

# Model and Algorithm for Rescue Resource Assignment Problem in Disaster Response Based on Demand-Ability-Equipment Matching

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**Abstract.** The rapid and accurate response in post-disaster is of vital importance of emergency management. This article mainly focuses on the optimizing assignment process and aims to allocate rescue resources to diverse disaster points in an attacked area. The proposed model contains the allocation of rescue teams and equipment, and a corresponding transportation strategy was provided when the rescue team and equipment are assigned. A multi-objective optimization problem was established on the basis of cost and time consideration. Moreover, an improved epsilon-constraint algorithm was developed to find Pareto fronts of the multi-objective optimization problem. Some numerical examples are analyzed and the computational results confirm the feasibility of the assignment method.

**Keywords:** Assignment method · DAEM · Multi-objective ·  $\epsilon$ -constraint

## 1 Introduction

A disaster is the result of a vast ecological breakdown in the relations between man and his environment [1], so that timely response and effective disposal in order to restore the original situation after a disaster occurred are crucial aspects in emergency management., there are not only casualties, but also the destruction of infrastructures in an area of post-disaster, frequent natural disaster sets unprecedented challenges for emergency decision maker especially in the process of distributing rescue resources which always expose the shortcomings when reevaluating the rescue activities in post-disaster. Thus, taking the earthquake as a background, providing optimization strategy for distribution problem in restore infrastructures has the profound realistic significance. This article will mainly focus on the response phase of which optimizing the distribution problem from aid center includes the warehouse of engineering equipment and the location of rescue teams which assigned to restore the infrastructures in disaster points. Aiming at designing a distribution approach which on the premise of Demand-Ability-Equipment Matching (DAEM), and the concept of DAEM will be described in detail as follow.

The limited district in an affected area in post-disaster is described as disaster point. Because the types and the degrees of damages within each disaster point is not the same, the demand of each point to rescue and restore infrastructure is different. Since the Wenchuan earthquake happened in 2008, Chinese government had been pay more attention to emergency response ability. Standardization Administration of the People’s Republic of China (SAC) tries to establish a series of comprehensive national standard for the process of post-earthquake rescue. One of these standards is Classification of Earthquake Damage to Lifeline Engineering (CEDLE), it defines all kinds of damage to lifeline engineering in post-earthquake [5], definitions are showed as Table 1.

**Table 1.** Related infrastructure of different classification of earthquake damage to lifeline engineering

Classification	Related infrastructure
Traffic system	Road; Bridge; Tunnel; Railway line
Water supply	Treatment pool; Treatment plant; Supply pumping station; Distribution network
Oil system	Refinery; Oil pumping station; Oil depot; Oil pipeline
Gas system	Gas station; Gas storage; Gas pipeline
Electric system	Generating station; Transformer substation; Transmission line
Communication system	Center control room; Telecommunication line
Water conservancy	Earth and rockfill dam

For a long time, rescue teams are the key of response phase in the disaster management. The rescue technology owned by rescue teams determines whether the objective of rescue will be achieved. These standards attend to categorize the different kind of damage in disaster points and designate related rescue skill for each classification. As any kind of damage has a corresponding rescue skill owned by rescue teams to restore, it form a mechanism for matching rescue skill between demand of disaster points and ability of rescue team. When a natural or an anthropogenic disaster occurs in a region, there are some incipient disaster points appearing. Decision makers estimate what rescue skills do each disaster point needs by damage characteristics, and assign rescue teams to disaster points. For example, a disruptive earthquake damages the electric power system and the transportation system in a disaster point, this disaster point needs those two corresponding rescue skills to carry out rescue, And a team or teams will go to the disaster point to complete the rescue mission. In addition, it is understandably that large engineering equipments are used by rescue teams in rescue activities. For example, excavators are widely used in transportation system rescue, especially in a road destroyed. Hence, as previous research [2], all elements of the objective function including the commodities are represented in an equivalent common unit of number of persons not served. So, in this paper, D-A-E Matching is a direct and universal approach of decision-making which not only matches rescue teams based on disaster point demand, but also ensure the assigned rescue teams to have the ability to complete the mission of disaster points in response phase. Considering the condition of

constrained resources and the demand of disaster point, D-A Mating proves that dispatching the closet rescue team to the accident point is not always the best strategy.

