Multi-stage multi-objective engineering evaluation method for the ability of the emergency resources reserve system

Juan Liu*a, Jianming Zhua, Jun Huanga

*aGraduate University of Chinese Academy of Science, Beijing, 100049, China

Abstract

Emergency Plans play an important role in engineering emergency management. Evaluating the ability of the current resources reserve system is the first step of developing Emergency Plans, while the demand of affected areas are always different for different kinds and levels of the disasters. In this paper, we will present a multi-stage multi-objective evaluation model. Based on satisfaction function of resource, we consider both the amount and arriving time of resource arrived at each affected area. Because of the dynamic rescue process, the transportation scheme is multi-stage and we divide the emergency rescue period into three stages. Then a heuristic algorithm is proposed for the evaluation model. Computational results show both the model and algorithm are helpful when evaluating the ability of reserve resource system.

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Keywords: emergency resources serve system; engineering evaluation; multi-stage; multi-objective

1. Introduction

In recent years, many kinds of disasters either natural or human-made occurred frequently. Whether the SARS outbreak in 2003, south snowstorm and Wenchuan earthquake in 2008, or Japan’s magnitude 9.0earthquake and the tsunami caused by the nuclear explosion, and so on, all these disasters lead to heavy loss of human lives and properties. In order to prepare for the respond of disasters, and relieve the loss of the disaster, Emergency Plans are indispensable. Before developing Emergency Plans, evaluation of the ability for the current resource reserve system of the region is essential.

There are lots of researches on the layout of emergency resources and lots of better results. Lei Fang[1] puts forward a new nonparametric DEA model for resources allocation, to evaluate the performance of resources utilization during the emergency system according to the total relative efficiency. Qian Wang et al. [2] study a budget constrained location problem in which they simultaneously consider opening some new facilities and closing some existing facilities. The objective is to minimize the total weighted travel distance for customers subject to a constraint on the budget for opening and/or closing facilities and a constraint on the total number of open facilities desired. Mohan R. Akella[3] et al evaluating the reliability of automated collision notification systems in emergency management by models. Meiwen Wu et al.[4] provide four indexes about coveting and fire area of fire stations in a city to evaluate layout of fire stations in the city. And analyzed the indexes in detail, gave the related mathematic models. Yingying Yu et al. [5] propose a loss function based on time, resource supply and demand to evaluate the loss under a given resource distribution when different degrees of emergencies will occur. And an optimization
model is developed to adjust the current resource location and allocation when the loss is not accepted. To solve the evaluation problem of sites-setting for short wave air-to-ground communications, Wen Wu et al.[6] gave two evaluating indicators, coverage degree and coverage efficiency. And Grid scanning algorithm and Monte Carlo method are used respectively to calculate the two evaluating indicators. Libo Xi et al.[7] according to the task of military materials support system and formulating ride of evaluating index system, set up index system for military material support ability, studied BP network model to evaluate material support ability. In order to evaluation the allocation planning and service level of passenger stations in comprehensive transportation terminal, and to optimize the planning schemes, Yuan Tian[8] established a synthetic evaluation system by AHP theory based on planning harmony, the need of transportation terminal, the impact to environment and convenient transportation terminal. Meanwhile, the fuzzy evaluation was used in setting up the traffic impact system to appraise it. Based on the features of emergency logistics, Xiaolan Shi et al[9] establishes a hub-and-spoke-based dynamic network in the light of the idea of grading, step by step, with hub and ascription and brings forth a tripartite start-up mode according to the development tendency of emergency. Li Zhuang et al[10] discussed the evaluation criteria for the distribution of the fixed shelters in urban disaster, including main assessment points and the specification technical requirements, etc. And taking Qingdao as an example, analyzed the current problems of the fixed shelter’s layout. Aiming at the design discipline about optimizing earthquake relief transport, Pan Qiu et al[11] set up a model by introducing the theory minimum cost max-flow, and discussed the application of the theory into earthquake relief transport.

The remainder of this paper is organized as follows. We present the multi-stage multi-objective evaluation model in section2. Then a heuristic algorithm is proposed in section3. Finally, computational results are shown in section4 and draw a conclusion in section 5.

2. Multi-stage multi-objective evaluation model

After an emergency, emergency resources need to be transported to the affected areas from storage directly or indirectly. Especially in the initial stage the demand is greater than the supply, so rational scheduling of the limited emergency resources to achieve maximum aid effectiveness is very necessary. In this paper, we study in the rescue period, the ability of emergency resources (tents) reserve system.

