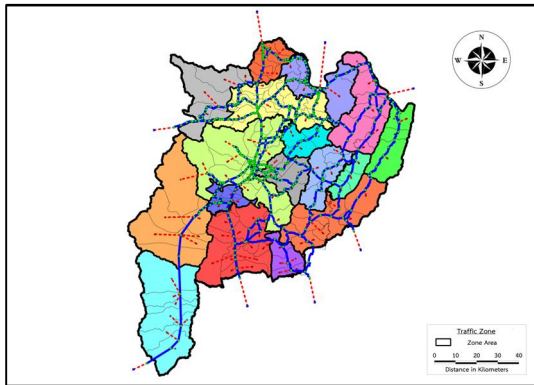


Fig. 2 Simulated geographical and road network

However, developing the travel demand models of study area was analyzed by three scenarios at day time: 1) Without earthquake; 2) After earthquake (1 hour); and 3) After earthquake (1 day). This research assumes that the earthquake magnitude of a case study was 6.7 on the Richter scale, which was the extreme case of Thailand in the past decade. The historical earthquake statistics and earthquake fault data of case study was assumed, as shown in Fig. 3.

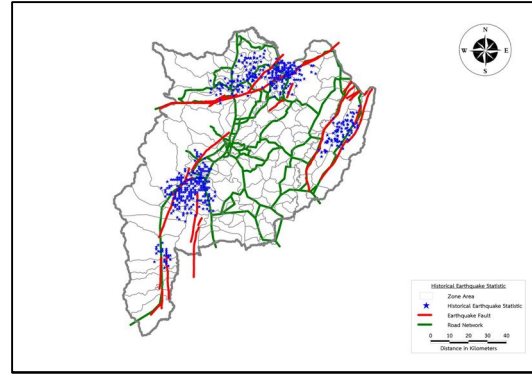


Fig. 3 Historical earthquake statistics and earthquake fault data of case study

4. RESULTS

The results of the development and application of models with the case study were as follows:

4.1 Results of Seismic Risk Analysis

The results of seismic risk analysis by the spaghetti and meatballs method, which used historical earthquake statistics and earthquake fault data was demonstrated the area-covering disruptions and vulnerability of road network in Fig. 4 and 5, respectively.

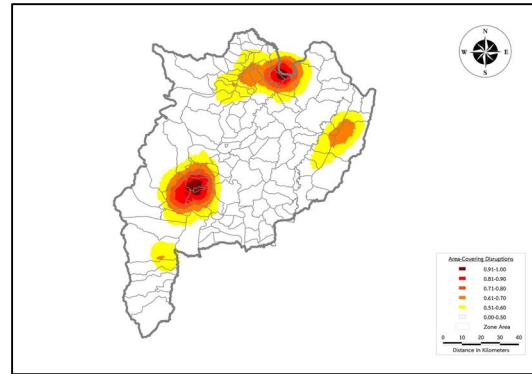


Fig. 4 Area-covering disruptions

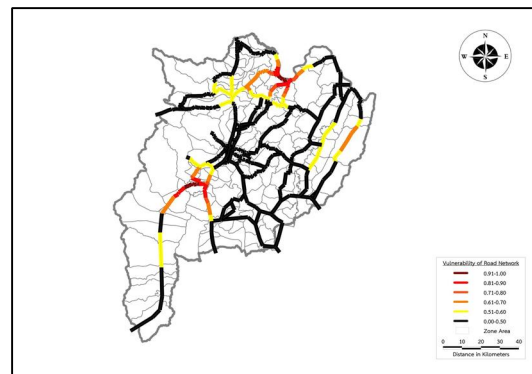


Fig. 5 Vulnerability of road network

4.2 Results of Travel Demand Analysis

The results of travel demand analysis by the four-step transportation model, which used field traffic survey data and seismic risk analysis was shown in Table 1 and Fig. 6 and 7. It showed that travel demand model analysis in three scenarios at day time showed that travel demand, travel behavior and traffic conditions before and after the earthquake were different, as follows.

Before the earthquake, the study area had overall level of service (LOS) in peak hour at B level, with traffic volume equal to 18,791 PCU/Hr., vehicle kilometers of travel (VKT) equal to 1,461,585 PCU-Km./Hr., vehicle hours of travel (VHT) equal to 25,070 PCU-Hr./Hr., and average

speed equal to 58.30 Km./Hr..

However, the traffic condition of an hour after earthquake was worse than before the earthquake. LOS changed from B to C level (up 1 level), where traffic volume, VKT, and VHT increased approximately 20.18%, 19.16%, and 76.73%, but average speed decreased about 32.57%.

Moreover, overall of LOS in case of a day after earthquake did not change significantly, but the overall traffic condition was still worse than before the earthquake. Because of the average speed decreased approximately 23.64% and VHT increased about 7.84%, although the traffic volume and VKT decreased by 17.45% and 17.65%, respectively.

