Emergency Distribution Center Selection with Network Reliability Consideration

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ABSTRACT: Due to climate change, frequencies of natural disasters, including earthquake, hurricane, typhoon and heavy precipitations, increase rapidly. The emergency distribution center (EDC) plays an important role in emergency planning and disaster response. During the process of delivering relief to shelters, the infrastructure could be deteriorated by the disaster. Most of the existing models neglect the possibilities of network failure and thus the network reliability is not considered in the process. This research proposes a model with the consideration of connectivity reliabilities for selecting emergency distribution centers under emergency. Firstly, the connectivity reliability is obtained through a simulation-assignment model. Secondly, the connectivity reliability is added in the objective function to reflect the possibilities of network failure under emergency using CPLEX. Numerical experiments are conducted based on a test network and a real city network, and different demand levels of items are simulated to select the EDCs.
Keywords: emergency distribution center, covering model; network reliability

1. INTRODUCTION

In the 21st century, climate change has become a global and environmental issue (IPCC, 2007a). Due to climate change, frequencies of natural disasters, including hurricane, typhoon and heavy precipitations, increase rapidly. All natural, human, and transportation infrastructure systems are heavily affected by climate change.

Emergency management has become an important issue around the world. The Hurricane Katrina, Rita and Sandy struck the United States, the Sichuan Earthquake in China caused the large amount of casualties, the Typhoon Morakot hit southern Taiwan and the earthquake and tsunami caused serious impacts in Japan. Emergency management aims at reducing economical and human losses through a scheduled planning and operations under emergency. The emergency distribution center (EDC) plays an important role in emergency planning and disaster response. The EDC provides relief to shelters and victims of natural disasters. There are some different models for selecting the EDC, and these models include the center models, median models and covering models. The covering models locate EDCs among candidate sites such that all demand sources are covered with a minimum number of facilities. Covering models have been extensively applied for EDC selection under emergency.

The increase of disasters, the typhoons and heavy precipitations, deteriorate transportation infrastructure, travel time, delay, and safe of drivers significantly. During the process of delivering relief to shelters, the infrastructure could be deteriorated by the disasters. Most of the existing models neglect the possibilities of network failure and thus the network reliability is not considered in the process. There are many different types of network reliability, like: travel time, connectivity and capacity reliability. In order to ensure smooth travel of drivers and avoid serious delays due to the unexpected disabled roads under emergency, the network reliabilities are required to be considered in the network. The heavy rainfall caused a flood. A flood destroyed infrastructure like road and bridge. Disabled roads are defined as the capacity of roads reduced to 0. The advantage of the assessment measures of network reliability is that the assessment measures can evaluate the travel time, delay, and the connectivity of networks. Based on the results of measurements and evaluations, the traffic management can improve the performance of network. In recent years, the assessment measures of network reliability are proposed and becoming more and more important. The network reliability is defined as the probability or ability of a system to keep workable for a target in the future. For roads, network reliability is the probability of the infrastructure to keep operational for drivers (Ang and Tang, 1990). Assumed given the uncertainties and resource limitations in an emergency environment, the problem is how to determine the number and location of the EDCs and the number of different relief to meet the need of affected people. The problem of selecting emergency distribution center can be defined as a maximal covering location problem with reliability consideration.

This research proposes a maximal covering location model with the consideration of connectivity reliability for selecting emergency distribution centers. Connectivity reliability is an important index. This index reveals the probability of completing a trip between EDC and shelters. Firstly, the connectivity reliability is obtained through a simulation-assignment model. The simulation-assignment model supplies the paths and travel cost information for calculating network reliability. Secondly, the connectivity reliability is added in the objective function in the maximal covering location model to maximize the total expected demand and to reflect the possibilities of network failure under emergency using CPLEX. CPLEX is a software tool for solving mathematical programming. Numerical experiments are conducted based on a test network and a real sub-network of Kaohsiung City. Different demand levels of items are simulated to select the EDCs.

Next section presents a brief review of related researches. The mathematical formulations are presented in Section 3. Numerical experiments for a test and a real network are described and discussed in Section 4 and 5, follow by the brief summary.

2. LITERATURE REVIEW

Some relative researches based on system of emergency distribution center, selecting emergency distribution center and network reliability are reviewed. These studies are described to provide basic understandings on the locating of the emergency distribution center under disasters.

2.1 System of Emergency Distribution Center

FEMA established four steps for the disaster prevention and management, including: mitigation, accoutrements, response and recovery. There were 9 emergency distribution centers. Six centers were in the continental United States and three centers were in Guam, Hawaii and Puerto Rico. Emergency distribution centers stored resources like cots, blankets, emergency meals, bottled water, emergency generators, hygiene kits, plastic sheeting and tarps. Emergency distribution centers played important roles to store goods under disasters.

FEMA classified shelters into two categories, one was named community shelters and the other was named residential safe rooms. Community shelters supplied short-term protection and were usually constructed in public places, commercial buildings, schools, hospitals. Residential safe rooms were usually constructed in home, like in the bathrooms, wardrobes and cellars. Community shelters can supply the capacity of more than hundreds of people, hence emergency distribution centers were usually set in community shelters.

Ukkusuri and Yushimito (2008) revealed natural disasters caused more than 134.5 million affected people, and $19 billion economic loss in 2005.

