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Effectiveness Evaluation of Emergency Donations in Emergency Logistics Operation Based on FAHP

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Abstract. This paper focused on effectiveness evaluation of emergency donations in emergency logistics operation. Based on researches on key problems in emergency resources operation, an effectiveness evaluation index system of emergency donations was discussed and analyzed. Given the uncertainty, subjectivity and ambiguity of human knowledge in the index system, a fuzzy analytic hierarchy process (FAHP) was applied to accommodate the inherent uncertainty, and the effectiveness of emergency donations were calculated. Finally, a numerical example illustrating the application of this method to the effectiveness and ranking of emergency donations in logistic operation was given.

Keywords: Effectiveness of emergency donations, FAHP, Emergency logistics, Resource allocation, information matching platform

1. Introduction

China, as one of the world most affected area by natural disasters, infested by natural disasters very often in recent years. The survey found that in the disaster relief operation to large-scale natural disasters and emergency response to public events, donations' structural surplus and the shortage co-exist, and some donations are out of line with actual demand situation in the disaster area. The reason to these discordant phenomenons is that before the schedule of the resource allocation, the matching between the donated resource supply information and the affected area demand information is not taken into consideration, resulting in the ineffective operation in emergency logistics. On the other side, the decision making process of emergency resource allocation is a complicated one, decision-makers are uncertain about the results of their choices, and many factors are involved in making a resource allocation scheme, thus decision making of optimal allocation falls into the category of Multi-criteria Analysis (MA) problem.

In order to solve the problem, we propose to setup a platform for optimal information matching between affected areas and emergency donations. In this platform, the emergency donations of supply-side are classified and ranked by their effectiveness, and the optimal one will be selected according to the affected areas of demand -side, which are classified and ranked by their urgency degrees as well. Based on this optimal demand and supply information matching, the goal of scientific, effective and rational distribution of emergency resource will achieved. Thus how to evaluate the effectiveness and ranking of emergency donations is one of the key problems in the development of the optimal information matching platform.

In this paper, an attempt is made to further the understanding of the FAHP method introduced in Chang [2] and developed by Zhu et al. [2] which includes the utilization of the Extent Analysis method and the use of group decision-making in the FAHP. A redefining of the measure of emergency donations effectiveness was made which is able to be utilized in future studies. Sets of weights of emergency donations effectiveness

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were calculated. The structure of the rest of the paper is as follows. In Section 2, the details of the evaluating the effectiveness, and ranking and selecting of emergency donations are described, and an index system is proposed. In Section 3, the FAHP evaluation model is presented. In Section 4, the results of the FAHP analysis of the emergency donations' effectiveness evaluation case are illustrated. In Section 5, conclusions are given as well as directions for future research.

2. Index System of Emergency Donations' Effectiveness

2.1. Identification of the Emergency Donations Selection Problem

This section presents the details of the emergency donations problem investigated throughout this study. The problem concerns an affected area and its selection of the emergency donations to be adopted. This selection is an important decision, with a large proportion of risk and uncertainty tied up in the final choice. The key is to make the emergency demand characteristics and emergency donations' effectiveness definite.

Emergency resources include various resources such as human resources, material resources, financial resources, scientific and technological resources, information resources, services resources. Wang et al. [3] took snow storm happened in 2008 and the "5.12" Wechuan earthquake emergency management for case study, and analyzed the emergency resource demands and the classification about emergency resources. They suggested that based on the characteristics of emergency response, emergency resources has the characteristics of timeliness, completeness, flat malleable, sharing, seasonal and cyclical. Fu et al.[4] pointed out that during the management of donations in "5.12" Wechuan earthquake, the effective management of donated resource is the basic of response operation in a quickly and efficient matter. They suggested that the resource demand includes the quantity and quality of emergency resource, and the structure of demand. The quantity of emergency resource is the most important factor. The closer the number of donated emergency resource to the minimum required amount of resource demand, the more effective response operation result will be achieved. The quality of emergency resource means timeliness、accuracy of supply, resources, safety and cost. Therefore, the timeliness of emergency donations, the quantity and quality are also key factors to measure the effectiveness of emergency donations.

The structure of demand for emergency resource mainly refers to the demand structure between the various types of materials which using the ratio, such as number, between the indicators to describe. Different emergency situation often has different structure of demand, appears as different combination of emergency resource. Therefore, the structure of emergency resource is also an important indicator to measure the effectiveness of the donated supplies.

Qiao [5] suggested an index system for emergency demand classification, which is constituted by the bi-level specific indicators system as follows: up-level contains importance, scarcity and timeliness of the donations. In low-level : the importance of donations includes the importance of irreplaceable resource, prices, the extent and impact on emergency response, shortage cost; the scarcity of donations includes procurement, inventory shortage rate, supplier availability and the scheduling difficulty; the timeliness of donations includes requirements and demand stage.