Considering 3 stages, storages set $I$, affected areas set $J$, Hubs set $M$, and each Hub collects emergency resources from other storages that belong to the same administrative district (municipal). Main Hubs set $K$ (Main hubs choose from the hubs which is convenient and nearly to the affected areas), $M \subseteq I$, $K \subseteq I$, $M \cap K = \Phi$. The aim of emergency rescue is to transport tents to affected areas from storages directly or indirectly, made the utility of tents achieve to the maximum. In our model the central and the provincial storages are considered as the county storages, if the disaster is not serious enough to start the central or the province storage, they will not be considered, and omit the Save Points. After simplification, transportation network $\langle V, A \rangle$ $V$: vertices (storages, Hubs, Main Hubs), $A$: directed arcs set that from storages to Hubs or Main Hubs, Hubs to Main Hubs, Main Hubs to the affected areas.

2.1. Model assumptions:

1) Information system is reliable, and we can obtain every resource supply point and the demand of each affected area in every stage.
2) Relevant people can effectively evaluate the disaster weight coefficient of the affected area depends on casualties, economic losses of the affected area.
3) The satisfaction function of affected area: suppose demand point $d$, supply point $s$, the waiting time $[l, u]$, arrival time $t$; For a affected area, the satisfaction depends on both the amount and arriving time of resource:

$$g(t)$$

- When $t < l$, $g(t) = 1$;
- When $t > u$, $g(t) = 0$;
- When $t \in [l, u]$, let $g(t) = \left(\frac{u - t}{u - l}\right)^k$. When $S > D$,

$$w(S) = 1; \quad \text{When } S < D, \quad w(S) = \frac{S}{D}.$$ The expression of Satisfaction: $f(s, r) = w(S) \cdot g(r)$

2.2. Parameters
\[ n: \text{Stage number, the stage of the tent in the way, } n=1,2,3; \ n_s, n_o: \text{The start and the end time of the stage, } n=1,2,3; \]
\[ D_{jn}: \text{The } n\text{th stage, the total tent demand of the affected area } j, j \in J, n=1,2,3; \]
\[ S_i: \text{The total tent of the storage } i, i \in I; \]
\[ u_{jn}: \text{In stage } n, \text{ the dead line for tent of the affected area, } n=1,2,3; \]
\[ q_{jn}: \text{In stage } n, \text{ the disaster weight coefficient of the affected area } j; \]
\[ P_{ij}: \text{The path set from tent supply point } i \text{ to affected area } j, i \in I, j \in J; \]
\[ \tau_a: \text{The time of pass section } \alpha (\text{include loading and delivery time}), \alpha \in A; \]
\[ \Delta t_j: \text{The ready time of storage } i \text{ to send tent, } i \in I; \]
\[ \Phi_{jn}: \text{In stage } n, \text{ the storage and transport path combinations set that can arrive at the affected area } j; \]
\[ \alpha_n: \text{The stage weight coefficient, } 0 < \alpha_n < 1, \text{ and } \sum_{n=1}^{3} \alpha_n = 1, \quad \alpha_1 < \alpha_2 < \alpha_3; \]

2.3. Decision variables:
\[ x_{i,j,p}: \text{The tent number of the storage } i \text{ to affected area } j \text{ along the path } p, i \in I, j \in J, p \in P_{ij}; \]
\[ y_{jn}: \text{The total tent of affected area } j \text{ received in stage } n, j \in J, n=1,2,3; \]
\[ \delta_{ap}: 0-1 \text{ variables, if section } \alpha \text{ on the path } p, \delta_{ap} = 1, \text{ otherwise } \delta_{ap} = 0; \]

2.4. Model

From assumption (3) about the definition of satisfaction, we have the satisfaction of the stage \( n \) of affected area \( j \):

\[
\frac{1}{D_{jn}} \left[ \sum_{(i,p) \in \Phi_{jn}} x_{i,j,p} \left( \frac{u_n - \left( \Delta t_j + t_p \right)}{u_n - l_n} \right)^k \right]
\]

So the satisfaction of affected area \( j \) in the whole rescue period:

\[
Q_j = \sum_{n=1}^{3} \alpha_n \left[ \sum_{(i,p) \in \Phi_{jn}} x_{i,j,p} \left( \frac{u_n - \left( \Delta t_j + t_p \right)}{u_n - l_n} \right)^k \right] \frac{1}{D_{jn}} \sum_{n=1}^{3} \alpha_n = 1
\]

\[ q_{jn} = \alpha_n \frac{y_{jn}}{D_{jn}} \text{ is the safeguard rate of affected area } j \text{ in stage } n, \text{ by } q_n = \sum_{a} \frac{\sum_{j=1}^{J} \alpha_n y_{jn}}{D_{jn}}, \text{ and we can have the average safeguard rate of stage } n. \text{ According to } \sigma^2 = \sum_{j=1}^{J} \left( \frac{q_n - q_n}{\sigma_n^2} \right), \text{ we have the deviation of the safeguard rate between the whole emergency system and the average.} \]