2.2 Selecting Emergency Distribution Center

Several research discussed selecting the emergency distribution centers and distribution of relief based on the objective of optimizing the flow of supplies and travel cost on networks. Some relative research were summarized below:

Knott (1987) discussed freight routing problems with good relief based on linear programming under emergency events. This research considered multiple emergency distribution centers under post-disasters. The routes and number of demand were assumed to be known. Rathi et al. (1993) used three linear programming formulations to allocate resources for supporting multi-commodity flow problems. Limited numbers of transport resources within time windows were considered. The objective was to minimize delay time of delivering cargo during time intervals. Some basic experiments were shown to test the three formulations. Haghani and Oh (1996) presented a formulation and two solution methods for a large-scale multi-commodity and multi-modal network flow problem under disaster relief management. This research used two heuristic algorithms to solve the problem. The synthetic data was used for the experiment on small and large networks. Ozdamar et al. (2004) pointed out the emergency logistics aimed to minimize amount of unsatisfied demand of commodity. This research developed a planning model with the integration of a natural disaster logistics decision support system. Balcik and Beamon (2008) simulated a network for emergency relief based on the data of National Geophysical Data Center (NGDC) from 1900 to 2006. The data was about the statistical of casualties under earthquake. A mathematical model was proposed to make a decision toward locating the emergency distribution centers and management of good under pre-disaster events. Lu (2010) focused on the emergency logistics distribution centers locating problems under uncertainty. A robust vertex p-center model based on robust optimization was used for locating urgent relief distribution centers. The objective was to minimize the distance from distribution centers to the shelters. The model was implemented in a case of earthquake. De La Torre et al. (2012) discussed the disaster relief logistics. The disaster relief logistics were defined as the distribution of commodities to shelters. This research analyzed operations research models, reviewed relative papers and interviewed with aid organizations under different perspectives. Sheu (2007) proposed a hybrid fuzzy clustering-optimization approach under emergency logistics. A three-layer conceptual framework was proposed to reflect the disaster-affected area grouping and relief co-distribution. Numerical studies were based on a real network in Taiwan.

Covering models were commonly used in locating problems (Schilling et al. 1993; Daskin, 1995). Maximal covering location models located emergency distribution centers to maximize the amount of covered demand subject to resource limitations. Maximal covering location models were suitable for relief chain network design (Balcik and Beamon, 2008). Church and ReVelle (1974) supplied some applications of maximal covering location models. Current and Storbeck (1988), Pirkul and Schilling (1991), and Haghani (1996) added the capacity constraints on the locating of emergency distribution centers. Viswanath and Peeta (2003) proposed a multi-commodity maximal covering network design model under earthquake.

2.3 Network Reliability

Disasters influenced infrastructure, hence the network reliability decreased during the emergency distribution. Network reliability was a critical issue to determine the efficiency during relief goods.

Iida (1999) pointed out that the road reliability would be influenced by the congestion and capacity and suggested a method to estimate the reliability of links. Two road network reliabilities, including connectivity reliability and travel time reliability, are recommended. Basic analysis of reliability is illustrated in normal and abnormal conditions.

The typhoon and heavy precipitations affected the infrastructure in Taiwan. In 2009, Taiwan was hit by Typhoon Morakot, and it caused a serious flooding. The flooding deteriorated the infrastructure and caused large number of disabled roads.

In summary, adverse weather deteriorated the traffic conditions and traffic parameters such as travel time, delay, speed and safety of drivers. Thus, the issue of network reliability assessment measures needs to be considered during the process of relief distribution.

3. RESEARCH METHODOLOGY

This research aims to propose a model combined with reliability to select the emergency distribution centers. This section describes the mathematical model formulations, the connectivity reliability, and the solution procedure.

3.1 Model Formulation

In this study, a maximal covering model with reliability considerations is proposed to optimize the number and location of emergency distribution centers. The reliability is considered in the objective function. Reliability R is calculated based on formulation of connectivity reliability. R is multiplied to the objective function to maximize the total expected demand covered by the EDCs.
The variables are defined below:

Set

E : set of shelters, $e \in E$.
J : set of emergency distribution centers, $j \in J$.
IT : set of item types, $it \in IT$.

Decision Variables

f_{ejk} : percentage of item type *it* satisfied by distribution center j in shelter e
Q_{jk} : stored units of item type *it* at emergency distribution center j

$$\mathrm{X_j} = \begin{cases} 1, & \text{if distribution center j is chosen} \\ 0, & \text{otherwise} \end{cases}$$

Parameters

pr_e : probability of occurrence of shelter e.
$d_{e,it}$: expected demand for item type *it* in shelter e.
$J_e(l_{it})$: emergency distribution center locations that can provide l_{it} coverage level for item type *it* for shelter e;
L_{it} : coverage level for item type *it*, $l_{it} = 1 \le 2 \le ... \le L_{it}$;
w_{it} : weight for item type *it*, $\sum w_{it} = 1$ and $w_{it} \ge 0$;
$\alpha_{it}^{l_{it}}$: coverage level weight, $\alpha_{it}^{1} = 1 > \alpha_{it}^{2} > ... > \alpha_{it}^{l_{it}} > 0$;
$R_{e,j}$: connectivity reliability from distribution centers j to shelter e;
Cap_j : capacity of distribution center j;
γ_{it} : unit volumes of item type *it*;
B_0 : pre-disaster budget;
B_1 : post-disaster budget;
F_j : fixed cost of establishing emergency distribution center j;
$g_{j,it}$: unit cost of acquiring and storing item type *it* at emergency distribution center j;
$C_{e,j,it}$: unit cost of shipping item type *it* from emergency distribution center j to shelter e.