2.2. The System of Emergency Donations' Effectiveness

The first stage of evaluating the emergency donations' effectiveness is the identification of the necessary criteria to be considered, which here is a consequence of a semi-structured interview with the headquarters of the emergency logistics operation (hereafter DM). Following discussion with the DM concerning the nature of the application and theory analysis in above paragraphs, it was decided to restrict the number of criteria to tow areas: time effectiveness and resource attribute (hereafter B1, B2), as Figure 1 illustrated.

Based on the above analysis, the system of emergency donations' effectiveness has shown in figure 1.

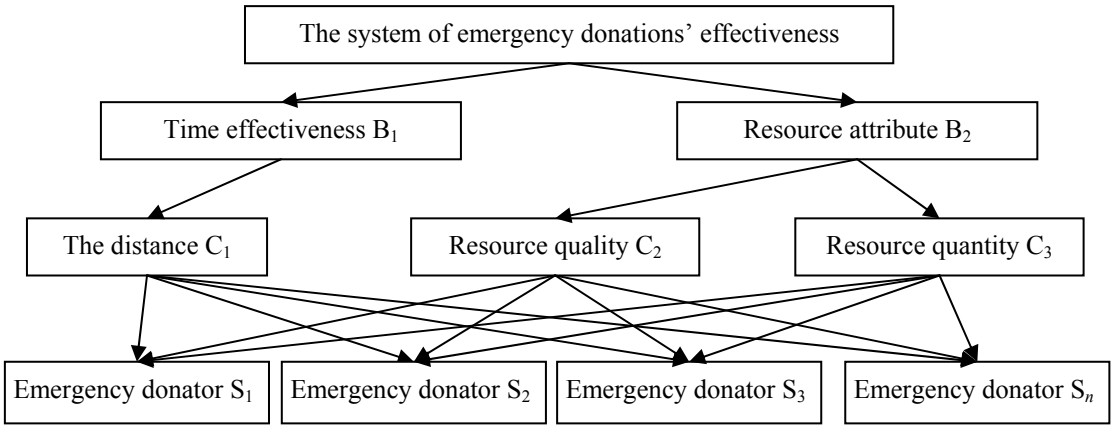

Fig. 1: The index system of emergency donations' effectiveness

In summary, the last indicators of the effectiveness of donated emergency resource are resource attribute and timeliness. Resource attribute includes the quality (hereafter C_2) and quantity (hereafter C_3), and timeliness appears as the distance (hereafter C_1). The following is the meaning of each indicator:

- resource quantity: the sum of certain emergency resource
- resource quality: specific requirement of the features of the emergency resource
- the distance: the distance between the donation's location and the affected area

3. Emergency Donations' Effectiveness Evaluation Based on FAHP

Given the timeliness and weak economy in emergency logistics operation, it is impossible to get full information of emergency donation resource to evaluate its utility timely, effectively and accurately, and impossible to find out which donator's donated emergency resource is the most optimal one. Since the incomplete affected area demand information, disaster types and period, and the descriptions given by personnel are all fuzzy or abstraction, emergency donation's effectiveness can be classified as unstructured or half structural problems. Thus, Analytic Hierarchy Process (AHP) as a multi-criteria decision technique can be applied by the combination of quantitative and qualitative analysis, in some certain extent, which really brings convenience to the evaluation solution. But in practical application, the traditional AHP is often criticized for its inability to adequately handle inherent uncertainty and imprecision associated with the mapping of the decision maker's perception to exact numbers [6].

In order to improve traditional AHP such as judge and consistent with the matrix by different consistency, consistency check and lack of scientific and so on problems in order to improve the reliability of this project, Thus a fuzzy AHP method is considered to tolerate vagueness or ambiguity, which is capable of capturing a human's appraisal of ambiguity when complex multi criteria decision making problems[7].

3.1. Problem Structuring

The first step of the proposed model is to determine all the important criteria and their relationship with the decision variables in the form of a hierarchy, in emergency donations' effectiveness case the construction of hierarchy is given in Figure 1. In this hierarchy construction, the goal is placed at the top of hierarchy, and the general criteria are placed at second level. The secondary sub-criteria with respect to each dimension are placed at third level.

3.2. Evaluation of Fuzzy Pair Wise Comparison

Once the hierarchy construction is established, the fuzzy pair wise comparison takes place. By the questionnaires gathered from selected experts, we obtained the relative importance of paired criteria factors at level $n+1$ under the evaluation of criteria at level n by individual experts' opinions, and the pair-wise comparison matrix was accordingly conducted.

Notes the aggregation of the price influence factors of emergency donations effectiveness as:

$$y = \{y_1, y_2 \cdots y_m\}$$

where, y_i is the i–th factor, $i = 1,2 \cdots m$, m is the number of impact factor .

Here the fuzzy comparison matrix is defined as:

$$Y = (y_{ij})_{m \times n}$$

where, $y_{ij} = \begin{cases} 0.5, s(i) = s(j) \\ 1.0, s(i) > s(j) \\ 0, s(i) < s(j) \end{cases}$, in which $s(i)$ and $s(j)$ respectively mean the relative important degree of the indicators y_i and y_j .