Moreover, *CEDLE* divides post-earthquake damage into different levels, the feature of each level are shown in Table 2. As with in-person training, levels of rescue skill can be uneven in all rescue teams, and problems can be sloved from the same or a lower level. It indicates that the best match inters to when a team be assigned to a disaster point, all the abilities of this rescue team are used. For example, the rescue teams which have the abilities of *fourth-level* power system rescue skill and *third-level* transportation system rescue skill save a disaster point with only *second-level* power system damage is a waste of rescue resources. So, D-A Matching further means to assign teams of a disaster point by a fit conjunction with less redundancy should be concerned.

**Table 2.** Feature of each level

Level	Feature
I	Basically intact
II	Slight damage
III	Moderate damage
IV	Serious damage
V	Destroy

However, only chasing after the little redundancy in the process of assignment can not make the assignment scheme get a high performance in practice in terms of response and rescue. Other constraints based on practical issues need to be considered.

The remainder of the paper is organized as follows. A literature review is given in the next section. In Sect. 3 the proposed multi-objective mathematical formulation is described. In Sect. 4, an improved exact solution method is proposed. Numerical examples are illustrated in Sect. 5, and the concluding remarks are given in the final section.

## 2 Literature Review

In recent years, the response phase has been the main focus of emergency management researching in previous studies. Meanwhile, the study of rescue resource distribution problem has become one of the most popular topics within the response phase. Tofighi et al. [3] developed a novel two-stage scenario-based possibilistic-stochastic programming approach to formulate the problem under a mixture of probabilistic and possibilistic uncertainties for solve the problem of two-echelon humanitarian logistics network design involving multiple central warehouses and local distribution centers. Torabi et al. [4] accounted for epistemic uncertainty of critical data and proposed a bi-objective model for the supplier selection and order allocation problem to build the resilient supply base under operational and disruption risks. Wallace et al. [5] has developed a formulation of mixed-integer programming to minimize the cost terms from traditional network flow models; Campbell et al. [6] developed some

methodologies of traveling salesman problem (TSP) and the vehicle routing problem (VRP) for disaster relief. Minimized the maximum arrival time and the average arrival time to bounded the worst-case performance of optimal TSP solutions. And presented solution approaches for these two variants of the TSP and VRP, which are based on well-known insertion and local search techniques. Nurre et al. [7] considered the integrated network design and scheduling (INDS) problems applicate in infrastructure restoration after an extreme event and building humanitarian logistics networks. And they proposed a novel heuristic dispatching rule algorithm to solve the NP-hard problem of INDS. Boland et al. [8] studied the problem of scheduling maintenance on arcs of a capacitated network. They maximized the total flow from a source node to a sink node over a set of time periods and proposed an additional constraint which limits the number of maintenance jobs per time period.

In addition, for D-A-E matching, Altay [9] pointed out the mechanism of distributing rescue resource according to demand in each disaster point, and they built a simple inter programming model to allocate resources. However, no solution was proposed to this model and the notion of nationwide resource inventory listing is too ambiguous.

### 3 Model Formulation for Rescue Resource Assignment Problem

*Assumptions:*

The proposed mathematical model is based on the following assumptions

- (1) All rescue units can cover all demand in disaster points.
- (2) The known capacity of the road is no longer changing in post-disaster.
- (3) The transportation of rescue team on road and helicopter, equipments on road transport.

*Parameters:*

$V$ :	set of disaster points, $V = \{1, \dots, n\}$
$S$ :	set of rescue teams, $S = \{1, \dots, m\}$
$W$ :	set of equipment warehouse, $W = \{1, \dots, w\}$
$E$ :	set of equipment sorts, $E = \{1, \dots, e\}$
$T$ :	set of time interval. $T = \{1, \dots, t\}$
$R$ :	set of transport type to send rescue teams
$R'$ :	set of transport type to send equipment without helicopter
$P_k(i, j)$ :	transporting from support point $i$ to disaster point $j$ on $k$ transport type
$P'_k(i, j)$ :	transporting from support point $i$ to disaster point $j$ on $k$ transport type without helicopter
$a_{is}$ :	quantity of equipment $s$ owned by warehouse $i$
$b_{js}$ :	quantity of equipment $s$ demanded by disaster point $j$
$c_k$ :	cost of transportation on $k$ transport type
$c'_k$ :	cost of transportation on $k$ transport type without helicopter
$t_{ikj}$ :	time of needed traveling from support point $i$ to disaster point $j$ on $k$ transport type

