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# Emergency Supply Chain Management Based on Rough Set – House of Quality

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**Abstract:** Due to the frequent occurrence of various emergencies in recent years, people have put forward higher requirements on the emergency supply chain management. It is of great significance to explore the key management indicators of emergency supply chain for its management and efficient operation. In order to reveal the essence of emergency supply chain management, production, procurement, distribution, storage, use, recycling and other emergencies, supply chain links are considered to establish an emergency supply chain management index system to identify the key influencing factors in the emergency supply chain. The emergency supply chain involves many management elements and the traditional qualitative analysis and comprehensive evaluation methods have their shortcomings in practice. In order to get a more suitable method, a novel evaluation model is proposed, based on Rough set – house of quality method. In this paper, Rough set is used to filter the indexes, eliminate redundant indicators, and simplify many management indicators of the emergency supply chain system to a few core indicators. Then, the house of quality is used to analyze and sort the core index to get the key management index of emergency supply chain. The effectiveness of the proposed evaluation model is validated through a series of numerical experiments. The experimental results also show that the proposed evaluation model can assist decision makers in optimizing the emergency supply chain procedure and improving the efficiency of accident rescue.

**Keywords:** Emergency supply chain, Rough set, House of quality, management indicators, attribute reduction.

## 1 Introduction

In recent years, because of the many devastating disasters that have occurred in populated regions of the world, there has been an increased focus on the management effectiveness of emergency supply chains[1]. Different from general supply chain management, emergency supply chain poses higher requirements on material preparation, route planning and environmental adaptation. It also contains prominent characteristics such as paroxysm, unpredictability, strong timeliness, high synergy and multi-resource emergency dispatch. Emergency supply chain is a dynamic network with rapid response to environmental changes. Participating members should be agile enough to make the flow of information quickly reacted and processed, and logistics delivered efficiently. Emergency supply chain should take the time efficiency as the core and timely respond to the disaster requirements to meet the needs of the people in the disaster area and reduce the loss of person and property. It also guarantees rapid, sustained, high quality emergency supplies and minimizes social losses, all of which increase the management difficulties. As a result of this complexity, there has been increased focus on efficient methods to extract useful information from the many emergency supply chain indicators to ensure that demands are met in fuzzy, complex emergency events. If clear key management indicators can be identified, problems within the emergency supply chain can be solved, improving the overall effectiveness of emergency supply chain management to efficiently meet demand in the affected areas and communities. Therefore, research on emergency supply chains can improve supply chain management to better meet the needs of the affected.

Supply chain management and emergency supply chain management have been concerned by management and logistics scholars for long. Seuring and Müller[2] reviewed the research from the perspective of sustainable supply chain management. Xu et al.[3] combined data envelopment analysis and Rough set theory to develop a rough data envelopment analysis model to study the operational efficiency of the supply chain network. Shi et al.[4] applied Rough sets and a back propagation neural network to a supply chain performance evaluation to improve supply chain management. Guo and Zhu[5] used a fuzzy Rough set method to evaluate the performance of a logistics supply chain. Bai and Liu[6] used a house of quality model to translate customer demand into logistics resource elements to assist enterprises improve logistics service quality.

Ma et al.[7] studied emergency characteristics and established an emergency supply chain management model. Chen[8] introduced synergetic theory into emergency sup-

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ply chain management. The collaborative management framework of emergency supply chain was designed from strategic, tactical and technical levels. He believes that emergency supply chain collaborative management can promote the integration of emergency resources. Xu et al.[9] studied an emergency supply chain reliability evaluation model under uncertain conditions using an analytic hierarchy process, entropy method and other methods. Hong et al.[10] focused on the design of emergency relief supply chain. The emergency relief supply chain (ERSC) design framework was proposed by simultaneously considering total logistics cost, risk level and amount of demands covered in an ERSC. The authors established a goal programming model to distribute emergency relief items to affected locations. He et al.[11] presented an optional contract model of service supply chain for emergencies which was based on the review of service properties for emergencies such as an early order in advance and a short implementation time. It provided accurate decision guidance for emergency service supply chain. Zheng and Ling[12] believed that emergency transportation was the most important part of disaster relief supply chain operations. They proposed a multi-objective fuzzy optimization problem of emergency transportation planning in disaster relief supply chains. They developed a collaborative optimization method and constructed a complete solution, which greatly improved the performance of emergency transportation planning in disaster management. Zheng et al.[13] surveyed the application of evolutionary algorithms in disaster relief operations. Several advanced methods were compared in a set of practical examples of emergency transportation problems to effectively plan and arrange relief operations, save lives and reduce disaster losses. Alem et al.[14] constructed a new two-stage stochastic network flow model from the perspective of emergency logistics planning and operational challenges to provide humanitarian aid to victims of a disaster within this context.

## 2 Emergency supply chain management research model and index system

### 2.1 Research model analysis

The common qualitative evaluation methods, such as Delphi method and experts grading method, have their advantages. However, if a certain qualitative evaluation method is used alone, because of less quantitative data and more qualitative components, the objectivity of research results is not strong enough to be convincing.

There are many other comprehensive evaluation methods. The commonly used methods include analytic hierarchy process (AHP), data envelopment analysis (DEA), fuzzy comprehensive evaluation (FCE), back propagation (BP) neural network[15−18]. Although these traditional methods contain their own characteristics, most of them cannot be applied to solve the problem of emergency supply chain management in special environment. For example, AHP is not objective enough and the comparison and judgment process is rough, so it cannot be used in decision-making problems with high accuracy[19]. DEA is very sensitive to data and valid decision unit provides less information[20]. FCE cannot effectively solve the problem of information duplication among the evaluation indexes. The process of determining the membership function is too complicated and the practicability is weak[21]. BP neural network requires a large number of training samples and the accuracy of the calculation is not high[22, 23].

As emergency supply chain index systems are complex due to management impact factor diversity, it is often difficult to identify the scientific criteria. Because of time and resource limitations, it is more difficult to effectively operate and manage the overall emergency supply chain. In view of this and based on previous emergency supply chain research, this paper proposes a Rough set – house of quality (RS-HOQ) model. The main advantages of this model are as follows:

1) Fuzzy evaluation and other related methods need to determine the membership function of index with the help of prior data, while the Rough set (RS) is not needed and the evaluation process is simplified. In addition to dealing with quantitative indicators, it can also effectively deal with uncertainty and qualitative indicators[24]. It is a large amount of work to use the house of quality (HOQ) alone. However, the powerful attribute reduction function of RS reduces the workload for the index analysis of HOQ and increases the objectivity of HOQ and improves the efficiency and accuracy of the model.