The objective is to balance the safeguard rate between each affected area \( j \) in the whole system, and maximize the minimum satisfaction of affected areas:

\[
\min \max_{n \in [1,2,3]} \sigma_n^2 \]
\[
\max \min_{j \in J} Q_j
\]

s.t. \[ Q_j = \sum_{n=1}^{3} \alpha_n \left[ \sum_{(i,p) \in \Phi_{jn}} x_{i,j,p} \left( \frac{u_n - \left( \Delta t_j + t_p \right)}{u_n - l_n} \right)^k \right] \frac{1}{D_{jn}} \sum_{n=1}^{3} \alpha_n = 1 \quad (1) \]
\[
\sigma_n^2 = \frac{\sum_{j=1}^{n} a_j \cdot \frac{\sum_{i=1}^{m} x_{i,j} \cdot p_{ij}}{P_{ij}}} {j-1} \quad (2)
\]

\[
y_{j,n} = \sum_{(i,p) \in \Phi_{jo}} x_{i,jp} \quad (3)
\]

\[
\sum_{j \in J} \sum_{p \in P_{ij}} x_{i,jp} \leq S_j \quad (4)
\]

\[
\Phi_{jo} = \left\{(i,p) \mid p_s < A_t + t_p \leq n, \forall i \in I, p \in P_{ij}, j \in J, n = 1,2,3 \right\}
\]

\[
t_p = \sum_{a \in A} t_a \cdot \delta_{ap} \quad (6)
\]

\[
x_{i,jp} \geq 0 \quad (7)
\]

Constraints (1) the satisfaction of affected area \(j\); Constraints (2) the deviation of the safeguard rate between the whole emergency system and the average; Constraints (3) in stage \(n\) the total tent that affected area \(j\) received; Constraints (4) the total tents that each storage transports to the affected area is no more than its reserves; Constraints (5) In stage \(n\), the combination of storage and transport path that can arrive at the affected area \(j\); Constraints (6) the transportation time along the path \(p\); Constraints (7) variables negative;

3. Heuristic algorithm design

The basic idea of the algorithm is shown below. For any storage \(i\), its tents firstly are transported to the Hub that belongs to the same administrative district, then from Hubs to its nearest Main Hub. Considering both transportation time and the balance of safeguard rate between each affected area, tents in the Main Hubs are transported to the affected areas.

**Heuristic Algorithm:**

Step 1: According to the shortest path principle, storages transport tents to the affected area, and calculate safeguard rate of each affected area in stage \(n\), i.e. \(q_{jo} = \omega_{jo} \cdot \frac{y_{j,n}}{P_{j,n}}\), \(y_{j,n}\) is the total tents of the affected area \(j\) received in stage \(n\), \(P_{j,n}\) is the total tents that affected area \(j\) received from storages in \([n_s, n_e]\) \((n=1,2,3)\).

Step 2: Adjust the amount of tents that each affected area received in every stage, balance the deviation of the safeguard rate between them.

Step 1: \(n=1\), if \(\frac{\max_{j \in J} q_{j,n} - \min_{j \in J} q_{j,n}}{\Delta} > \varepsilon\), Choose the affected area \(j\) which has the maximum safeguard rate, and take out \(\lambda\) times of the group of tents which has the smallest contribution to the satisfaction of it, then according to the proportion of the satisfaction of these tents' contribution to other affected areas, distribute these tents to other affected areas; otherwise \(n=n+1\).

Step 2: Recalculate the safeguard rate of each affected area \(j\), then return to Step 1.

Step 3: Calculate the satisfaction of each affected area \(j\), the minimum satisfaction is the objective value of this model.

4. Computational results

Consider 2008 Wenchuan earthquake as an example, use the evaluation model and the Heuristic algorithm to analysis the ability of emergency resources (tents) reserve system, and verify the practical of the model and the algorithm. When Wenchuan earthquake happened, reserving tents in 10 central storages are shown below (The
loading time of storage is proportional to the number of tents that its reserves (take Tianjin loading time 12 h for the standard)):

Table 1. The amount of tents

<table>
<thead>
<tr>
<th></th>
<th>Single tent</th>
<th>Cotton tent</th>
<th>Total number</th>
<th>Loading time(h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tianjin</td>
<td>22050</td>
<td>7050</td>
<td>43200</td>
<td>12</td>
</tr>
<tr>
<td>Shenyang</td>
<td>16100</td>
<td>12200</td>
<td>52700</td>
<td>15</td>
</tr>
<tr>
<td>Haerbin</td>
<td>8000</td>
<td>5000</td>
<td>23000</td>
<td>6</td>
</tr>
<tr>
<td>Hefei</td>
<td>14000</td>
<td>1000</td>
<td>17000</td>
<td>5</td>
</tr>
<tr>
<td>Zhengzhou</td>
<td>39000</td>
<td>22200</td>
<td>105600</td>
<td>29</td>
</tr>
<tr>
<td>Wuhan</td>
<td>32540</td>
<td>9500</td>
<td>61040</td>
<td>17</td>
</tr>
<tr>
<td>Changsha</td>
<td>800</td>
<td>800</td>
<td>3200</td>
<td>1</td>
</tr>
<tr>
<td>Nanning</td>
<td>9000</td>
<td>0</td>
<td>9000</td>
<td>3</td>
</tr>
<tr>
<td>Chengdu</td>
<td>6000</td>
<td>0</td>
<td>6000</td>
<td>2</td>
</tr>
<tr>
<td>Xi’an</td>
<td>10500</td>
<td>0</td>
<td>10500</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 2. The time from storage to Chengdu