$t'_{ikj}$ :	time of needed traveling from support point $i$ to disaster point $j$ on $k$ transport type without helicopter
$c_d^\lambda$ :	cost of the skill of type $d$ in level $\lambda$
$\tau$ :	maximum tolerable waiting time

$$cs_i^{d\lambda} = \begin{cases} 1 & \text{if rescue team } i \text{ can support skill of type } d \text{ of level } \lambda \\ 0 & \text{otherwise} \end{cases}$$

$$cv_j^{d\lambda} = \begin{cases} 1 & \text{if attacked point } j \text{ needs skill of } d \text{ type of level } \lambda \\ 0 & \text{otherwise} \end{cases}$$

*Decision variables:*

As mentioned before, we have three decisions in the proposed model. One of these decisions is determining the time of start transporting from each warehouse and is determined by  $\theta_{ij}(i \in w, j \in n)$ . This decision variable can decide the departure time to conform to the constraint which limits the number of servicing disaster points per unit time. And the others are determining the distributing status of rescue units.

$\theta_{ij}^{team}$ :	the moment of start traveling for rescue team $i$ to disaster points $j$
$\theta_{ij}^{equ}$ :	the moment of start traveling for equipment from warehouse $i$ to disaster points $j$
$Q_{ij}^s$ :	quantity of equipment $s$ delivered to disaster point $j$ from equipment warehouse $i$

$$x_{ikj} = \begin{cases} 1 & \text{if rescue team } i \text{ visit to disaster point } j \text{ on its } k\text{th type} \\ 0 & \text{otherwise} \end{cases}$$

*Auxiliary variables:*

The auxiliary variable is decide by  $Q_{ikj}^s$ .

$$y_{ikj} = \begin{cases} 1 & \text{if equipments delivered to disaster point } j \text{ from warehouse } i \text{ on its } k\text{th type} \\ 0 & \text{otherwise} \end{cases}$$

**3.1 Multi-objective Integer Programming Model**

A new mathematical model to solve DAEM problem is proposed based on the assignment problems and transportation problems. Assignment problem is applied to determine which rescue teams and equipment warehouses to complete the mission in each disaster point, and the transportation problem is applied to make decision for type of transport.

$$f_1 = \min \left[ \max_{i,k,j \in S} (t_{ikj} + \theta_{ij}^{team}) x_{ikj} \right] \quad (1)$$

$$f_2 = \min \left[ \max_{i,k,j \in W} (t'_{ikj} + \theta_{ij}^{equ}) y_{ikj} \right] \quad (2)$$

$$f_3 = \min \sum_{j=1}^n \left[ \sum_{i=1}^m \left( \sum_{\lambda=1}^a \sum_{d=1}^l c_d^\lambda c_s^{d\lambda} x_{ikj} + \sum_{k=1}^r c_k x_{ikj} \right) + \sum_{i=1}^w \left( \sum_{s=1}^e c_s Q_{ikj}^s + \sum_{k=1}^{r'} c'_k y_{ikj} \right) \right] \quad (3)$$

$$\sum_j Q_{ij}^s \leq a_{is} \quad \forall i \in W, \forall s \in E, \forall k \in R' \quad (4)$$

$$b_{js} \leq \sum_i Q_{ij}^s \quad \forall j \in V, \forall s \in E, \forall k \in R' \quad (5)$$

$$Q_{ij}^s \leq \sum_k y_{ikj} a_{is} \quad \forall i, j, s, \forall k \in R' \quad (6)$$

$$\sum_i \sum_j Q_{ij}^s \geq \sum_k y_{ikj} \quad \forall s \in E \quad (7)$$

$$\sum_k y_{ikj} \leq 1 \quad \forall i \in W, \forall j \in V \quad (8)$$

$$\sum_i \sum_{\lambda=u}^v \sum_k x_{ikj} c_s^{d\lambda} - c v_j^{du} \geq 0 \quad \forall w, u, d \in Z^+, \forall j \in V \quad (9)$$