Table 1 Summary of overall traffic condition in peak hour

Traffic condition (Overall)	Unit	Scenarios				
		Without earthquake	After earthquake (1 hour)		After earthquake (1 day)	
			Value	Diff. (%)	Value	Diff. (%)
1) Traffic volume	PCU/Hr.	18,791	22,583	+20.18	15,512	-17.45
2) Vehicle kilometers of travel (VKT)	PCU-Km./Hr.	1,461,585	1,741,564	+19.16	1,203,550	-17.65
3) Vehicle hours of travel (VHT)	PCU-Hr./Hr.	25,070	44,306	+76.73	27,036	+7.84
4) Average speed	Km./Hr.	58.30	39.31	-32.57	44.52	-23.64
5) Level of service (LOS)	-	LOS B	LOS C	Up 1 Level	LOS B	No Change

Remark: PCU is passenger car unit

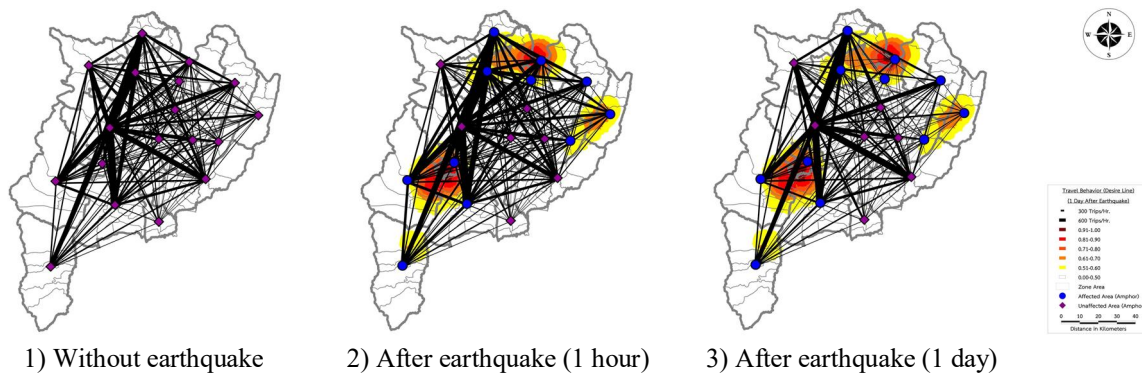


Fig. 6 Travel demand and travel behavior (Desire line in peak hour)

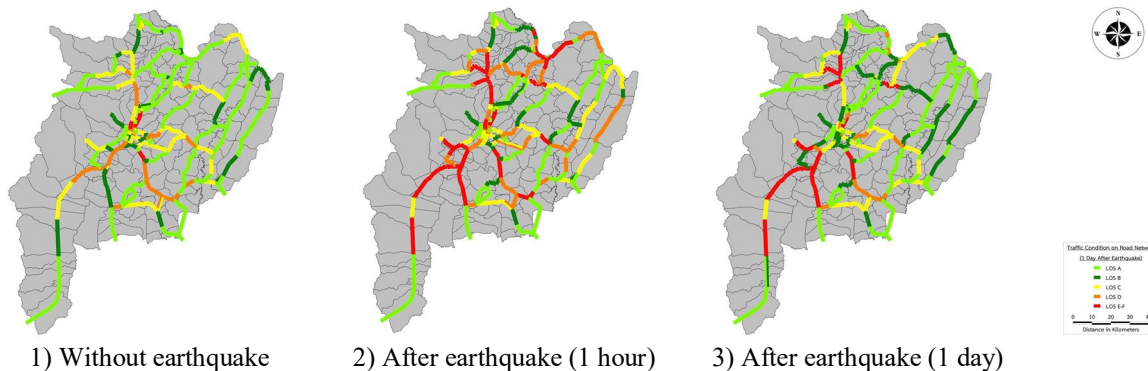


Fig. 7 Traffic condition on road network (Level of service: LOS in peak hour)

4.3 Results of Facility Location Problem Analysis

The facility location problem analysis, using hierarchical location problem model formulated based on a meta-heuristic genetic algorithm (GA) optimization technique was applied to Chiang Rai Province, Thailand. The application was used to locate optimal earthquake disaster relief centers with three levels of demand. The demand of rescue equipment and survival bags (relief goods) for the victims in the three levels equal to 350,406, 174,747 and 32,693 victims or 89.68%, 44.72% and 8.37% of population in affected areas.

As a result two-level hierarchical disaster relief centers in response to earthquakes, taking into account accessibility and functional ability of transportation networks, risk covered/uncovered demand and supply distribution, can be viably determined. In the upper-level, a central disaster relief center is functioned to collect rescue equipment and survival bags from both inside and outside the area and to distribute those to local disaster relief centers in the area. In the lower-level, three local disaster relief centers were optimally located, functioned to receive supplies from the central disaster relief center and then distribute to demand points affected by earthquakes.

In high level of demand, the optimal location of a central earthquake disaster relief center in the upper-level was Rim Kok sub-district, Mueang district, Chiang Rai province. In the lower-level, three local disaster relief centers located at Pa O Don Chai sub-district, Tha Sut sub-district, Mueang district and Maetam sub-district, Phaya Mengrai district, Chiang Rai province. However, at medium level and low level, some local disaster relief centers are closed because less demand, as shown in Fig. 8.