2) There is still a complex relationship between the indexes after the rough set selection, and the relationship between the indexes can be clearly given through HOQ[25]. The importance ranking can better support decision-making and use the model for emergency supply chain management.

3) The RS-HOQ model combines RS theory with HOQ theory, which avoids the limitations of RS and HOQ and effectively exerts their advantages[26]. Because RS-HOQ model integrates identification, reduction, filtering, information processing and sorting, it improves the responsiveness and synergy of the entire emergency supply chain system.

### 2.2 Research model construction

Emergency supply chains are focused on the demands that arise in natural disasters and other emergencies such as explosions or building collapses[27]. Consequently, emergency supply chains have significantly higher requirements than ordinary industrial supply chains, because it is essential that they provide fast, efficient, economic and environmental protection services[28]. Emergency supply chain management research models are based on the input of several management indicators. First, the management index dimension is reduced using a rough set based on a rough set attribute reduction algorithm, which reduces the influence of the subjective factors, streamlines the index system and determines the streamline index weights. The house of quality model is then used to assess and rank the key indicators, allowing for better focused emergency supply chain management. This ranking of the key indicators can provide a valuable reference for emergency supply chain management optimization and quality emergency services. The model is shown in Fig. 1.

## 2.3 Index system construction

Emergency supply chain management research is necessary to identify the importance of the many factors that influence efficiency and effectiveness and to determine the key factors for management optimization. Therefore, the establishment of an index system is an important precondition for emergency supply chain management. Research results from data and supply chain management evaluation systems were used[29–31] for an in-depth analysis of emergency supply chain demand based on systematic and important principles and a combination of qualitative and quantitative elements to establish the index system[32]. Then, considering the characteristics, influencing factors and actual emergency situations of the emergency supply chain, a subsystem is constructed. This subsystem includes six elements: production, purchase, transportation, storage, use and recovery. It covers eighteen emergency supply chain management indicators[33]. The selection of emergency supply chain management index is as follows:

1) Due to the uncertainty, timeliness and lagging characteristics of emergency supplies, government should be able to effectively integrate emergency resources when the emergencies take place. Partners can dynamically collaborate with them to ensure suppliers' timely delivery[34]. It also requires the firm to possess a strong strain ability, quick response ability, emergency production capacity and punctual delivery capability. Therefore, following indicators are selected: Emergency material supply rate, emergency product development and improvement ability, emergency production flexibility, emergency purchase agreement rate, material purchasing time flexibility, guaranteed ability of the agreement enterprise.

2) If the emergency material is not available in the beginning, it may lose its value or cannot be used effectively. This is a requirement on transportation link.

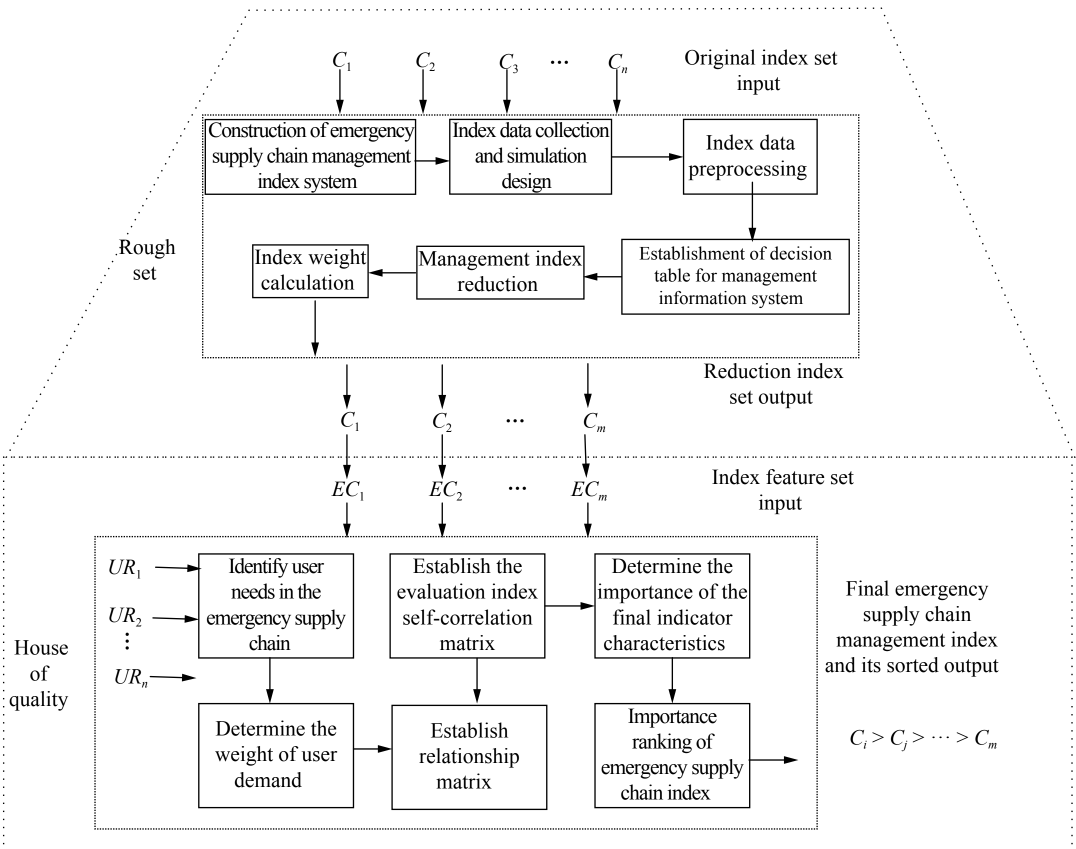


Fig. 1 Emergency supply chain management RS-HOQ based model

What's more, efficient operation of the emergency supply chain transport link means is that the emergency supplies can be delivered quickly and smoothly. Therefore, the following indicators should be concerned: timeliness of materials delivery, emergency supply chain node material throughput efficiency, transport route planning capability, damaged traffic network reopened rate.

3) Unexpected events are uncertain about the quantity, location and type of the demand for emergency supplies. Some emergency supplies such as blood and vaccine may not be replaced and the government reserves are needed to play their role[35]. In addition, the supply side of emergency supply chain is pluralistic and disorderly. If the material is not integrated and transported directly to the disaster area, this will cause the waste of materials, the low efficiency of distribution and the confusion of management. Therefore, the management of government reserve ratio, storage material wastage rate and storage management and big data level is very important.