$$\sum_k \sum_j x_{ikj} \leq 1 \quad \forall i \in S \quad (10)$$

$$-\tau \leq x_{ikj} (t_{ikj} + \theta_{ij}^{team}) - x_{fjj} (t_{fjj} + \theta_{fj}^{team}) \leq \tau \quad \forall j \in V \quad (11)$$

$$-\tau \leq x_{ikj} (t_{ikj} + \theta_{ij}^{team}) - y_{hvj} (t_{hvj} + \theta_{hj}^{equ}) \leq \tau \quad \forall j \in V \quad (12)$$

$$x_{ikj} \in \{0, 1\} \quad \forall i, j, \forall k \in R \quad (13)$$

$$y_{ikj} \in \{0, 1\} \quad \forall i, j, \forall k \in R' \quad (14)$$

$$l \in \{1, \dots, r\} \quad (15)$$

$$v \in \{1, \dots, r-1\} \quad (16)$$

$$h \in \{1, \dots, w\} \quad (17)$$

$$f \in \{1, \dots, n\} \quad (18)$$

The three objectives are given by Eqs. (1)–(3). The objective function (1) minimizes the time of latest arrival rescue teams. Objective function (2) minimizes the time of latest arrival equipment. The third objective function minimizes the sum of all cost including in the using cost and transporting cost for both rescue teams and equipments. Constraint (4) ensures that the total quantity of equipment  $s$  delivered for each disaster point does not exceed the quantity of equipment  $s$  available in this warehouse. Constraint (5) ensure that the total quantity of given equipment  $s$  in disaster point  $j$  delivered from each warehouse must exceed the quantity of demand. Constraints (6 and 7) shows that relationship between decision variable  $Q_{ij}^s$  and auxiliary variable  $y_{ij}$ . Constraint (8) ensures that there is only one type of transporting equipments which sending from a warehouse to a disaster point. Constraint (9) ensures that the teams assigned from its location can match the demand in disaster point  $j$ . Constraint (10) ensures that any rescue team can only be assigned once. Constraints (11 and 12) setting the maximum tolerance value to control the waiting time.

### 3.2 Model Linearization

The proposed mathematical model is nonlinear because of Constraints (11) and (12). New variables are proposed as  $\Omega_{ij}^{team}$  and  $\Omega_{ij}^{equ}$  instead of multiplication of variables  $\theta_{ij}^{team}$  and  $x_{ikj}$ ,  $\theta_{hj}^{equ}$  and  $y_{ij}$  respectively, in order to  $x_{ikj}\theta_{ij}^{team} = \Omega_{ij}^{team}$ ,  $\forall i, j$  and  $y_{ij}\theta_{ij}^{equ} = \Omega_{ij}^{equ}$ ,  $\forall i, j$ . Thus, in the mathematical model, Constraints (11) and (12) will be replaced by Constraints (19) and (20), and the additional Constraints (21–24) should be added to the proposed model, and the parameter  $M$  is a large enough value to constraint the relationships with two binary variables  $x_{ikj}$  and  $y_{ikj}$ .

$$-\tau \leq x_{ikj}t_{ikj} + \Omega_{ij}^{team} - x_{fj}t_{fj} + \Omega_{fj}^{team} \leq \tau, \forall j \in V \tag{19}$$

$$-\tau \leq x_{ikj}t_{ikj} + \Omega_{ij}^{team} - y_{hvj}t_{hvj} + \Omega_{hj}^{equ} \leq \tau, \forall j \in V \tag{20}$$

$$\Omega_{ij}^{team} \leq Mx_{ikj} \forall k \in R \tag{21}$$

$$\Omega_{ij}^{team} \geq 0 \tag{22}$$

$$\Omega_{ij}^{equ} \leq My_{ikj} \forall k \in R' \tag{23}$$

$$\Omega_{ij}^{equ} \geq 0 \tag{24}$$

## 4 Exact Solution Method for Demand-Ability-Equipment Matching

### 4.1 Achieving a Lower Bound of Objective Function

The  $\epsilon$ -constraint method finds all the Pareto points of multi-objective integer linear programming problems starting from the one corner Pareto point and finding an

adjacent one each iteration [10]. Functions  $f_1$  and  $f_2$  exist their certain range of values, lower bounds of these two object functions must to be find in order to start with a corner Pareto slice in a highly discriminating way.