The functions are describes below:

$$\text{Maximize} \quad \sum_{e}\sum_{it}\sum_{l_{it}}\sum_{j\in J_{ss}(l_{it})} pr_e d_{e,it} w_{it} \alpha_{it}^{l_{it}} R_{e,j} f_{e,j,it} \tag{1}$$

$$f_{e,j,it} d_{e,it} \le Q_{j,it} \quad \forall e\in E, j\in J, it\in IT \tag{2}$$

$$\sum_{it\in IT} \gamma_{it} Q_{j,it} \le Cap_j X_j \quad \forall j\in J \tag{3}$$

$$\sum_{j\in J} (F_j X_j + \sum_{it\in IT} Q_{j,it} g_{j,it}) \le B_0 \tag{4}$$

$$\sum_{it\in IT}\sum_{j\in J} d_{e,it} c_{e,j,it} f_{e,j,it} \le B_1 \tag{5}$$

$$\sum_{j\in J} f_{e,j,it} \le 1 \quad \forall e\in E, it\in IT \tag{6}$$

$$f_{e,j,it} \ge 0 \quad \forall e\in E, j\in J, it\in IT \tag{7}$$

$$X_j \in \{0,1\} \quad \forall j\in J \tag{8}$$

The objective of the model is to maximize the total expected demand covered by the EDCs, the objective is shown in Eq (1).

Constraint (2) ensures demand is smaller than the inventory at a distribution center.

Constraint (3) keeps inventories do not exceed the capacity.

Constraint (4) keeps inventories do not exceed the pre-disaster budget.

Constraint (5) guarantees transportation costs are less than the expected post-disaster budget.

Constraint set (6) ensures the supplies do not exceed the demand.

Constraint set (7) is the non-negativity constraint.

Constraint set (8) defines the binary selecting variable.

3.2 Connectivity Reliability

Connectivity reliability indicates the probability of completing a trip between two nodes with a path. A path is formed by a series of links, X_a means the connectivity reliability of link a, if link a is operational, then X_a =1; otherwise, X_a =0. The connectivity reliability of link a is shown in equation (9) .

$$X_a = \{ \begin{matrix} 1, & \text{link a works} \\ 0, & \text{otherwise} \end{matrix} \tag{9}$$

The condition of the system is represented by function of $\phi(X)$, and is shown in equation (10), where X is the state vector of link variables. If the system works, then the function is equal to 1, otherwise, $\phi(X)$ is 0.

$$\phi(X) = \{ \begin{matrix} 1, & \text{if the system works} \\ 0, & \text{otherwise} \end{matrix} \tag{10}$$

Minimal path sets in network reliability under series connection system is represented in equation (11). Minimal cut sets in network reliability under parallel connection system and is represented in equation (12).

P: set of connective paths in series connection system. K: set of connective paths in parallel connection system. s: set of paths.

$$\phi(X) = 1 - \prod_{s=1}^{p} (1 - \prod_{a\in P_s} X_a) \tag{11}$$

$$\phi(X)=\prod_{s=1}^{k}(1-\prod_{a\in K_s}(1-X_a)) \tag{12}$$

3.3 Solution Procedure

The solution procedure is summarized in the following three steps:

Step 1: Initialization.

From the given information on the scenarios, set the expected demands $d_{e,it}$ for item type *it* in shelter e. Based on the list of potential EDCs locations in the network, enter the related data of the potential EDCs to the model, such as the capacity, the fixed cost.

Step 2: Calculate the connectivity reliability.

DynaTAIWAN is used to simulate the failure of links. Calculate the reliability in minimal path sets in the network, and calculate the reliability in minimal cut sets in the network based on simulation information and Equation (11) and (12).

Step 3: Optimization of maximal covering location model with connectivity reliability.

Connectivity reliability obtained from step 2 is added in the maximal covering location model. From the given information related to the scenarios, solve the maximization to get the decision variable of f_{ejk} and Q_{jk}. That is, the EDCs locations and the expected demand from the EDCs to the shelters. If the solution satisfies the stopping criteria, stop the solution procedure. If the scenarios are completed, stop. Else, go to step 1 to initialize the procedure and calculate the connectivity reliability under different scenarios.

4. NUMERICAL ANALYSIS

4.1 Experimental Design of a Test Network

The emergency relief funds are classified into pre-disaster budget and post-disaster budget. The pre-disaster budget constrains the fixed cost and cost of items. The post-disaster budget constrains the transportation cost from EDCs to shelters. The test network is shown in Figure 2.

Assuming a natural disaster happens, and several items need to be delivered from EDCs to shelters. There is 2 EDCs (j_1, j_2) and 1 shelter (e_1). There are two item types (it_1, it_2). A weight w_{it} is given to each item type *it* to represent relative importance. There are different weights (w_{it}) under different item type *it*.