4) The demand for emergency supplies in the disaster area is dynamic. In order to reduce waste and save manpower, material and financial resources, strengthen the utilization of resources and the protection of the environment[36], the decision-makers should pay attention to the factors such as emergency material utilization rate and emergency materials repair and replacement ratio. In addition, there are many factors which are easily ignored by the traditional emergency supply chain management, such as return product damage degree, recovery cost, and hazardous waste safe transportation capacity. The index system model is shown in Fig. 2.

## 3 Theoretical foundation

### 3.1 Evaluation index selection and management analysis based on Rough sets

The index system model considers many influential emergency supply chain management factors. To quickly identify the most important indicators and to eliminate the non-critical indicators, Rough set theory is used to deal with the uncertain information to reduce the index set in the above model. To reduce the complexity of the indicators, HOQ is used.

Rough set theory is a data mining tool first proposed by the polish mathematician, Pawlak, in 1982[37]. It has been consequently used for quantitative analyses and the processing of fuzzy, inconsistent or incomplete information to unearth the hidden knowledge in the information and to find suitable rules. Rough set theory takes the information system as the research object and is based on a classification mechanism. It starts with the observation data from a given problem, after which an approximate classification is determined by reducing the knowledge based on the equivalence relations in a certain space, which constitutes the division of the space. Attribute dependency and importance principles are then applied to reduce index redundancies, with the attribute index importance after the reduction being the index weight. Finally, an effective attribute set reduction is realized. As Rough set theory only uses the data set provided by the problem itself, it is more objective when seeking to describe and deal with a problem[38].

#### 3.1.1 Management index pretreatment

1) Index data standardization

As the dimensions and orders of magnitude of the data differ, the index data is not comparable, leading to calculation errors. To avoid this problem, the data needs to be standardized before data processing. The general index includes a benefit index, in which a larger value is considered better (see Fig. 2, $C_{11}$, $C_{32}$, etc.) and a cost index, in which a smaller value is better (see Fig. 2, $C_{42}$, $C_{52}$, etc.). This paper used an extreme value and (1) to standardize the original index data to [0, 1].

$$y_{ij}=\begin{cases}\dfrac{x_{ij}-\min x_j}{\max x_j-\min x_j}, ① \\ \dfrac{\max x_j-x_{ij}}{\max x_j-\min x_j}, ②\end{cases} \tag{1}$$

In (1), $x_{ij}$ represents the data value corresponding to the item $j$-th index in the $i$-th material reserve library and $\max x_j$ and $\min x_j$ are the maximum and minimum values of the index data within the scope. ① represents the benefit index, ② represents the cost index.

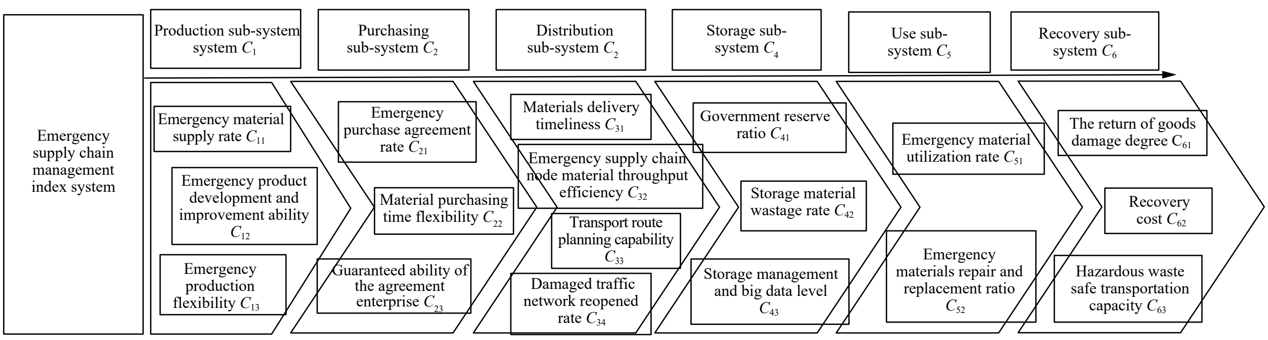

Fig. 2 Emergency supply chain management index system model

2) Index data discretization

The characteristics of rough sets mean that they are only able to deal with discrete data. However, in the emergency supply chain management index information system, there are both discrete and continuous type indexes. To ensure that the index system is consistent, data discretization of the continuous index is required. There are many index data discretization methods that can be used such as equal width discretization, equal frequency discretization, information entropy, hyper plane method and others[39]. In this paper, based on the properties and characteristics of the management index, the continuous condition attributes in the sample data were processed using equal width discretization. The segmentation point was defined using (2). In (2), "1" represents unimportant and "2" represents important.

$$\mu_{ij} = \begin{cases} 1, \ 0 \le \mu_{ij} \le 0.5 \\ 2, \ 0.5 < \mu_{ij} \le 1. \end{cases} \tag{2}$$

### 3.1.2 Rough set theory analysis

1) Management information system

Set the number of emergency supply chain management indicators as $n$. After the pretreatment of the index data, establish the emergency supply chain management information system: $S = \langle U, A, V, F \rangle$[40], in which $U$ is the discourse domain.

In this paper, $U$ is a finite non empty set of objects composed of $T$ relief material reserves. $U = \{x_1, x_2, x_3, \cdots, x_t\}$ and $A$ is an object attribute set made up of finite non null attributes related to $n$ management indicators. $A = \{a_1, a_2, \cdots, a_n\}, A = C \cup D, C \cap D = \varnothing$. $C$ is an index attribute set, $D$ is a set of decision attributes, $V$ is the range of index attribute $A$, so $F : U \times A \to V$ is a management information function. $f(x_i, a) \in V_a, \forall x_i \in U$, $\forall a \in A$ defines the data value for each disaster relief material reserve $x_i$ under management index $a$[41].

The management information system can be constructed as a two dimensional index information decision table, from which the resolution matrix can be determined. As the resolution matrix is a $n$ order square matrix on the main diagonal symmetry, the upper (lower) triangular matrix is considered in the computation.

2) Non distinguishable relations

In management information system $S$, the definition for each index attribute subset $B \subseteq A$ is a non-distinguishable relation $ind(B) : ind(B) = \{(x, y) \in U \times U \,|\forall b \in A, f(x, b) = j(y, b)\}$. This binary equivalent non-resolution relation $ind(B), B \subseteq A$ constitutes a division of $U$, denoted as $U/ind(B)$.