### 4.2 The $\epsilon$ -Constraint Method

The  $\epsilon$ -constraint method has a good performance for solving non-convex optimization problems, not only restricted to biobjective problem but can also efficiently adapted to multi-objective integer linear programming problems [11]. In this study, the solution method is developed as an exact solution approach based  $\epsilon$ -constraint, and the proof of using this method can generate the exact Pareto front is shown in [12].

The Demand-Ability-Equipment matching is a three-objective combinatorial optimization problem for which we proposed the mathematical model. The three objectives  $f_1, f_2, f_3$  which defined by Eqs. (1)–(3), consist in minimizing the traveling time and the totally cost respectively. We choose  $f_3$  as objective function to optimize, and the constrained problem  $P(\epsilon_1, \epsilon_2)$  is defined by

$$P(\epsilon_1, \epsilon_2) \text{ Min } f_3(X) \quad \text{s.t.} \begin{cases} f_1(X) \leq \epsilon_1 \\ f_2(X) \leq \epsilon_2 \\ X = (x, y, \theta, Q) \in D \end{cases}$$

where  $X = (x, y, \theta, Q)$  denotes the set of variables defined in the proposed mathematical model; and  $D$  is the feasible region defined by Eqs. (4)–(24);  $\epsilon_1$  and  $\epsilon_2$  are the two parameters in iteration to yield the Pareto front.

## 5 Computational Result

In this section, a simple case is presented to test the application of this distribution model. The Ludian earthquake occurred on August 3, 2014, with its epicenter located in Ludian Country. This disaster caused a large number of infrastructure damaged in Zhaotong, Yunnan Province. According to the HD image of Ludian earthquake area published by National Administration of Surveying and Geoinformation (NASG) [13], 36 disaster-affected sites, which located in or near epicenter were identified. Only except Shuifu Country and Weixin Country, disaster-affected sites throughout the city in Zhaotong. Figure 1 displays the location and number of these 36 disaster-affected sites.

To restore lifeline engineering in each disaster-affected site, the lighting equipment is an essential equipment to support constructing. Analyzing the record of using lighting equipment from Yunnan Power Grid Corporation, a subsidiary of China Southern Power Grid, can get parts of information about disaster sites. Combining with the report on direct economic losses of Ludian 6.5 earthquake which described the situation of damage by 8.3 earthquake published by Yunnan Seismological Bureau (YSB), we can easily come to know the classification of damage and their corresponding level for each affected site. Details is shown by Table 12 in Appendix A.



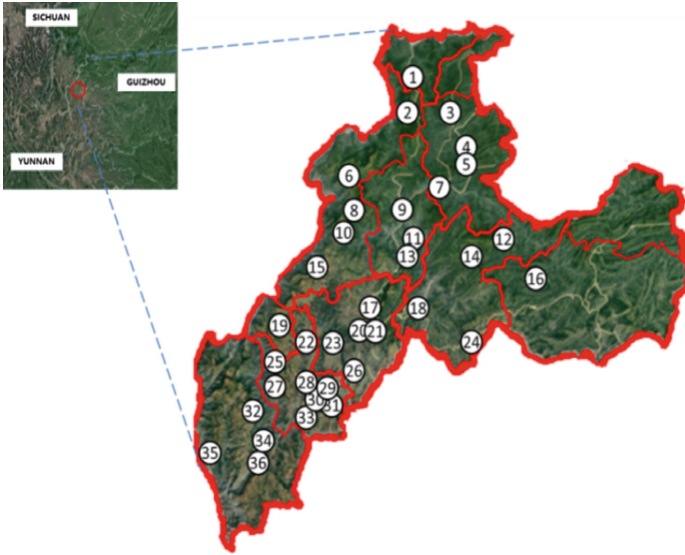


Fig. 1. Disaster-affected sites in Zhaotong, Yunnan.

Table 3. Demand of restoring in each disaster point

Disaster point	Traffic system	Water supply	Oil system	Gas system	Electirc system	Communication system	Water conservancy
Urban district	II	–	I	–	III	–	II
Ludian	IV	I	–	I	IV	III	V
Qiaojia	III	–	–	–	I	II	–
Yanjin	II	I	–	–	–	–	I
Daguan	I	II	–	–	–	–	–
Yongshan	II	–	–	–	–	–	III
Suijiang	–	–	–	–	I	–	–
Yiliang	II	–	–	–	–	–	–
Weixin	I	–	–	–	–	–	–

Taking each administrative district as an disaster point, the demand of restoring in each disaster point an be listed by Table 3.