3.3. Reconstruct the Hierarchical Precedence Relation Matrix Y to Fuzzy Consistent Matrix R

If matrix $R = (r_{ij})_{m \times n}$ meets $r_{ij} = r_{ik} - r_{jk} + 0.5$, then it is called fuzzy consistent matrix. For this, sum each line in Y firstly to get the important degree of i –th factor corresponding other factor, noted as:

$$r_i = \sum_{k=1}^{m} y_{ik} \qquad (i = 1,2 \cdots m)$$

Then reconstruct as:

$$r_{ij} = \frac{r_i - r_j}{2m} + 0.5$$

The judgment matrix established as above can ensure that fuzzy consistency. In this paper we use MATLAB software to processing the data, and calculate the fuzzy consistent matrix. The programming codes are listed in appendix 1.

3.4. Hierarchy Layer Sequencing

Use the judgment matrix of fuzzy consistent matrix to calculate the importance order of hierarchical factors, and the weight indicator is normalized. Here, we use root method, take i as a factor in k hierarchy, p as a factor in $k-1$ hierarchy, and w_{pi}^k as the weight that factor i in k hierarchy to factor p in $k-1$ hierarchy. The procedures as follows:

First step: multiply the elements in R to get a new vector:

$$S_i = \prod_{j=1}^{m} r_{ij} \qquad (i = 1,2 \cdots m)$$

where, $i = 1,2 \cdots m$, m is the number of factors i in k hierarchy.

Second step: the new vector of each component open m power:

$$\bar{w}_i = (S_i)^{\frac{1}{m}}$$

Third step, the normalization of the vector gotten above is a weight vector:

$$w_{pi}^k = \frac{\bar{w}_i}{\sum_{j=1}^{m} \bar{w}_j}$$

Then, we get $w_p^k = (w_{p1}^k, w_{p2}^k, \cdots w_{pm}^k)^T$.

3.5. The Total Weight Calculation in Secondary Sub-criteria Level

Assuming that there are n hierarchies level in the hierarchy ladder structure, w_i ($i = n-1$) is the final weight of the factors in secondary sub-criteria level, p is one of the factors in k hierarchy, thus:

$$w_i = w_{pi}^n \times w_{pi}^{n-1} \times \cdots \times w_{pi}^1 \ (n-1 \geq k \geq 1)$$

3.6. Total Sort

Given the actual situation, the weight calculation formula is presented as following:

$$w_i^s = \frac{num_i}{\sum_i^m num_i}$$

where, num_i is the data that donor filled to a factor, m is the number of donors.

Thus, the comprehensive weight vector that the bottom hierarchy to the top one is

$$S_i = w_i^s \times \prod_{j=1}^{z} w_j$$

where, z is the number of the factors in n hierarchy of rule hierarchy)

And finally, sequencing according to the magnitude of S_i.

According to the information of donation, firstly normalize the data that the different donator filled to the same factor (distance from the disaster is excluded, which is normalized by the numerical inverse instead of expert scores), and then using FAHP model to calculate the value of each emergency donation's effectiveness.

4. Empirical Results

Here, we take four quilt donations in earthquake for example. In this case, the construction of hierarchy is given in figure 1. Questionnaires gathered from selected experts, authority offices and affected people is 50%, 40% and 10% respectively. Apply the FAHP model mentioned above, we get the weight of each factor as following:

{ timeliness, material attribute } = {0.6554, 0.3446}

{ material quantity, the quality of goods } = {0.5217, 0.4783}

{ timeliness, material quantity, the quality of goods }={0.6554, 0.1798, 0.1648}

Four quilt-manufacturing companies (note as A, B, C, and D) donate the quilt. The donated quilt information listed in table 1.

Table 1: Emergency Donations Information of Quilt-manufacturing

donator	distance	resource quantity	resource quality
A	1000	4000	qualified
B	400	8000	qualified
C	300	7000	qualified
D	400	2000	qualified

Then the emergency donations effectiveness sequence is {C, B, A, D} = {0.4432, 0.3971, 0.2646, 0.3458}, which means that in emergency logistics operation of the empirical case, we should assign the supply mission to the C company first due to its highest effectiveness.

5. Conclusion

In this paper the emergency donations' effectiveness evaluation problem in emergency logistics operation was discussed. Firstly, based on the analysis of emergency donation resource's demand characteristic, an index system of emergency donations' effectiveness was constructed. Secondly, FAHP method was applied, and calculation algorithms were designed to get each indicator's weight which provided the basis of the final result. Finally, a case study was conducted to illustrate the applicability and potential advantages of the proposed method.

Nevertheless, there is still a great potential for improving the scheme of emergency resource allocation problem. One extension is to consider more affected area in emergency logistics resource allocation.

Furthermore, the urgency degree of demand for emergency resource in disaster affected area should be taken into consideration.

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