3) Lower and upper approximation

For the non-distinguishable relation $ind(B)$, the lower approximation of set $X$ when $X \subseteq U$ is defined as $\underline{B}(X) = U\{Y \in U/ind(B) \,|Y \subseteq X\}$. The upper approximation is defined as $\overline{B}(X) = U\{Y \in U/ind(B) \,|Y \cap X \ne \varnothing\}$.

On this basis, the positive region for set $X$ is defined as $Pos_B(X) = \underline{B}(X)$ and the negative region is defined as $Neg_b(X) = U - \overline{B}(X)$, with the boundary region being $Bn_B(X) = \overline{B}(X) - \underline{B}(X)$[42].

4) Rough set index reduction

Let $B$ be a family of equivalence relations, and $b \in B$, if

$$ind(B) = ind(B - \{b\}). \tag{3}$$

That is, when removing equivalence relation $b$, its non-distinguishable relation remains unchanged, so $b$ is the redundant attribute of $B$, and needs to be reduced. On the contrary, $b$ in $B$ is a necessary indicator. This is the main basis for judging whether an emergency supply chain index is important. If $\forall b \in B$ is necessary for $B$, then $B$ is independent, otherwise $B$ is dependent. If $E \subseteq B$, $E$ is independent, $ind(E) = ind(B)$, then $E$ is a reduction of $B$. The intersection of all reductions of $B$ constitutes the kernel of $B$: $core(B)$.

5) Importance and weight

To determine the importance of the $P$ indicators after screening in the management information system $S$, the definition for the importance of the index attribute $D$ for $C$ is

$$K_{c_j} = \frac{card(Pos_C(D)) - card(Pos_{\{C - c_j\}}(D))}{card(U)}. \tag{4}$$

If $K_{c_j}$ is larger, this indicates that the attribute for $C_j$ is more significant to the emergency supply chain decision attribute. If $K_{c_j} = 0$, then the index has little influence on the management decisions in the emergency supply chain. Therefore, it can be reduced from a conditional attribute set $C$ and is not given a weight. In the formula, $card(*)$ represents the number of elements in the collection *.

The weight of the index attribute $C_j$ is

$$w_{c_j} = \frac{K_{c_j}}{\sum\limits_{j=1}^{p} K_{c_j}}, \ (j = 1, 2, \cdots, p). \tag{5}$$

## 3.2 Emergency supply chain management optimization model based on HOQ

The quality function deployment[43] (QFD) takes the customer or market demand as the starting point, and then, using a series of graphics, the enterprise product quality evaluation method can be used to fully meet customer requirements, improve customer satisfaction and reduce production costs. The HOQ demand conversion method and QFD matrix structure tools are the core of QFD. To date, HOQ has been widely used in the manufacturing and software industry[44] and has not been widely applied to emergency supply chains. In this paper, however, the HOQ is applied to the emergency supply chain in combination with the rough set reduction index system. The emergency supply chain management HOQ model is established from five aspects: Emergency supply chain demand, the extraction of the characteristics for the management index, determining the self-correlation matrix for the index characteristics, and determining a relationship matrix between each management index, customer demand and the house of quality construction. The model is shown in Fig. 3.

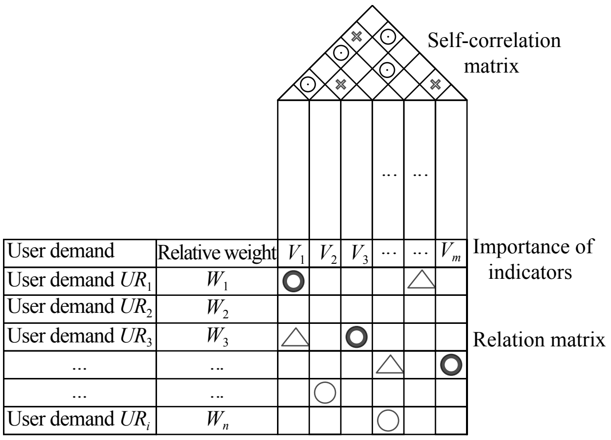


Fig. 3 Basic model for the emergency supply chain management HOQ

The ultimate goal of this model is to use the HOQ tool to assist in the evaluation of the emergency supply chain factors to identify the associations and conflicts. Management and control of the critical factors in the emergency supply chain are strengthened and optimized as the target values, so that overall user satisfaction is optimized. The selected high satisfaction evaluation indicators are ranked from high to low to focus the emergency supply chain management and control the object optimization[45].

#### 3.2.1 Parameter symbol description

Set user requirements (UR) in the HOQ as $n$, and there are $m$ engineering characteristics (EC) after the reduction of the management indicators.

The HOQ model parameters are described as follows:

1) $UR_i$: the emergency supply chain related to the end-user's $i$-th need $(i = 1, 2, \cdots, n)$.

$EC_j$: the characteristics of the $j$-th emergency supply chain management index after reduction $(j = 1, 2, \cdots, m)$.

2) $R$: the relationship matrix between emergency supply chain end-user requirements and the management index characteristics, which is the main part of the HOQ model.

$R_{ij}$: the correlation coefficient between the $i$-th end-user demand $UR_i$ and the $j$-th process evaluation index $EC_j$ in relationship matrix $R_{ij}$.

3) $P$ : the self-correlation matrix for the index characteristic.

$P_{hk}$: the self-correlation coefficient between $EC_h$ and $EC_k$.

4) $W$: the relative weight vector for user demand $UR$.

$W_i$: the relative weight for the user demand in the $i$-th emergency supply chain, for which, $0 < W_i < 1, \sum_{i=1}^{n} w_i = 1$.

5) $V^*$: the absolute weight vector for the management index characteristic $EC_j$.

$V_j^*$: the absolute weight value for $EC_j$ .

6) $V'$: the absolute weight vector for the modified management index characteristic $EC_j$.

$V_j'$: the absolute weight for the modified $EC_j$.

7) $V$: the relative weight vector for management index characteristic $EC_j$.

$V_j$: the relative weight for $EC_j$.