In addition, the quantity of equipment is generated by estimating the situation of each disaster point. Table 4 shows the demand in each disaster point.

After the earthquake, Zhaotong municipal government and Yunnan provincial government should be in charge of emergency rescue. Surveying the data from available rescue resources in Zhaotong and Kunming, the supporting ability of each rescue team and the quantity of equipment in each warehouse can be obtained and shown as Tables 5 and 6.

**Table 4.** Large engineering equipment demand in each disaster point

Disaster point	Emergency lighting vehicle	Excavator	Diesel generator	Crane	Water pump
Urban district	3	5	2	0	2
Ludian	13	17	7	7	4
Qiaojia	4	4	3	4	2
Yanjin	2	2	2	0	0
Daguan	3	3	2	0	0
Yongshan	1	2	4	3	0
Suijiang	3	3	1	4	0
Yiliang	0	2	0	0	0
Weixin	3	5	2	0	0

**Table 5.** Ability of each rescue team can support.

No.	Team affiliation	Location district title	TS	WS	OS	GS	ES	CS	WC
1	Yunnan power grid Zhenxiong power supply company	Zhenxiong	-	-	-	-	III	II	-
2	Yunnan power grid substation in Zhaotong	Zhaotong urban district	-	-	-	-	IV	III	-
3	Zhaotong fire brigade	Zhaotong urban district	-	-	II	IV	-	-	II
4	Zhaotong Highway Bureau	Zhaotong urban district	III	-	-	-	-	-	-
5	Zhaotong municipal engineering company	Zhaotong urban district	II	II	-	-	-	II	-
6	Zhaotong branch of China petroleum & amp; chemical corporation	Zhaotong urban district	-	-	IV	-	-	-	-
7	Zhaotong water conservancy machinery construction team	Zhaotong urban district	-	V	-	-	-	-	III
8	Yunnan armed police detachment of Zhaotong	Zhaotong urban district	IV	-	-	-	-	IV	II
9	Yunnan power grid Yongshan power supply company	Yongshan	-	-	-	-	I	I	-

(continued)

**Table 5.** (continued)

No.	Team affiliation	Location district title	TS	WS	OS	GS	ES	CS	WC
10	Yunnan power grid Yiliang power supply company	Yiliang	–	–	–	–	II	I	–
11	Yiliang fire brigade	Yiliang	–	–	II	II	–	–	I
12	Yiliang road administration team	Yiliang	I	–	–	–	–	–	–
13	Kunming fire brigade	Xishan District		–	III	V	–	–	III
14	Kunming Highway Bureau maintenance team	Xishan District	IV	–	–	–	–	–	–
15	Kunming municipal engineering group construction team	Xishan District	IV	IV	–	–	–	III	–
16	Sinopec engineering construction team	Wuhua District	–	–	V	–	–	–	–
17	Yunnan armed police corps 1	Wuhua District	V	III	–	–	–	V	III
18	Yunnan armed police corps 2	Wuhua District	V	III	–	–	–	IV	III
19	Yunnan armed police corps 3	Wuhua District	V	III	–	–	–	V	III
20	Yunnan power grid Weixin power supply company	Weixin	–	–	–	–	III	II	–
21	Weixin road administration team	Weixin	II	–	–	–	–	–	–
22	Yunnan power grid Qiaojia power supply company	Qiaojia	–	–	–	–	I	I	–
23	Qiaojia road administration team	Qiaojia	I	–	–	–	–	–	–
24	Yunnan power grid Ludian power supply company	Ludian	–	–	–	–	III	III	–
25	Ludian highway administration	Ludian	III		III	–	III-	–	III
26	Ludian Zhongcheng gas company	Ludian	–	–	–	II	–	–	–
27	Yunnan Provincial Highway Bureau maintenance team	Guandu District	V	–	–	–	–	–	–
28	The second water conservancy and hydropower construction co., ltd.	Guandu District	–	III	–	–	–	–	V
29	Kunming power supply Bureau of Yunnan power grid of China Southern power grid	Guandu District	–	–	–	–	V	V	–
30	The first water conservancy and hydropower construction co., ltd.	Chenggong	–	V	–	–	–	–	V