<table>
<thead>
<tr>
<th>Time(h)</th>
<th>Tianjin</th>
<th>Shenyang</th>
<th>Haerbin</th>
<th>Hefei</th>
<th>Zhengzhou</th>
<th>Wuhan</th>
<th>Changsha</th>
<th>Nanning</th>
<th>Xi’an</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chengdu</td>
<td>44</td>
<td>52</td>
<td>59</td>
<td>35</td>
<td>33</td>
<td>28</td>
<td>29</td>
<td>40</td>
<td>26</td>
</tr>
</tbody>
</table>

Table 3. The time from Chengdu to affected areas

<table>
<thead>
<tr>
<th>Time(h)</th>
<th>Wenchuan</th>
<th>Beichuan</th>
<th>Mianzhu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chengdu</td>
<td>15</td>
<td>15</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 4. The time from storage loading tents and through Chengdu conveyed tents to affected area: wenchuan, beichuan, mianzhu

<table>
<thead>
<tr>
<th>Time(h)</th>
<th>Tianjin</th>
<th>Shenyang</th>
<th>Haerbin</th>
<th>Hefei</th>
<th>Zhengzhou</th>
<th>Wuhan</th>
<th>Changsha</th>
<th>Nanning</th>
<th>Xi’an</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wenchuan</td>
<td>71</td>
<td>82</td>
<td>80</td>
<td>55</td>
<td>77</td>
<td>60</td>
<td>45</td>
<td>58</td>
<td>44</td>
</tr>
<tr>
<td>Beichuan</td>
<td>71</td>
<td>82</td>
<td>80</td>
<td>55</td>
<td>77</td>
<td>60</td>
<td>45</td>
<td>58</td>
<td>44</td>
</tr>
<tr>
<td>Mianzhu</td>
<td>68</td>
<td>79</td>
<td>77</td>
<td>52</td>
<td>74</td>
<td>57</td>
<td>42</td>
<td>55</td>
<td>41</td>
</tr>
</tbody>
</table>

Table 5. Different stage, demand of each affected area

<table>
<thead>
<tr>
<th>Demand(ten thousand)</th>
<th>Wenchuan</th>
<th>Beichuan</th>
<th>Mianzhu</th>
</tr>
</thead>
<tbody>
<tr>
<td>First stage(24hour after disaster)</td>
<td>1</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>Second stage(24hour- 72hour Golden relief)</td>
<td>1.0</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Third stage(72hour- Emergency period 10 days)</td>
<td>8</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

After Wenchuan earthquake, all of the central storages are started to transport tents to the affected areas, all the central storages as Hubs of the emergency logistics activities, Chengdu storage as the Main Hub to transport tents. Convenient to calculate, assuming the disasters weight coefficient of all affected area is 1, each stage’s waiting time limit is at a quarter and 3/4 time points of the duration, the parameter of the time satisfaction function $k = 2$ , and $\alpha_1 = \alpha_2 = 0.3, \alpha_3 = 0.4$ . Applying the above model and the algorithm calculate the results: Wenchuan and Beichuan’s satisfaction is 0.35, Mianzhu’s satisfaction is 0.44, three affected area at each stage have the same tents safeguard rate, i.e. the deviation is 0.

In guarantee Wenchuan, Beichuan, Mianzhu get the same tents’ safeguard rate, all disaster area choose its own nearest storages to transport tents, we can get Wenchuan’s satisfaction is 0.42, Beichuan’s satisfaction is 0.43,
Mianzhu’s satisfaction is 0.46, which, of course, these three satisfaction value cannot achieve at the same time. The relative difference between the satisfaction that calculated by the algorithm and upper limit value of the satisfaction: Wenchuan 16%, Beichuan 17%, Mianzhu 2%.

5. Conclusion

In this paper, we have introduced and studied the problem of evaluating the ability of the current emergency resources reserve system in developing Emergency Plan. Based on satisfaction function of resource, we consider both the amount and arriving time of resource arrived at each affected area, and satisfaction is considered as a way to evaluate the ability of the current emergency resources reserve system. In the future work, we will consider the capacity of the transportation network, and in a fee restriction to increase the tents of the storage, study the ability of the emergency resources reserve system.

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References