#### 3.2.2 User demand *UR* and its weight determination

To build the left wall of the HOQ, first determine the emergency supply chain user demand $UR$, and then, based on this determination, use the expert scoring method to calculate the user demand weight vector $(W_1, W_2, \cdots, W_n)$. The $i$-th weight for user demand $W_i$ is the ratio of the $i$-th user′s demand score and the sum total of each user′s demand:

$$W_i = \frac{UR_i}{\sum\limits_{i=1}^{n} UR_i}. \qquad (6)$$

#### 3.2.3 Establish relation matrix

The relationship matrix shows the correlations between user demand $UR$ and the evaluation index characteristic $EC$. The relative degrees in a relation matrix are generally defined as: ◎: strong correlation, ○: medium correlation, △: weak correlation, Blank: no correlation. According to the strong and weak relationship matrix; when the relationship between $UR_i$ and $EC_j$ is strong, the correlation is $r_{ij} = 9$; when the relationship between $UR_i$ and $EC_j$ is medium, the correlation is $r_{ij} = 3$; when the relationship between $UR_i$ and $EC_j$ is weak, the correlation is $r_{ij} = 1$; and when there is no relationship between $UR_i$ and $EC_j$, $r_{ij} = 0$.

#### 3.2.4 Establish the evaluation index self-correlation matrix

The management index is the foundation for the establishment of the self-correlation matrix. The self-correlation matrix shows the correlation and influence of each evaluation index on emergency supply chain management. The self-correlation relationship between the indexes can influence the HOQ model as it represents the HOQ roof. The correlation for the self-correlation matrix $P$ is generally defined as: ⊙: positive correlation, $X$: negative correlation, Blank: uncorrelated.

When $j = k$, $EC_j$ with its own degree of correlation is the largest, so $p_{ij} = 1$. The self-correlation matrix is a set of symmetric matrices, $p_{jk} = p_{kj}$. When $j \neq k$, if $EC_j$ and $EC_k$ are independent, then $p_{jk} = 0$. If the relationship between $EC_j$ and $EC_k$ is positively correlated, then $p_{jk} > 0$, and if the relationship between $EC_j$ and $EC_k$ is negatively correlated, then $p_{jk} < 0$.

#### 3.2.5 Determination of the importance weights for management index *EC*

Based on the relative weight $W$ obtained from $UR$ and the relationship matrix $R$, the absolute weight vector $V^*$ for management index characteristic $EC$ can be determined[46]:

$$V^* = R^{\mathrm{T}} W. \tag{7}$$

To obtain the absolute weight value $v_j^0$ for $EC_j$:

$$v^*{}_j = \sum_{i=1}^{m} w_i r_{ij},\ j = 1, 2, \cdots m.$$

As the self-correlation between the $EC$ index characteristics affects the $EC$ weight, the weight calculations should be modified to eliminate any influences, so that the absolute weight vector $v'$ for the modified $EC$ can be determined:

$$V' = P^{\mathrm{T}} V^* = P V^*. \tag{8}$$

Calculate the relative weight $V$ for the emergency supply chain evaluation index characteristics $EC$, which are the management indicators′ importance degrees.

Based on these extracted importance degrees, the emergency supply chain management indicators are ranked from large to small:

$$v_j = \frac{v'j}{\sum_{j=1}^{m} v'{}_j}, 0 \le v_j \le 1, \sum_{j=1}^{m} V_j = 1, j = 1, 2, \cdots m. \tag{9}$$

### 3.3 Emergency supply chain process management research steps

**Step 1**. Establish the index system (Fig. 2).

**Step 2**. Data were collected and example was designed for the article.

**Step 3**. The data of the example are standardized and discretized.

**Step 4**. Establish a decision table for the domain related to the relief material reserve decision information. The emergency supply chain index system is used as the attribute set for the decision table. To improve the corresponding attribute value, the data is processed, and the emergency supply chain management information system decision table is established.

**Step 5**. The index is reduced using the RS attribute reduction principle.

**Step 6**. Determine the indicator and weight importance.

**Step 7**. Establish a new index system after simplification.

**Step 8**. Determine the HOQ user needs and determine the weight.

**Step 9**. Establish the user demand $UR$ relationship matrix and the management index $EC$. Establish the $EC$ self-correlation matrix and construct the emergency supply chain management house of quality (Fig. 3).

**Step 10**. Determine the weight of the index characteristics.

**Step 11**. Determine the management index characteristic importance ranking, from which the final emergency supply chain key management indicators are extracted.

## 4 Numerical experiments

### 4.1 Study of a regional situation and an example design

After the "5/12" Wenchuan earthquake disaster, the Sichuan Province relief materials supply was inadequate and the materials distribution was slow and poorly executed, causing significant difficulties in the emergency response. Because of these difficulties, Sichuan Province developed a "Master plan for restoration and reconstruction after the Wenchuan earthquake" to ensure that there was an adequate disaster emergency relief materials reserve system from "distribution" to the "network". At present, Sichuan Province has built a central disaster relief material supply center. It has established twenty municipal level and 146 county level relief supplies reserve centers. Sichuan Province has also built nearly 800 village level relief supply reserves centers in natural disaster prone villages and remote towns[47].

This article assumes a sudden earthquake disaster in Ganluo County, Liangshan Yi Autonomous Prefecture in Sichuan Province which would require a great deal of disaster relief personnel and supplies[48]. However, there are serious shortages in the Ganluo County relief material storage supplies. Surrounding Ganluo County, there are ten large municipal relief material storage facilities to provide the supplies needed for rescues, medical needs, sustenance and other relief supplies in case of a Ganluo disaster. These ten relief materials storage are in Ya'an (180.2 km traveling distance), Leshan (193.2 km), Meishan (300.1 km), Zigong (305.9 km), Liangshan Yi Autonomous Prefecture (245.8 km), Panzhihua (438.6 km), Yibin (332.3 km), Luzhou (420.4 km), Neijiang (445.3 km) and Ziyang (390 km). These ten relief materials reserve banks are taken in this case study as the research focus for the emergency disaster relief supply chain management ability evaluation. The data in this paper was taken from Sichuan government website and related documents, emergency relief news reports, logistics industry databases and books, previous research data, and from hypothesis and simulation[49]. The data is shown in Table 1.

## 4.2 Data processing and establishment decision table

Using (1) and Table 1, the data was processed, standardized and normalized for discrete processing, after which discretization was conducted. Formula (2) was then used to define the segmentation points to finally determine the discretization width.

Ten relief materials storage areas were selected as the research objects with the domain $U, U: x_i, (i = 1, 2, \cdots, 10)$. Each first-class management indicator $C_i, (i = 1, 2, \cdots, 6)$ represented the $i$-th process in the emergency supply chain, and $C_{ij}, (i = 1, 2, \cdots, 6,\ j = 1, 2, 3, 4)$ was the second-class index attribute corresponding to each level's indicator. Decision attribute set $D$ indicated the importance degree of the supply chain management indicators for the selection of the reserves. $D = \{1, 2\} = \{\text{Unimportant, important}\}$. From the standardization of the data table and the discrete processing, the management information system decision table was established, as shown in Table 2.