There are two covering levels (l_{it_1}, l_{it_2}). l_{it_1} means level 1 and l_{it_2} is level 2. There are different coverage benefits ($\alpha_{it}^{l_{it}}$) under different coverage levels. Coverage levels are obtained based on distance information. The reliability information is reflected in connectivity reliability. The coverage benefit means the demand would decrease with the increase of distance from a facility. The coverage benefits ($\alpha_{it}^{l_{it}}$) decrease with the increase of coverage level, increase of cost and distance.

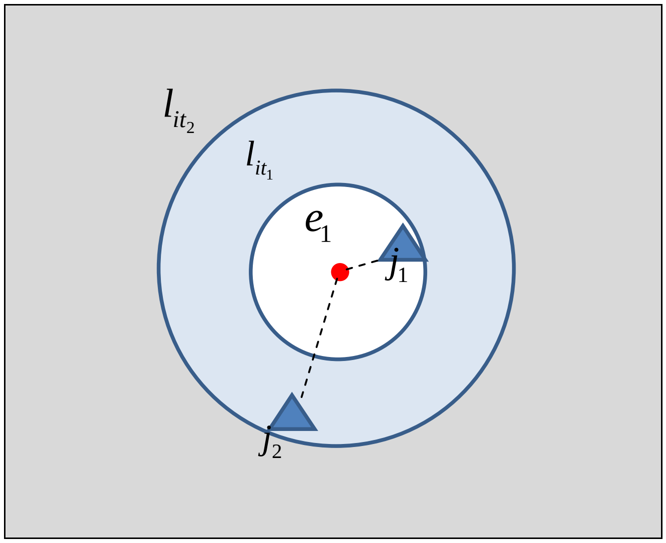

Figure 2 Test network (Balcik and Beamon, 2008)

4.2 Parameter Setting of a Test Network

The parameters are assumed values in test network.
The assumptions are described below:

1. There are 2 emergency distribution centers delivering goods to 1 shelter.
2. The expected demand of item type 1 is 18,000, and expected demand of item type 2 is 10,000.
3. The pre-disaster budget and post-disaster budget are 400,000.
4. The fixed costs of establishing emergency distribution center are $10,000.

The parameter settings are shown in Table 1.

Table 1 Parameters setting

pr_{e_1}	1	$R_{e_1 j_1}$	0.9
$d_{e_1 it_1}$	18,000	$R_{e_1 j_2}$	0.8
$d_{e_1 it_2}$	12,000	F_{j_1}、F_{j_2}	\$10,000
w_{it_1}	0.6	$g_{j_1 it_1}$、$g_{j_2 it_1}$	\$18/unit
w_{it_2}	0.4	$g_{j_1 it_2}$、$g_{j_2 it_2}$	\$20/ unit
$\alpha_{it_1}^{l_{it_1}}$	1	Cap_{j_1}、Cap_{j_2}	10,000 square meter
$\alpha_{it_1}^{l_{it_2}}$	0.7	γ_{it_1}、γ_{it_2}	1 square meter
$\alpha_{it_2}^{l_{it_1}}$	1	$C_{e_1 j_1 it_1}$、$C_{e_1 j_1 it_2}$	\$5/ unit
$\alpha_{it_2}^{l_{it_2}}$	0.7	$C_{e_1 j_2 it_1}$、$C_{e_1 j_2 it_2}$	\$7.14/ unit
B_0	\$400,000	B_1	\$400,000

4.3 Result Analysis of a Test Network

The result is shown in Table 2. The objective value is 19,316. For item 1, 100% of demand (18,000 units) is satisfied. The 10,000 units of item type 1 is from j_1 and 8,000 unit of type 1 is from j_2. For item 2, only 16.7% of demand (2,000 units) is satisfied. The 2,000 unit of item type 2 is from j_2. The major reason for the short fall is the capacity of the EDCs is less than the demand for items.

Table 2 Result of test network

Objective Value	19,316
Decision values	
$f_{e_1 j_1 it_1}$	0.556
$f_{e_1 j_2 it_1}$	0.444
$f_{e_1 j_1 it_2}$	0
$f_{e_1 j_2 it_2}$	0.167
$Q_{j_1 it_1}$	10,000
$Q_{j_1 it_2}$	0
$Q_{j_2 it_1}$	8,000
$Q_{j_2 it_2}$	2,000
X_{j_1}	1
X_{j_2}	1

Besides the capacity of EDCs, the budget variation (including pre-disaster budget and post-disaster budget) is a factor to influence the result.

Table 3 shows the results of budget variation. Figure 3 is the result of total expected demand covered by EDCs under fixed post-disaster budget and variable pre-disaster budget. Figure 4 reveals the result of total expected demand covered by EDCs under fixed pre-disaster budget and variable post-disaster budget. Figure 5 indicates the result of total expected demand covered by EDCs under variable pre-disaster budget and post-disaster budget.

The above results show while the budget increases, total expected demand covered by EDCs increases. The test network shows applicability of the model. Next section describes the application of the model in a real sub-network of Kaohsiung City.