The performance measurement of the developed model was the comparison of solution between the direct method and the genetic algorithm (GA) method, which compared the convergence of the results with the iteration and time of process, as shown in Table 2. The results shown that the optimal solution of both methods was similar, which differed only 2.85%, but iteration process and time process were very different, approximately 154.36 times and 4.95 times or 99.35% and 79.79%, respectively. Therefore, the developed models that formulated based on a meta-heuristic genetic algorithm (GA) optimization technique able to find the optimal solutions in a more reasonable time.

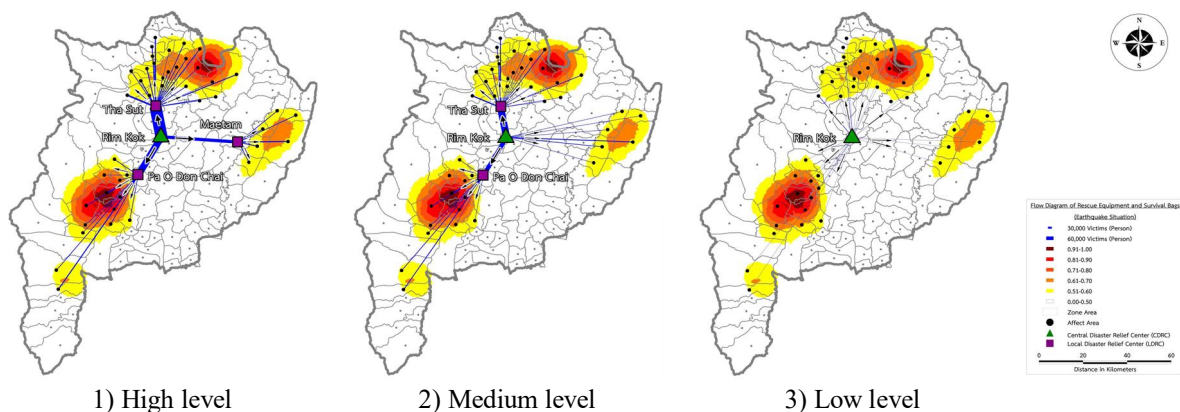


Fig. 8 Flow diagram of rescue equipment and survival bags

Table 2 Performance measurement

Performance measurement	Method		Difference	
	Direct	Genetic Algorithm	(%)	(Times)
Optimal solution	275,405	283,246	2.85	0.97
Iteration/Generation process	7,718,004	50,000	99.35	154.36
Time process (Hours : Minutes : Seconds)	26:01:08	5:15:34	79.79	4.95

5. CONCLUSION

The development of earthquake disaster relief center location choice models that using the spaghetti and meatballs method, four-step transportation model and hierarchical location problem model can provide government and related agencies profound information in planning and developing either pre- or post-disaster operations, which was achieved the objectives of this research: 1) To propose a modeling for the locating earthquake disaster relief centers; 2) To evaluate the vulnerability of both road network and area-covering disruptions; 3) To forecast travel demand, travel behavior, travel pattern, and traffic volume; and 4) To locates the optimal earthquake disaster relief centers.

However, the developed model was applied to the simulated geographical area with simulated road network of Chiang Rai Province, Thailand. The results showed that the travel demand, travel behavior, and traffic conditions before and after the earthquake were different. The traffic condition at day time of an hour after the earthquake was worse than before the earthquake. Level of service (LOS) changed from B to C level (up 1 level), where traffic volume, VKT, and VHT increased approximately 20.18%, 19.16%, and 76.73%, but average speed decreased about 32.57%. Moreover, overall of LOS in case of a day after earthquake did not change significantly, but the overall traffic condition was still worse than before the earthquake. Because of the average speed decreased approximately 23.64% and VHT increased about 7.84%, although the traffic volume and VKT decreased by 17.45% and 17.65%, respectively.

Moreover, the optimal location of a central earthquake disaster relief center in the upper-level was Rim Kok sub-district, Mueang district, Chiang Rai province, which is functioned to collect rescue equipment and survival bags from both inside and outside the area and to distribute those to local disaster relief centers in the area. In the lower-level, three local disaster relief centers located at Pa O Don Chai sub-district, Tha Sut sub-district, Mueang district and Maetam sub-district, Phaya Mengrai district, Chiang Rai province, which functioned to receive supplies from the central disaster relief center and then distribute to demand points affected by earthquakes. However, the developed model was compared the optimal solution between the direct method and the genetic algorithm (GA) method. The results shown that the optimal solution of both methods was similar, which differed only 2.85%, but round process and time process were very different, approximately 154.36 times and 4.95 times or 99.35% and 79.79%, respectively. Therefore, the developed

models that formulated based on a meta-heuristic genetic algorithm (GA) optimization technique able to find the optimal solutions in a more reasonable time.

However, the authors verified the proposed methodology with the simulated geographical area and simulated road network in previous study [45], before applying the model for Chiang Rai Province, Thailand in this research. The result showed that the different case studies provide analysis results depend on the study area considered but all case can provide profound information in planning and developing either pre- or post-disaster operations.

6. ACKNOWLEDGMENTS

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