## 4.3 Rough set attribute reduction

Based on Table 2, (3) and (4) were used to reduce the attributes in the decision table and calculate the equivalence classes for the decision attributes and the condition attributes:

Table 1 Original data for Sichuan Province Ganluo County emergency relief supply chain management evaluation

| Index | Production sub-system $C_1$ | | | Purchasing sub-system $C_2$ | | | Distribution sub-system $C_3$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Emergency material reserve center | Emergency material supply rate (%) | Emergency product development and improvement ability (Ten point system) | Emergency production flexibility | Emergency purchase agreement rate (%) | Material purchasing time flexibility (Ten point system) | Guaranteed ability of the agreement enterprise (Ten point system) | Timeliness of materials delivery (%) | Emergency supply chain node material throughput efficiency | Transport route planning capability (Ten point system) | Damaged traffic network reopened rate (%) |
| | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{21}$ | $C_{22}$ | $C_{23}$ | $C_{31}$ | $C_{32}$ | $C_{33}$ | $C_{34}$ |
| Ya'an | 85.00 | 5.80 | 0.60 | 88.00 | 7.40 | 6.50 | 84.32 | 76.00 | 9.00 | 88.00 |
| Leshan | 83.00 | 4.70 | 0.75 | 79.00 | 9.00 | 4.00 | 68.00 | 73.00 | 8.70 | 74.00 |
| Meishan | 89.00 | 6.90 | 0.62 | 87.00 | 7.00 | 6.20 | 78.00 | 80.00 | 7.00 | 80.00 |
| Zigong | 83.00 | 4.70 | 0.66 | 93.00 | 8.10 | 4.70 | 75.00 | 69.30 | 7.50 | 61.00 |
| Liangshan | 77.00 | 3.60 | 0.70 | 90.00 | 8.10 | 5.00 | 73.00 | 65.00 | 8.00 | 66.00 |
| Panzhihua | 84.00 | 6.00 | 0.60 | 87.00 | 7.20 | 6.00 | 73.00 | 75.00 | 5.80 | 75.00 |
| Yibin | 82.00 | 4.70 | 0.55 | 88.00 | 8.00 | 4.00 | 75.00 | 80.00 | 7.00 | 75.00 |
| Luzhou | 79.00 | 3.30 | 0.70 | 79.00 | 7.00 | 5.80 | 80.61 | 72.00 | 5.50 | 70.00 |
| Neijiang | 77.00 | 4.50 | 0.60 | 88.00 | 7.10 | 4.40 | 66.00 | 82.00 | 5.50 | 75.00 |
| Ziyang | 80.00 | 3.30 | 0.67 | 80.00 | 8.00 | 6.30 | 77.00 | 73.00 | 6.00 | 70.00 |

| Index | Storage sub-system $C_4$ | | | Use sub-system $C_5$ | | Recovery sub-system $C_6$ | | |
|---|---|---|---|---|---|---|---|---|
| Emergency material reserve center | Government reserve ratio (%) | Storage material wastage rate (%) | Storage management and big data level (Ten point system) | Emergency material utilization rate (%) | Emergency materials repair and replacement ratio (%) | The return of goods damage degree (Ten point system) | Recovery cost (Ten thousand Yuan) | Hazardous waste safe transportation capacity (Ten point system) |
| | $C_{41}$ | $C_{42}$ | $C_{43}$ | $C_{51}$ | $C_{52}$ | $C_{61}$ | $C_{62}$ | $C_{63}$ |
| Ya'an | 51.00 | 0.032 | 5.50 | 81.00 | 11.00 | 4.00 | 68.00 | 9.00 |
| Leshan | 36.00 | 0.010 | 3.80 | 88.00 | 8.00 | 5.00 | 55.00 | 9.20 |
| Meishan | 47.00 | 0.023 | 5.80 | 77.00 | 5.00 | 3.00 | 80.00 | 9.00 |
| Zigong | 38.00 | 0.018 | 4.70 | 92.00 | 9.00 | 6.00 | 80.00 | 9.20 |
| Liangshan | 38.00 | 0.012 | 3.80 | 89.00 | 10.00 | 2.00 | 85.00 | 10.00 |
| Panzhihua | 47.00 | 0.027 | 5.50 | 77.00 | 12.00 | 4.00 | 75.00 | 8.30 |
| Yibin | 40.00 | 0.011 | 4.00 | 78.00 | 18.00 | 4.00 | 100.00 | 8.00 |
| Luzhou | 46.00 | 0.010 | 6.00 | 70.00 | 18.00 | 4.00 | 125.00 | 10.00 |
| Neijiang | 42.00 | 0.020 | 5.00 | 75.00 | 20.00 | 5.00 | 125.00 | 8.50 |
| Ziyang | 49.00 | 0.030 | 6.00 | 70.00 | 20.00 | 7.00 | 100.00 | 9.80 |

Table 2 Discrete emergency supply chain management index data decision table

| $U$ (Domain) | $C$ (Conditional attribute) | | | | | | | | | | | | | | | | | | $D$ (Decision attributes) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $C_1$ | | | $C_2$ | | | $C_3$ | | | | $C_4$ | | | $C_5$ | | $C_6$ | | | |
| | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{21}$ | $C_{22}$ | $C_{23}$ | $C_{31}$ | $C_{32}$ | $C_{33}$ | $C_{34}$ | $C_{41}$ | $C_{42}$ | $C_{43}$ | $C_{51}$ | $C_{52}$ | $C_{61}$ | $C_{62}$ | $C_{63}$ | |
| $x_1$ | 2 | 2 | 1 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 1 | 2 | 2 | 2 | 1 | 2 |
| $x_2$ | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 1 | 2 | 2 | 1 | 2 | 2 | 1 |
| $x_3$ | 2 | 2 | 1 | 2 | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 1 | 2 | 1 | 2 | 2 | 2 | 1 | 1 |
| $x_4$ | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 1 | 2 | 2 | 1 | 2 | 2 | 2 |
| $x_5$ | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 1 |
| $x_6$ | 2 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 2 | 1 | 2 | 1 | 2 | 2 | 2 | 1 | 2 |
| $x_7$ | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 2 |
| $x_8$ | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 2 |
| $x_9$ | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 2 | 1 | 1 | 2 | 1 | 1 | 1 |
| $x_{10}$ | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 |

$$\begin{aligned} U/ind(D) = &\{\{x_1, x_4, x_6, x_7, x_8\}, \\ &\{x_2, x_3, x_5, x_9, x_{10}\}\} \\ U/ind(C) = &\{\{x_1\}, \{x_2\}, \{x_3\}, \{x_4\}, \{x_5\}, \\ &\{x_6\}, \{x_7\}, \{x_8\}, \{x_9\}, \{x_{10}\}\}. \end{aligned}$$