Table 3 Results of budget variation Unit: 10 thousand $

Scenarios	Case 1: fixed pre-disaster budget		Case 2: fixed post-disaster budget		Case 3: variable pre-disaster budget and post-disaster budget	
	pre-disaster	post-disaster	pre-disaster	post-disaster	pre-disaster	post-disaster
1	40	4	4	40	4	4
2	40	6	6	40	6	6
3	40	8	8	40	8	8
4	40	20	10	40	20	20
5	40	40	20	40	40	40

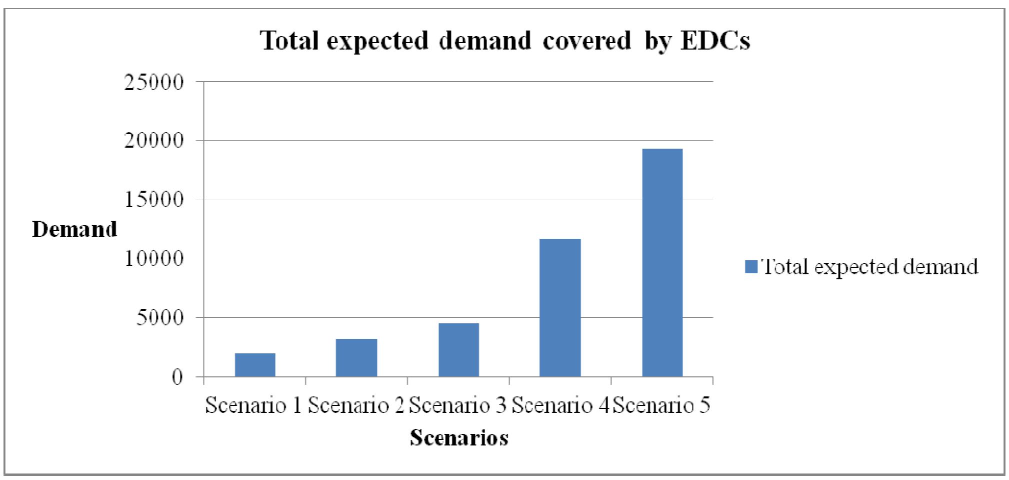

Figure 3 Total expected demand covered by EDCs under fixed post-disaster budget and variable pre-disaster budget

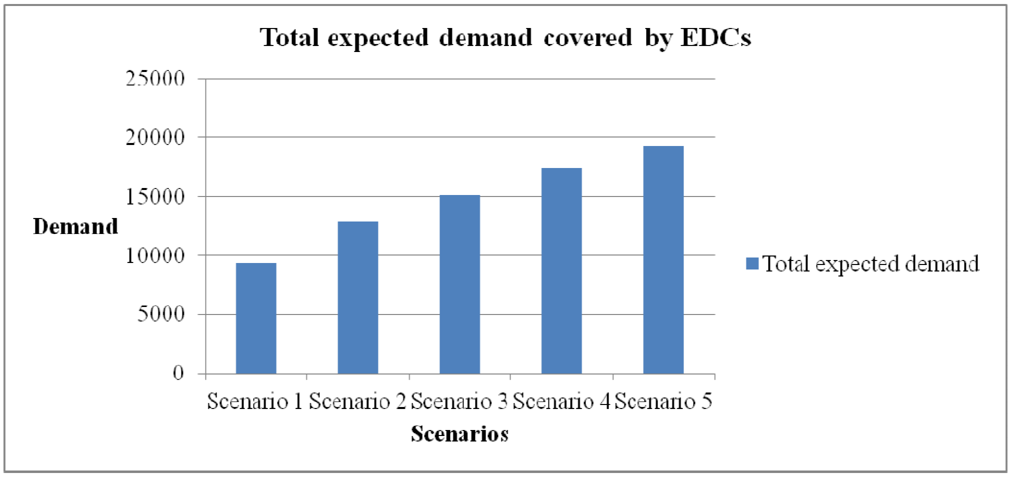

Figure 4 Total expected demand covered by EDCs under fixed pre-disaster budget and variable post-disaster budget

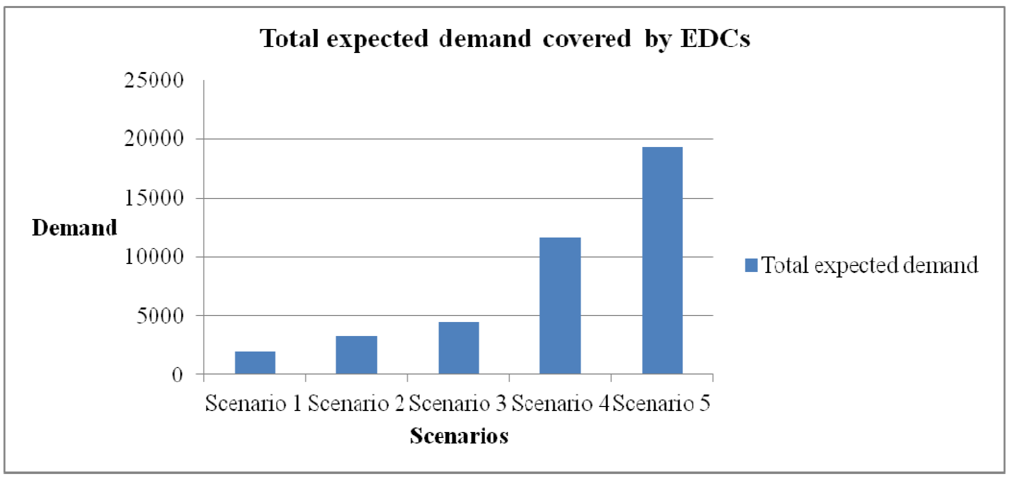

Figure 5 Total expected demand covered by EDCs under variable pre-disaster budget and post-disaster budget

5. EMPERICAL STUDY

In order to select of EDCs under emergency in real network, a real sub-network of Kaohsiung City is conducted to implement the model.