**TS:** Traffic system, **WS:** Water supply, **OS:** Oil system, **GS:** Gas system, **ES:** Electirc system, **CS:** Communication system, **WC:** Water conservancy

**Table 6.** The quantity of each equipment in each warehouse

No.	Location district title	Emergency lighting vehicle	Excavator	Diesel generator	Crane	Water pump
1	Zhaotong Urban district	20	–	20	–	–
2	Songming	20	–	20	–	–
3	Chenggong	4	30	–	10	2
4	Zhaotong Urban district	0	10	10	0	0
5	Wuhua Distirct	10	5	3	10	1
6	Zhaotong Urban district	5	10	1	10	2
7	Guandu District	–	–	–	–	10

The parameters related to the cost are presented in Tables 7, 8 and 9. The location of rescue teams and equipment warehouses comprises Zhaotong urban district, Ludian, Qiaojia, Yongshan, Suijiang, Zhenxiong, Yiliang, Weixin in Zhaotong and Xishan District, Wuhua District, Guandu District, Chenggong, Songming in Kunming. Table 10 shows the time matrix between any pair of points is determined by a geography information system (GIS). The data of time spent on road transportation and highway transportation are export from GIS, and the data of time spent on helicopter transportation is estimated by the distance between any pair of points with the 250 km/h ordinary speed for helicopter.

**Table 7.** Cost spent on using equipment (T\$).

Emergency lighting vehicle	Excavator	Diesel generator	Crane	Water pump
10	30	100	40	30

**Table 8.** Cost of restoring lifeline engineering in each level (T\$).

	I	II	III	IV	V
Traffic system	16	32	48	144	216
Water supply	8	16	24	72	108
Oil system	24	48	72	216	324
Gas system	10	20	30	90	136
Electric system	16	32	48	144	216
Communication system	24	50	74	224	336
Water conservancy	40	80	120	360	540

**Table 9.** Cost of each transportation type (T\$).

Road	Highway	Helicopter
10	50	500

**Table 10.** Time spent on road/highway/helicopter transportation (h).

	Urban district	Ludian	Qiaojia	Yanjin	Daguan	Yongshan	Suijiang	Yiliang	Weixin
Urban district	1/1/1	2/2/2	7/4/2	4/2/2	3/2/2	7/4/2	7/4/2	3/2/2	6/3/2
Ludian	2/2/2	1/1/1	7/4/2	5/3/2	3/2/2	7/4/2	7/4/2	4/2/2	6/3/2
Qiaojia	7/3/2	7/4/2	1/1/1	10/5/2	9/5/2	12/6/2	13/7/3	8/4/2	11/6/3
Yongshan	7/4/2	7/2/2	12/6/2	7/4/2	6/3/2	1/1/1	9/5/2	6/3/2	9/5/2
Zhenxiong	9/5/2	7/4/2	12/6/3	6/3/2	5/3/2	9/5/2	8/4/2	7/4/2	3/2/2
Yiliang	3/2/2	4/2/2	8/4/2	4/2/2	3/2/2	6/3/2	8/4/2	1/1/1	6/3/2
Weixin	6/3/2	6/3/2	11/6/3	5/3/2	5/3/2	9/5/2	8/4/2	6/3/2	1/1/1
Xishan District	6/3/3	6/2/3	9/5/3	8/4/3	7/4/3	10/5/3	11/6/4	9/5/3	11/6/3
Wuhua District	6/3/3	6/3/3	9/5/3	8/4/3	7/4/3	10/5/3	11/6/4	9/5/3	11/6/3
Guandu District	6/3/3	6/3/3	9/5/3	8/4/3	7/4/3	10/5/3	11/6/4	9/5/3	11/6/3
Chenggong	6/3/3	6/3/3	9/5/3	8/4/3	7/4/3	10/5/3	11/6/4	8/4/3	11/6/4
Songming	3/2/2	3/2/2	4/2/2	5/3/2	4/2/2	8/4/4	8/4/4	5/3/2	8/4/4