After the equivalence class was determined, the condition attributes were removed and the indiscernibility relationships revealed:

$$\begin{aligned} U/ind(C - C_{11}) = &\{\{x_1\}, \{x_2\}, \{x_3\}, \{x_4\}, \{x_5\}, \\ &\{x_6\}, \{x_7\}, \{x_8\}, \{x_9\}, \{x_{10}\}\} \\ \cdots& \\ U/ind(C - C_{31}) = &\{\{x_1\}, \{x_2\}, \{x_3, x_6\}, \{x_4\}, \\ &\{x_5\}, \{x_7\}, \{x_8\}, \{x_9\}, \{x_{10}\}\} \\ \cdots& \\ U/ind(C - C_{63}) = &\{\{x_1\}, \{x_2\}, \{x_3\}, \{x_4\}, \{x_5\}, \\ &\{x_6\}, \{x_7\}, \{x_8\}, \{x_9\}, \{x_{10}\}\}. \end{aligned}$$

The positive regions for $C$, $C - C_{11}$, $C - C_{12}, \cdots$, $C - C_{63}$ for $D$ were then computed:

$$\begin{aligned} Pos_C(D) = &\{\{x_1\}, \{x_2\}, \{x_3\}, \{x_4\}, \{x_5\}, \\ &\{x_6\}, \{x_7\}, \{x_8\}, \{x_9\}, \{x_{10}\}\} \\ Pos_{\{C-C_{11}\}}(D) = &\{\{x_1\}, \{x_2\}, \{x_3\}, \{x_4\}, \{x_5\}, \\ &\{x_6\}, \{x_7\}, \{x_8\}, \{x_9\}\} = Pos_C(D) \\ \cdots& \\ Pos_{\{C-C_{31}\}}(D) = &\{\{x_1\}, \{x_2\}, \{x_4\}, \{x_5\}, \\ &\{x_7\}, \{x_8\}, \{x_9\}, \{x_{10}\}\} \neq Pos_C(D) \\ \cdots& \\ Pos_{\{C-C_{63}\}}(D) = &\{\{x_1\}, \{x_2\}, \{x_3\}, \{x_4\}, \{x_5\}, \\ &\{x_6\}, \{x_7\}, \{x_8\}, \{x_9\}\} = Pos_C(D). \end{aligned}$$

From the results of the above reduction, it can be seen that the emergency purchase agreement rate ($C_{21}$), materials delivery timeliness ($C_{31}$), transport route planning capability ($C_{33}$), storage material wastage rate ($C_{42}$), storage management and big data level ($C_{43}$), the return of goods damage degree ($C_{61}$) were the important indicators in the emergency supply chain management, so were included in the management index system. From these results, a new streamlined emergency supply chain management index system was developed:

$$C' = \{C_{21},\ C_{31},\ C_{33},\ C_{42},\ C_{43},\ C_{61}\}.$$

## 4.4 Importance degree and index weight calculation

Based on $C$, the importance degree for each index was calculated using (4):

$$K_{c_{21}} = \frac{card(Pos_C(D)) - card(Pos_{\{C-c_{21}\}}(D))}{card(U)} = \frac{10-8}{10} = 0.2.$$

In the same way, $K_{c_{31}} = K_{c_{33}} = K_{c_{42}} = K_{c_{43}} = K_{c_{61}} = 0.2$.

Formula (5) was used to deal with the importance degree of the index, from which the objective weight for each index was obtained:

$$\begin{aligned} w_{c_{21}} &= \frac{K_{c_j}}{\sum_{j=1}^{p} K_{c_j}} = \frac{0.2}{1.2} = 0.167 = \\ &w_{c_{31}} = w_{c_{33}} = w_{c_{42}} = w_{c_{43}} = w_{c_{61}}. \end{aligned}$$

From the above weight results, it can be seen that the emergency purchase agreement rate, materials delivery timeliness, transport route planning capability, storage materials wastage rate, storage management and big data level and the return of goods damage degree all had an important influence on the emergency supply chain management. However, as the RS method can be easily affected by inadequate sample selection, based on the objective weight index results, the HOQ model was used to further optimize the index system.

## 4.5 HOQ customer demand and its weight determination

The emergency supply chain user demand is different from general customer demand as it is not aimed at a certain product, but refers to the overall requirements of the emergency supply chain, so is the demand for products and services at each emergency supply chain link. User demand is related not only to the emergency supplies, but also to the overall emergency rescue and relief operations, so is a measure of the quality of the emergency supply chain management. Therefore, the user needs $UR$ are to be determined from the overall emergency supply chain perspective. Similarly, the user needs of the survey object include multiple emergency event participants. In general, relevant experts were consulted to determine the emergency event participation subjects to obtain the emergency supply chain user demand. To determine the emergency supply chain management HOQ model for user demand, document analysis and expert investigations were conducted. The user demand importance was also determined based on expert evaluation. Five experts in the set[1, 5] were consulted to determine the integer scale range for each $UR$ grade. Using (6), the relative weight of user demand $W_i$ was calculated. The $UR$ evaluation results and weights are shown in Table 3.

## 4.6 Establish relationship matrix and self-correlation matrix

From the new emergency supply chain process management index system, the evaluation index characteristics were determined as: emergency purchase agreement rate, timeliness of materials delivery, transport route planning capability, storage material wastage rate, storage management and big data level and return of goods damage degree. To reduce uncertainty, a comprehensive evaluation by a group of experts was conducted to determine the self-correlation relationships between the $EC$ index characteristics. For the $P_{hk}$ assignment, the mean value of the expert opinion was taken to determine the self-correlation matrix $P$. According to the degree of correlation between $UR$ and $EC$ in the 0-1-3-9 sequence for the $R_{ij}$ assignment, the mean was taken to develop the relationship matrix $R$, from which the HOQ model was established, as shown in Table 4.