5.1 Data Collection

Three major data sets for numerical experiments, including: the network characteristics and historical O-D flows are described as below:

5.1.1 The network configuration

The sub-network of Kaohsiung City in this study area includes 132 nodes, 363 links and 27 traffic zones. The network is depicted in Figure 6.

Research scenarios of the experiments are described below:

1. There is an emergency caused by Typhoon.

2. There are 4 candidate EDC zones and 1 shelter zone. The EDCs and shelters are assumed to be schools, as shown in Table 4.
3. The location and capacity of EDCs and shelters are scheduled and known in advanced.

Table 4 Candidate EDCs

ID	EDCs	Capacity (square meter)
j_1	Kaohsiung Medical University	5079
	Kaohsiung Municipal San-Min Junior High School	
	Kaohsiung Municipal Po-Ai Elementary School	
j_2	Kaohsiung Municipal Senior High School	2888
j_3	Wen-Zao Ursuline College of Languages	1338
j_4	Kaohsiung Municipal Yang-Ming Junior High School	3723

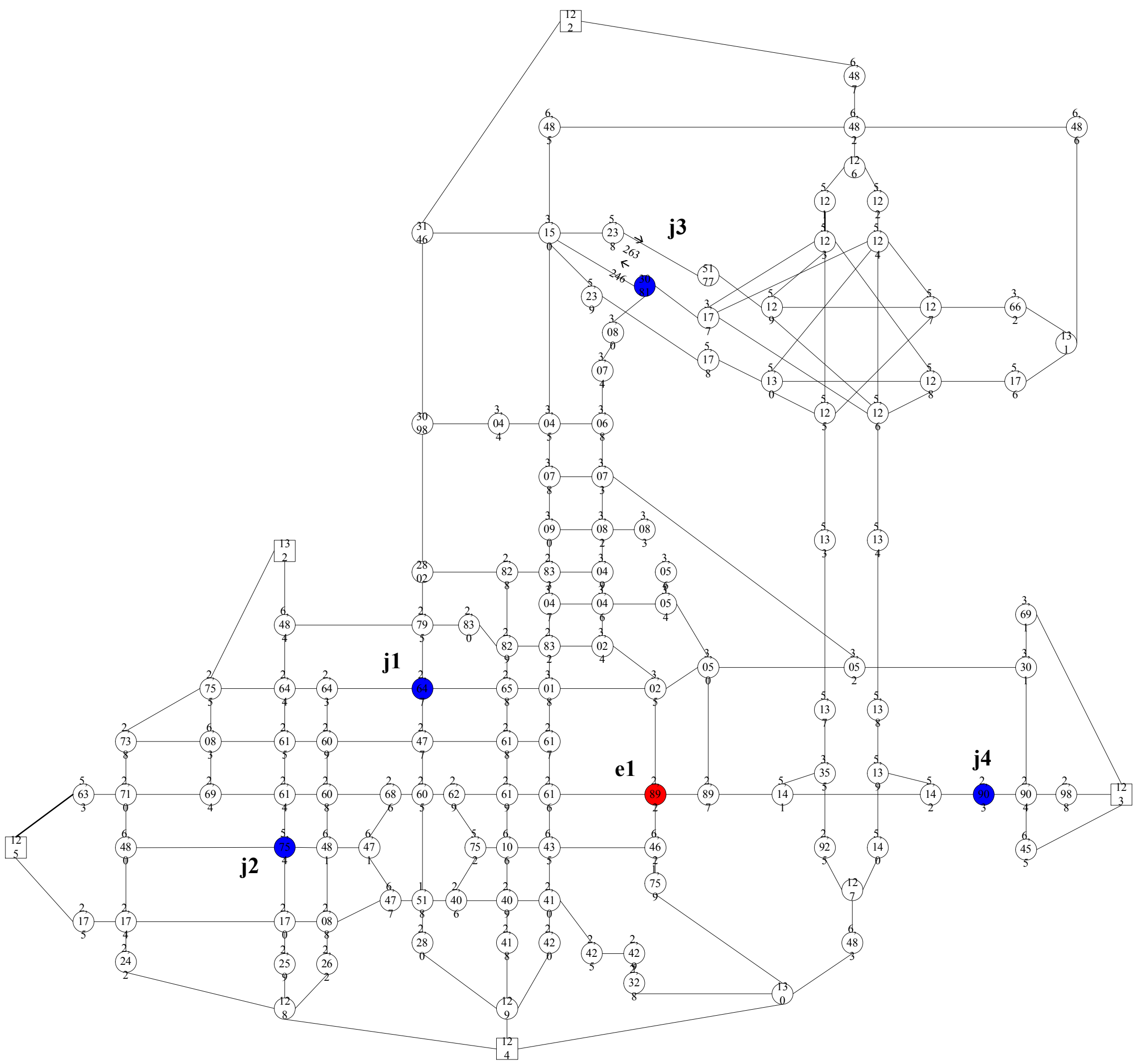

Figure 6 Network configuration

5.1.2 Historical O-D flows

Original O-D trip tables are obtained based on the project, titled “Comprehensive planning of light rail project in Kaohsiung Metropolitan Area” and based on the population data in Kaohsiung City.