**Table 11.** Detailed Pareto fronts statistics of the  $\epsilon$ -constraint method

$\epsilon_1$	$\epsilon_2$	Cost of rescue teams (T\$)	Cost of equipment (T\$)	$\min f_3$ (T\$)
3	3	6662	5090	11752
3	4	6662	4850	11512
4	3	5200	5090	10290
4	4	5200	4850	10050
4	5	5200	4810	10010
5	4	5096	4850	9946
5	5	5096	4810	9906
5	6	5096	4770	9866
6	5	4902	4810	9712
6	6	4902	4770	9672
7	6	4782	4770	9552
7	8	4782	4760	9542
8	8	4774	4760	9534
9	8	4702	4760	9462
11	10	4662	4760	9422

At the beginning of the computation, a tight lower bound have be find,  $f_1^{\min} = 2$  and  $f_2^{\min} = 3$ . Therefore, this example is implemented in MATLAB R2015a and run on a 2.93 GHz workstation with 2 GB of RAM. Gurobi 7.0.2 is the solver used. The result for exact Pareto fronts are given in Table 11, and the parameter  $\tau$  have been set to 1.

When the maximum time of objective  $f_1$  amplify 3 to 4, the total cost of objective  $f_3$  drops a lot. From the results we can see that, only **rescue team 25** (*Kunming municipal engineering group construction team*) and **rescue team 9** (*Yunnan power grid Yongshan power supply company*) go to disaster points by helicopter since the time of latest arrival rescue teams is limited. It fits the actual character which helicopter only can be used in costly short and long distance transportation. The **rescue team 25** is assigned in any determined time, because it has various skills with outstanding level and located within an appropriate distance between these disaster points.

## 6 Conclusion

An efficient auxiliary decision-making method, DAEM method to solve the transportation and assignment problem in the post-disaster in introduced in this paper. With this method, an improved strategy with novel decision-making basis is developed. The method includes two components, a 0–1 metric for assigning rescue teams and an integrated metric for assigning equipment, building a reasonable optimization of rescue process based on the abundant available rescue resources in a given disaster area.

In post-disaster allocation process, the dominating characteristics about suddenly-occurring demand in very large amounts and the short lead times for a wide variety of supplies [14]. It means that the information in the first time after a disaster happened may be ambiguous, being different from accurate simple case. Thus, how to identify the demand in disaster points accurately is of vital importance in the next research, a quantitative estimation method which is the premise to determine the condition of disaster point must be explored. It can provide great practical significance for this research.

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## A Appendix

**Table 12.** The classification and hierarchy in each disaster-affected site.

No.	District title	Damaged infrastructure	Classification	Level
1	Suijiang	Center control room	Electirc system	I
2	Yongshan	Road	Traffic system	I
3	Yanjin	Road	Traffic system	I
4	Yanjin	Road	Traffic system	II
5	Yanjin	Distribution network	Water supply	I
6	Yongshan	Earth and rockfill dam.	Water conservancy	I
7	Yanjin	Earth and rockfill dam.	Water conservancy	I
8	Yongshan	Bridge	Traffic system	II
9	Daguan	Distribution network	Water supply	II
10	Yongshan	Earth and rockfill dam.	Water conservancy	I
11	Daguan	Tunnel	Traffic system	I
12	Yiliang	Road	Traffic system	I
13	Daguan	Railway line	Traffic system	II
14	Yiliang	Road	Traffic system	I
15	Yongshan	Earth and rockfill dam.	Water conservancy	III
16	Weixin	Road	Traffic system	I
17	Urban district	Transformer substation	Electirc system	III
18	Yiliang	Railway line	Traffic system	II
19	Urban district	Earth and rockfill dam.	Water conservancy	II
20	Urban district	Oil depot	Oil system	I
21	Urban district	Transmission line.	Electirc system	II
22	Ludian	Transformer substation	Communication system	III
23	Urban district	Bridge	Traffic system	II
24	Yiliang	Bridge	Traffic system	I
25	Ludian	Road	Traffic system	II
26	Urban district	Highway	Traffic system	II
27	Ludian	Highway	Traffic system	IV
28	Ludian	Gas pipeline.	Gas system	I
29	Ludian	Distribution network	Water supply	I
30	Ludian	Transmission line.	Electirc system	IV
31	Ludian	Transmission line	Electirc system	II
32	Qiaojia	Transmission line	Electirc system	I
33	Ludian	Earth and rockfill dam.	Water conservancy	V
34	Qiaojia	Tunnel	Traffic system	III
35	Qiaojia	Center control room	Communication system	II
36	Qiaojia	Road	Traffic system	II

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