## 4.7 Determination of the importance degree for the index characteristics

Based on the obtained $W$ and $R$, (7) was used to derive the absolute weight vector $V^*$:

$$V^* = R^{\mathrm{T}}W = \begin{bmatrix} 6.6 & 3.8 & 6.6 & 1.6 & 0 \\ 5.4 & 7.8 & 5.4 & 3.2 & 0 \\ 4.2 & 9 & 9 & 6.2 & 0 \\ 0 & 0 & 0.4 & 6.6 & 4.2 \\ 3 & 0 & 5.4 & 9 & 3.8 \\ 0 & 0.6 & 0.2 & 2 & 5 \end{bmatrix} \times \begin{bmatrix} 0.237 \\ 0.204 \\ 0.247 \\ 0.194 \\ 0.118 \end{bmatrix} = \begin{bmatrix} 4.280 \\ 4.826 \\ 6.257 \\ 1.875 \\ 4.239 \\ 1.150 \end{bmatrix}.$$

Formula (8) was used to modify the $V^*$ to get $v'$:

$$V' = PV^* = \begin{bmatrix} 1 & 0.78 & 0.62 & 0 & 0.5 & 0 \\ 0.78 & 1 & 0.84 & -0.1 & 0.54 & 0 \\ 0.62 & 0.84 & 1 & 0 & 0.2 & 0.14 \\ 0 & -0.1 & 0 & 1 & -0.44 & 0.68 \\ 0.5 & 0.54 & 0.2 & -0.44 & 1 & -0.46 \\ 0 & 0 & 0.14 & 0.68 & -0.46 & 1 \end{bmatrix} \times \begin{bmatrix} 4.280 \\ 4.826 \\ 6.257 \\ 1.875 \\ 4.239 \\ 1.150 \end{bmatrix} = \begin{bmatrix} 14.043 \\ 15.522 \\ 13.973 \\ 0.309 \\ 8.882 \\ 1.351 \end{bmatrix}.$$

Table 3 Emergency supply chain HOQ user demand and weights table

| Demand decomposition | | The final customer demand $UR$ | Evaluation result | | | | | Mean value | Demand weight $W_i$ |
|---|---|---|---|---|---|---|---|---|---|
| | | | Expert $A$ | Expert $B$ | Expert $C$ | Expert $D$ | Expert $E$ | | |
| Emergency supply chain HOQ user demand | Time-sensitive | Emergency response speed $UR_1$ | 5 | 4 | 4 | 5 | 4 | 4.4 | 0.237 |
| | | High transportation reliability $UR_2$ | 4 | 4 | 5 | 3 | 3 | 3.8 | 0.204 |
| | Adaptability | Strong coordination ability $UR_3$ | 5 | 4 | 5 | 4 | 5 | 4.6 | 0.247 |
| | | High management level $UR_4$ | 3 | 3 | 4 | 5 | 3 | 3.6 | 0.194 |
| | Economical efficiency | Cost-effective and environment friendly $UR_5$ | 2 | 3 | 3 | 1 | 2 | 2.2 | 0.118 |

Table 4 Emergency supply chain management house of quality

| | | $EC_1$ | $EC_2$ | $EC_3$ | $EC_4$ | $EC_5$ | $EC_6$ |
|---|---|---|---|---|---|---|---|
| | $EC_1$ | 1 | 0.78 | 0.62 | 0 | 0.5 | 0 |
| | $EC_2$ | 0.78 | 1 | 0.84 | –0.1 | 0.54 | 0 |
| | $EC_3$ | 0.62 | 0.84 | 1 | 0 | 0.2 | 0.14 |
| | $EC_4$ | 0 | –0.1 | 0 | 1 | –0.44 | 0.68 |
| | $EC_5$ | 0.5 | 0.54 | 0.2 | –0.44 | 1 | –0.46 |
| | $EC_6$ | 0 | 0 | 0.14 | 0.68 | –0.46 | 1 |
| | Relative weight | 0.260 | 0.287 | 0.258 | 0.006 | 0.164 | 0.025 |
| $UR_1$ | 0.237 | 6.6 | 5.4 | 4.2 | 0 | 3 | 0 |
| $UR_2$ | 0.204 | 3.8 | 7.8 | 9 | 0 | 0 | 0.6 |
| $UR_3$ | 0.247 | 6.6 | 5.4 | 9 | 0.4 | 5.4 | 0.2 |
| $UR_4$ | 0.194 | 1.6 | 3.2 | 6.2 | 6.6 | 9 | 2 |
| $UR_5$ | 0.118 | 0 | 0 | 0 | 4.2 | 3.8 | 5 |

Using (9), the relative weight of $EC$ was calculated to determine the importance degree of $V$:

$$v = \{v_1, v_2, v_3, v_4, v_5, v_6\} = \{0.260, 0.287, 0.258, 0.006, 0.164, 0.025\}.$$

The importance ranking of $v_j$ was $v_2 > v_1 > v_3 > v_5 > v_6 > v_4$. The ranking results indicated that timeliness of materials delivery, emergency purchase agreement rate and transport route planning capability were the most important in the emergency supply chain management index system, while storage management and big data level, the return of goods damage degree and the storage material wastage rate were somewhat less important; however, all these should be considered to further strengthen the emergency supply chain management.

## 5 Conclusions

By determining the critical impact factors in emergency supply chain management, an index system and model were established based on an RS-HOQ method. First, the RS theory was applied to eliminate the less important management indicators so as to determine a streamlined index importance degree, after which HOQ theory was applied. The fuzzy emergency supply chain user demand was transformed into controllable supply chain user demand factors. Combined with these refined simplified emergency supply chain management indicators, a relationship matrix was established to determine the final importance degrees for the management index. Finally, from the importance ranking results, the critical emergency supply chain management direction was obtained. It was found that management needs to increase the speed of emergency supply deliveries and improve emergency purchase and transport route planning capacity efficiency to ensure efficient and timely rescue and meet the supply chain needs in the disaster areas. It was further found that the emergency supply chain management needs to harness big data technology to improve storage management and reduce the degree of damage in recycling materials so that the emergency relief is scientific, efficient and effectively addressing environmental protection requirements. A simulation and analysis using a case example proved the model was feasible, applicable and effective.

The developed Rough set – house of quality model provides a theoretical method for emergency supply chain management balance contradictions and conflicts to better meet emergency supply chain logistics service demands, carry out rescue and relief work, improve user satisfaction, assist management personnel to more effectively optimize the supply chain process and improve the management level. At the same time, this research on emergency supply chain management can add to supply chain management theories.

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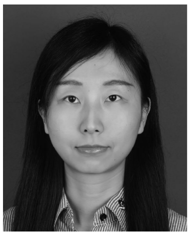

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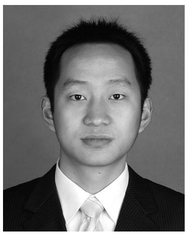

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