5.2 Experiment Design

The distance is used to decide the cost, covering level and weight.

Capacity is used to decide the fixed cost.

If the capacity is more than 3,000 square meters, the fixed cost is set to be $13,000 and if the capacity is less than 3,000 square meters, the fixed cost is set to be $10,000.

The parameter setting is shown in Table 5.

The assumptions are described below:

1. There are 3 emergency distribution centers delivering goods to 1 shelter.
2. The expected demand of item type 1 is 5,400, and expected demand of item type 2 is 3,600.
3. The pre-disaster budget and post-disaster budget are 300,000.
4. The risk of individual link failure is reflected in connectivity reliability of each shelter. For example, in the empirical analysis, the connectivity reliability of shelter 3 is the lowest. It is assumed the low connectivity reliability is due to some failure of links.

The connectivity reliability is calculated based on equation (11) and (12).

Table 5 Parameter Setting in real network

pr_{e_1}	1	$R_{e_1 j_1}$	0.93
F_{j_1}、F_{j_4}	$13,000	$R_{e_1 j_2}$	0.79
F_{j_2}、F_{j_3}	$10,000	$R_{e_1 j_4}$	0.81
w_{it_1}	0.6	$R_{e_1 j_3}$	0.58
w_{it_2}	0.4	$g_{j_1 it_1}, g_{j_2 it_1}, g_{j_3 it_1}, g_{j_4 it_1}$	$18/ unit
$d_{e_1 it_1}$	5,400	$g_{j_1 it_2}, g_{j_2 it_2}, g_{j_3 it_2}, g_{j_4 it_2}$	$20/unit
$d_{e_1 it_2}$	3,600	$Cap_{j_1}, Cap_{j_2}, Cap_{j_3}, Cap_{j_4}$	10,000 square meter s
$\alpha_{it_1}^{l_{it_1}}$、$\alpha_{it_2}^{l_{it_1}}$	1	$\gamma_{it_1}, \gamma_{it_2}, \gamma_{it_3}, \gamma_{it_4}$	1 square meter
$\alpha_{it_1}^{l_{k_{it}2}}$、$\alpha_{it_2}^{l_{it_2}}$	0.45	$C_{e_1 j_1 it_1}, C_{e_1 j_1 it_2}, C_{e_1 j_1 it_3}, C_{e_1 j_1 it_4}$	$10.8/ unit
B_0	300,000	$C_{e_1 j_2 it_1}, C_{e_1 j_2 it2}, C_{e_1 j_2 it3}, C_{e_1 j_2 it4}$	$12.7/ unit
B_1	300,000	$C_{e_1 j_3 it1}, C_{e_1 j_3 it_2}, C_{e_1 j_3 it_3}, C_{e_1 j_3 it_4}$	$12.7/ unit
		$C_{e_1 j_4 it_1}, C_{e_1 j_4 it_2}, C_{e_1 j_4 it3}, C_{e_1 j_4 it_4}$	$12.7/ unit

5.3 Results Analysis

There are two items need to be delivered from EDCs to the shelters. The number of demand for item 1 is 5,400. The number of demand for item 2 is 3,600.

The result is obtained from CPLEX and is shown in Table 6. The result shows when the demand of item in shelters is less than capacity of the 4 EDCs, the model can reflect the influence of reliability and can select the optimal EDCs. The optimal EDCs are j_1, j_2 and j_4. The utility rate of j_1 is 100%, the reason is the reliability $R_{e_1 j_1}$ from j_1 to the shelter is higher than others. The distribution of the optimal EDCs is shown in Figure 7.

Table 6 Results of Experiment in real network

Objective Value	6,024.425
Decision values	
$f_{e_1 j_1 i t_1}$	0.941
$f_{e_1 j_2 i t_1}$	0
$f_{e_1 j_3 i t_1}$	0
$f_{e_1 j_4 i t_1}$	0.059
$f_{e_1 j_1 i t_2}$	0
$f_{e_1 j_2 i t_2}$	0.059
$f_{e_1 j_3 i t_2}$	0
$f_{e_1 j_4 i t_2}$	0.941
$Q_{j_1 i t_1}$	5,079
$Q_{j_1 i t_2}$	0
$Q_{j_2 i t_1}$	0
$Q_{j_2 i t_2}$	214
$Q_{j_3 i t_1}$	0
$Q_{j_3 i t_2}$	0
$Q_{j_4 i t_1}$	321
$Q_{j_4 i t_2}$	3386
X_{j_1}	1
X_{j_2}	1
X_{j_3}	0
X_{j_4}	1

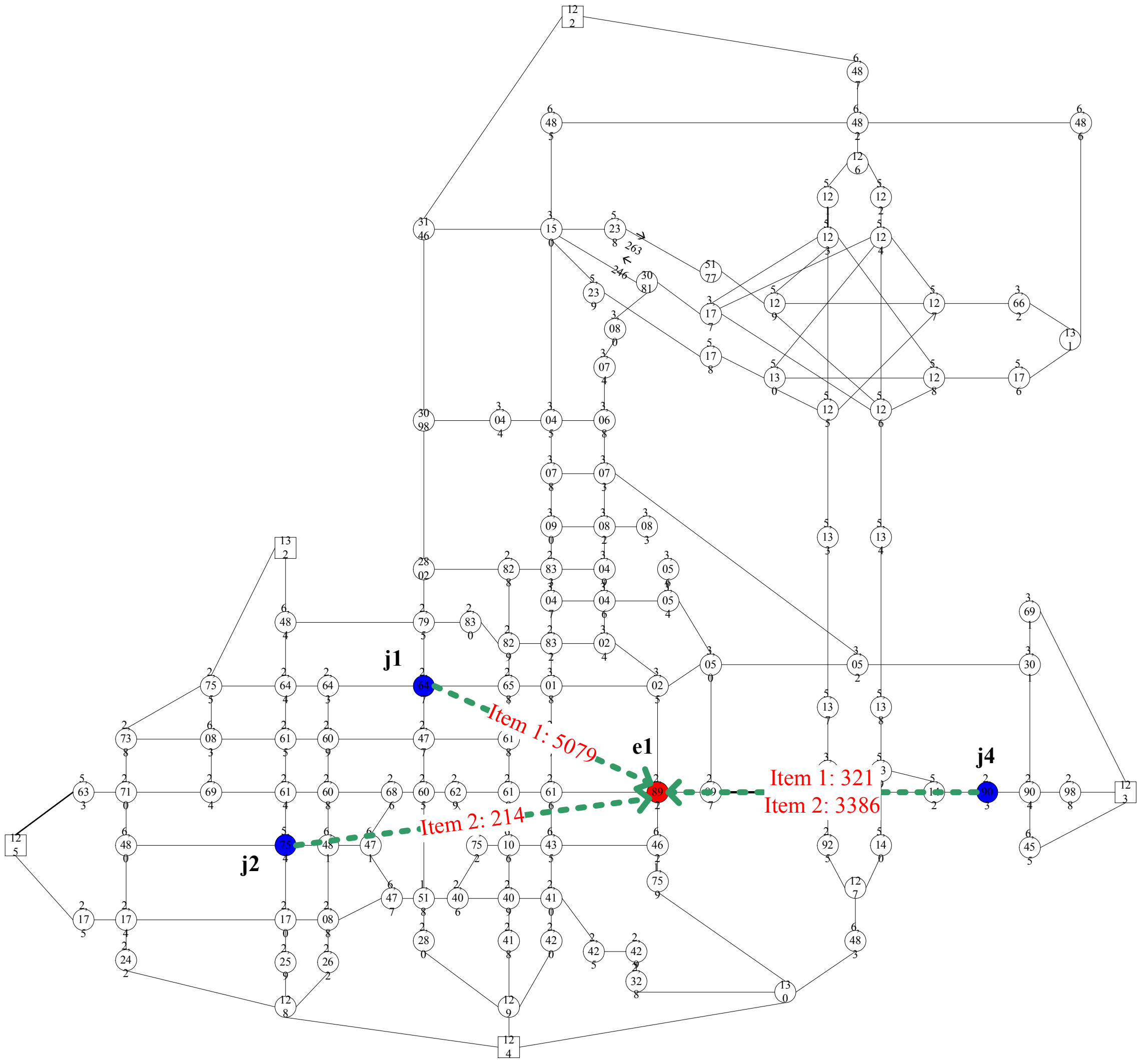

Figure 7 Distribution of the optimal EDCs

5.4 Sensitivity Analysis

In order to observe the impact and performance under different demand levels of items, several scenarios with different demand levels are developed. Three developed scenarios are listed in Table 7. The basic case is scenario 2.

The results show when the demand increase, the number of EDCs increases.

In scenario1 (high demand), the selected EDCs are j_1, j_2, j_3 and j_4. All of the EDCs are selected due to the fewer EDCs are insufficient to meet the demand of items.

In scenario 2, this scenario is a basic case in Table 5. The j_3 is deleted because the reliability and capacity of j_3 is less than others.

In scenario 3 (low demand), the only selected EDC is j_1. It shows j_1 is the best EDC under low demand. The results reveal the reliability and capacity are the two important factors to influence the selection of EDCs.

Table 7 Result of Sensitivity Analysis

		Scenario 1 (High demand)	Scenario 2 (Normal demand, basic case)	Scenario 3 (Low demand)
Desired demand	Item type 1	8,100	5,400	2,700
	Item type 2	5,400	3,600	1,800
Selected EDCs		j_1、j_2、j_3、j_4	j_1、j_2、j_4	j_1

6. CONCLUSION

This research proposes a model with the consideration of reliability for selecting emergency distribution centers under emergency. The unique feature of the proposed model is the consideration of connectivity reliability. Probability of connectivity reliability is added in the objective function to reflect the possibilities of network failure under emergency. DynaTAIWAN is used to simulate the failure of links, and the connectivity reliability is calculated based on the simulation information. CPLEX is used to solve the problem.

The results show the model can reflect the influence of reliability and can select the optimal EDCs. When the demand of item increase, the number of EDCs increases. When the demand of item is low, the model can select the best EDC with higher reliability and higher capacity. In the proposed model, the reliability and capacity are the two important factors to influence the selection of EDCs. In future research, different reliability index could be considered in the model, like: travel time and capacity reliability of roads. Variable failures on links, or randomly damaged links could be considered in the selection of EDCs.

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